Adéquation entre disponibilités alimentaires et sécurité alimentaire et nutritionnelle des populations : du commerce international à la relocalisation des approvisionnements

Sophie Drogue

Mémoire présenté en vue de l'obtention de

L'Habilitation à diriger des recherches en sciences économiques

Adéquation entre disponibilités alimentaires et sécurité alimentaire et nutritionnelle des populations : Du commerce international à la relocalisation des approvisionnements

Par

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Curriculum vitae

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Formation

1998 Doctorat ès Sciences Economiques, Université de Montpellier I

1992 DESS, Université de Montpellier I

1991 Maitrise ès Sciences Economiques, Université de Montpellier I

1990 Licence ès Sciences Economiques, Université de Montpellier I

1989 DEUG ès Sciences Economiques, Université de Perpignan

Parcours professionnel

07/2011 -	Ingénieure d'étude INRAE, UMR MoISA, Montpellier.
03/2010 -	Rédactrice en chef du support de communication INRAE Sciences Sociales
03/2010 – 09/2017	Chargée de mission communication du département SAE2 de l'INRA.
07/2000 – 06/ 2011	Ingénieure d'étude INRA, UMR Economie Publique, Paris.
09/2005 – 08/2006	Chercheuse au Centre d'Etudes Prospectives et d'Information Internationales, Paris.
09/2004 – 08/2005	Directrice adjointe de l'UMR Economie Publique, Paris.
01/2000 – 07/2000	Consultante pour l'Asociacion Nacional de Exportadores de CACAO, Guayaquil (Equateur).
05/1999 – 06/1999	Expert auprès du Tribunal de Grande Instance de Marseille.

Enseignement

Depuis 2013 Modélisation des politiques agricoles et environnementales (20h) Montpellier Supagro

2002-2013 Cours d'économie agricole en dernière année du cursus d'ingénieur (10h) l'ESTP de Paris-Cachan

2006-2008 Cours d'introduction à la modélisation EGC en deuxième année du cursus d'ingénieur à AgroParisTech Paris.

2005-2007 Cours sur la politique agricole commune en première année de master à l'ISA de Beauvais (2005), et à AgroParisTech Paris (2006-2007).
2002-2005 Cours d'introduction à la modélisation en deuxième année du cursus d'ingénieur à AgroParisTech Paris.

Activités d'encadrement

1- Stages de licence et mastère.

- *Agnieszka Klimkiewicz* (encadrante, directeur de stage : Jacques Gallezot), 2004, « Analyse comparative de la protection tarifaire des produits agroalimentaires des pays méditerranéens : Chypre, Egypte, Israel, Malte, Maroc, Tunisie, Turquie » Stage de DEA, EDDE, INAPG.
- *Romain Vignes* (Directrice de stage), 2014-2015, « Appariement de bases de données de nutrition et de base de données de commerce en vue de réaliser un modèle d'évaluation des politiques publiques » Stage de césure, diplôme d'ingénieur agronome de Montpellier SupAgro.
- *Clément Renoir* (Directrice de stage), 2015, « Découverte du projet ECOPHYTO et proposition de constitution d'un échantillon représentatif d'agriculteurs dans le Languedoc-Roussillon », Magistère ingénieur économiste Aix Marseille School of Economics.
- *Fatima Machou* (Directrice de stage), 2016-2017, « Mise en place de procédures automatisées pour apparier des bases de données sur le commerce alimentaire, la consommation et les valeurs » Stages de L3 et de M1, Mastère MIASHS, Université Paul Valéry.
- *Nesrine Chérif* (Directrice de stage), 2017, « Les modèles de ménage en programmation mathématique : Modélisation des relations entre les décisions de production et de consommation au sein des ménages agricoles », Mastère I3P, CIHEAM-IAMM.
- *Romain Bialek* (Directrice de stage), 2018, « Analyse statistique des importations d'aliments aux Antilles françaises », stage de L3, Mastère MIASHS, Université Paul Valéry.
- *Sylvestre Lankoande* (Directrice de stage), 2019, « Description et analyse de l'évolution de l'offre de fruits dans les Antilles Françaises », Mastère ECODEVA, Montpellier SupAgro.
- *Alessandra Gazzetto* (Co-directrice de stage), 2019, « The impact of Non-Tariff Measures on Food and Agriculture Global Value Chain participation », Universita degli studi di Milano.
- *Kawtar Alami* (Directrice de stage), 2020, « Analyse de l'approvisionnement en fruits de la Métropole de Montpellier », Mastère ECODEVA, Montpellier SupAgro.

2- Thèses de doctorat

- Youssef Chahed, (directeur de thèse : Jean-Christophe Bureau), 2003 : « Mesure de l'impact de la libéralisation des marchés agricoles sur les échanges et le bien-être ». AgroParisTech, Ecole doctorale ABIES.

- Priscila Ramos, (directeur de thèse : Jean-Christophe Bureau), 2007 : « Politique commerciale, qualité et environnement : une application aux négociations commerciales entre l'Union européenne et le Mercosur ». AgroParisTech, Ecole doctorale ABIES.
- Federica DeMaria, (directeur de thèse : Francesco Aiello), 2009 : « On the Impact of the EU GSP Scheme ». Université de la Calabre (Italie)
- Hilel Hamadache (directrice de thèse : Florence Jacquet), 2015 : « Réformes des subventions au marché du blé en Algérie : une analyse en équilibre général calculable ». Montpellier SupAgro, Ecole doctorale EDEG.
- Ahmed Ferchiou (directrice de thèse : Florence Jacquet), 2017 : « Quelles mesures de relances pour l'agriculture familiale en zone aride : évaluation intégrée par la modélisation bio économique des ménages agricoles de Sidi Bouzid ». Montpellier SupAgro, Ecole doctorale EDEG.
- Rosario Quintero (co-encadrante, directrice de thèse : Leila Temri), 2019 : « Améliorer la chaîne de valeur du manioc au Panama : approche par les ressources et compétences d'une coopérative agricole ». Montpellier SupAgro, Ecole doctorale EDEG.
- Pierre Chiaverina (co-encadrante, directrice de thèse : Florence Jacquet), thèse en cours : « Modéliser l'approvisionnement en fruits et légumes d'une métropole urbaine en conciliant les quatre dimensions de la durabilité : santé, environnement, économique et sociale. ». Montpellier SupAgro, Ecole doctorale EDEG.

3- Encadrement de post-doctorants

- Federica DeMaria 2010-2011 UMR Economie Publique (CDD 12mois) et 2012-2013 UMR MOISA CDD (12mois).
- Viola Lamani 2018-2020 UMR MOISA (CDD 12 mois).

Toutes les publications réalisées avec les étudiants sont dans la liste de publications indexée à la fin de ce mémoire.

Activités de référée

Agrekon (2019), Agricultural Economics (2018, 2017), Agricultural Systems (2018), American Journal of Agricultural Economics (2011, 2012, 2013), Cahiers Agriculture (2012, 2019), Economie Rurale (2001, 2006), Emerging Markets Finance and Trade Journal (2009), European Review of Agricultural Economics (2011), Food Policy (2015, 2014, 2012), Journal of Agricultural and Applied Economics (2016), Journal of Agricultural Economics (2009, 2019), Journal of Agricultural Science and Technology (2013).

XV et XVI congrès de l'European Agricultural Economics Association (2017, 2020)

170$^{\text{ème}}$ séminaire de l'European Agricultural Economics Association (2019)

Journée de recherches en Sciences Sociales (2018, 2019)

Autre activités scientifiques et administratives

Depuis novembre 2020 Membre élu du Conseil scientifique du département EcoSocio d'INRAE

Depuis Janvier 2020 Membre élu du Conseil d'unité de l'UMR MOISA

2012-2019 Membre nommé du Conseil de direction de l'UMR MOISA.

2000-2011 Membre nommé du Conseil de gestion de l'UMR Economie Publique

2006 Consultant BIPE pour le Ministère des transports

2006 Membre nommé de la Commission d'évaluation des ingénieurs de l'INRA

2001-2005 Membre élu du Conseil scientifique du département SAE2 de l'INRA

2003 Evaluateur pour l'European Union Programme of High Level Scholarships for Latin America

2000 Editrice du rapport mensuel « El Boletin de Estadistica », Guayaquil, Ecuador

Membre du comité d'organisation du séminaire EAAE170, Montpellier (2019) et Congrès de l'EAAE Saragosse (2002), ainsi que de divers événements scientifiques du département SAE2 : le séminaire ECOPROD (2012), la journée du département (6 journées organisées entre 2010 et 2019).

Séjours de recherche à l'étranger

10/2019 Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria - Centro di Politiche e Bioeconomia, Rome, Italie.

07/2015 International Food Policy Research Institute, Washington, United States.

10/2013 Université de la Calabre, Département d'économie et de statistiques, Rende, Italie.

11/2008 - 10/2009 Université de la Calabre, Département d'économie et de statistiques, Rende, Italie.

09/2006 - 11/2006 Trinity College, Department of economics, Dublin, Irlande.

05/2004 Comision Nacional de Comercio Exterior, Buenos Aires, Argentine

04/2004 Service de Coopération et d'Action Culturelle du Consulat de France, Rio de Janeiro, Brésil

01/2000 - 07/2000 Association Nationale de Exportadores de Cacao, Guayaquil, Equateur.

J'ai effectué à ce jour plusieurs séjours de recherche à l'étranger, dont 2 séjours post-doctoraux. Le premier a duré 3 mois (du 1er septembre 2006 au 30 novembre 2006) dans le département d'économie de Trinity College (Dublin) que j'ai rejoint pour travailler avec le professeur Alan Matthews et Federica Demaria qui effectuait alors sa thèse de doctorat. Nous avons travaillé dans le cadre du projet européen FP7 AgFoodTrade sur la réforme du système généralisé des préférences qui a donné lieu à la publication d'un article dans Development policy review (**DeMaria, Drogue et Matthews, 2008 [88]**).

Lors de mon second séjour post-doctoral à l'étranger, j'ai travaillé pendant 12 mois (du 1er novembre 2008 au 31 octobre 2009) dans le département d'économie et de statistique de l'université de la Calabre de Rende (Italie). J'ai travaillé avec les professeurs Giovanni Anania (Université de la Calabre) et Quirino Paris (de l'Université de Davis, Californie) dans le cadre du projet européen FP7 AgFoodTrade. Nous avons développé une méthode de calibrage pour les modèles spatiaux de commerce publié dans economic modeling (**Paris, Drogue et Anania, 2011 [91]**). J'ai aussi continué à collaborer avec Federica DeMaria qui a par la suite effectué un séjour de post doctorat dans l'UMR Economie Publique à Paris, financé par le projet FP NTM-Impact pour lequel j'étais co-leader de workpackage.

Par la suite F. DeMaria a réalisé 2 années de post-doctorat dans l'UMR MOISA, l'une grâce à une allocation de son université (Université de la Calabre) ; l'autre grâce à un financement par le projet ANR Sustain'apple.dont j'étais également workpackage co-leader. Je continue à collaborer avec Mme. DeMaria qui est actuellement chercheuse au CREA-PB (Conseil pour la Recherche en Agriculture et l'analyse de l'économie agricole – Centre de Politique et Bioéconomie) dans lequel j'ai séjourné 1 mois en octobre 2019.

Participation à des projets de recherche et expertises

2020-2023 H2020 InnoFoodAfrica *Locally-driven co-development of plant-based value chains towards more sustainable African food system with healthier diets and export potential* financé par la Commission européenne

2020-2024 Projet de Réseau Mixte Technologique (RMT) Filarmoni (Economie des filières alimentaires)

2020-2022 FooSIN *Participation française au GO FAIR Food Systems Implementation Network* financé par l'Agence nationale de la recherche

2020 BIOCOST financé par la fondation Olga Triballat (**Coordinatrice**)

2017-2021 NUTWIND financé par l'Agence nationale de la recherche (**Task leader**)

2017-2018 Agricultural trade : assessing reciprocity of standards financé par le comité AGRI du Parlement européen (**Task leader**)

2015-2017 RECONCIL financé par le Métaprogramme GloFoods (**Coordinatrice**)

2014-2018 ALID Sustain'Apple Sustainable management of the sanitary and phytosanitary risk in the fresh produce industry: the case of the apple chain financé par l'Agence nationale de la recherché (**WP co-leader**)

2013-2017 Transmed Medina Promotion of sustainable food systems in the Mediterranean financé par l'Agence nationale de la recherche

2009-2012 FP7 NTM-IMPACT Assessment of the impacts of non-tariff measures on the competitiveness of the EU and selected trade partners financé par la Commission européenne (**WP co-leader**)

2008-2011 FP7 AgFoodTrade New issues in agricultural, food and bioenergy trade financé par la Commission européenne

2005-2008 FP6 TRADEAG Agricultural trade agreements financé par la Commission européenne

2005 MAAPR 05G60201 Panorama des analyses prospectives sur l'évolution de la sécurité alimentaire mondiale à l'horizon 2020-2030 financé par the Ministère de l'Agriculture

2004-2007 FP6 EUMED-AGPOL Impacts of agricultural trade liberalization between the EU and the Mediterranean countries financé par la Commission européenne

2004 MAAPAR 04G50101 Concurrence et compétitivité des pays du Mercosur et etude de l'effet des accords tarifaires sur diverses filières françaises financé par Ministere de l'Agriculture **(Coordinatrice)**

2003 Barrières non-tarifaires et accès au marché de l'UE des pays tiers en développement : le cas des obstacles « TBT » et « SPS » Projet *Jeunes Chercheurs* financé par le département SAE2 **(Co-coordinatrice)**

2001 Protection du Secteur Agricole dans les Pays Tiers : un Outil pour les négociations du Millenium Round financé par le Commissariat General au Plan

Analyse des travaux scientifiques et projet de recherche

0. Introduction

Titulaire d'un doctorat en sciences-économiques de l'Université de Montpellier I, ma thèse porte sur l'analyse et la modélisation du marché communautaire de l'huile d'olive. Les travaux que j'ai menés à cette occasion s'appuyaient sur de la modélisation vectorielle autorégressive (**Drogue et Terraza, 1997 [16] ; Drogue et Lesourd, 1998 [17] ; Drogue, 1998 [78] ; Drogue, 2000 [80]**)[1]

En juillet 2000 J'ai été recrutée à l'Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE) dans l'Unité mixte de recherche (UMR) Economie Publique de Paris-Grignon pour travailler dans l'équipe « échanges internationaux » sur la quantification de l'impact des décisions de libéralisation du commerce. L'UMR Economie Publique avait en charge la mise au point de méthodes d'analyses, de modèles de simulation et de conseil aux décideurs publics en matière de politique économique, que ce soit sur l'organisation du secteur agricole (économie de la production), la politique publique dans le secteur agroalimentaire (politique agricole commune) et le commerce international (négociations commerciales, négociations sur le changement climatique).

En intégrant cette équipe, j'ai également changé de « paradigme scientifique ». Mes travaux de thèse relevaient de l'économétrie des séries temporelles et donc de l'estimation de modèles non structurels j'ai été recrutée pour travailler sur des modèles d'équilibre général calculable qui repose sur un corpus théorique classique et se résolvent par des méthodes de calibrage. Mon activité scientifique s'articulait autour de l'analyse des effets des accords commerciaux dans le domaine agricole. Mes recherches concernaient au début essentiellement la mesure de la protection tarifaire et des effets de scénarios de baisse de cette protection soit dans le cadre multilatéral soit dans le cadre d'accords bilatéraux ou régionaux. Progressivement, mes travaux en commerce international ont évolué vers une mesure de l'impact de réglementations non-tarifaires sur les échanges, notamment les réglementations de limites maximales de résidus (LMR) de pesticides. En 2009, j'ai participé à un projet européen sur l'évaluation de l'impact des barrières non tarifaires au commerce en tant que leader de workpackage. J'ai publié avec Federica DeMaria, un article dans Food Policy (**Drogue et Demaria, 2012 [91]**) qui est cité 116 fois dans Google Scholar.

En 2011, j'ai rejoint l'UMR Marchés Organisations Institutions et Stratégies d'Acteurs (MOISA) de Montpellier. Forte de mes travaux sur l'impact des réglementations sur les limites maximales de résidus de pesticides, j'ai intégré l'équipe NORMES qui travaillait sur la construction et les effets des instruments de régulation. J'ai poursuivi mes travaux sur l'impact des LMR de pesticides en

[1] Je ne détaillerai pas mes travaux de thèse car ils ne sont pas représentatifs de mon activité scientifique depuis mon recrutement à INRAE.

m'intéressant en particulier au lien entre ces réglementations et les effets sur la santé des substances réglementées.

A partir de 2014, l'arrivée d'une équipe de 4 chercheuses en nutrition publique et épidémiologie de la nutrition dans l'UMR a orienté mes recherches dans une nouvelle direction sur l'étude du lien entre l'origine des approvisionnements, la nutrition et la santé. En effet, l'enjeu de mes recherches a évolué au cours du temps mais il peut se traduire aujourd'hui par : participer à la réflexion scientifique sur **l'évaluation de l'adéquation entre les disponibilités alimentaires et la sécurité alimentaire et nutritionnelle des populations**. Dans ce contexte, je m'intéresse plus particulièrement à la relocalisation des approvisionnements alimentaires. J'entends par évaluation sa mesure, l'analyse de ses déterminants ou de ses impacts ainsi que la définition des actions publiques à mettre en œuvre.

Dans le premier chapitre de ce mémoire je vais montrer en quoi mes travaux ont participé aux recherches menées à INRAE sur la mesure et la quantification des effets des politiques publiques sur le commerce international. Les trois premières sections sont consacrées essentiellement aux instruments tarifaires, dans le cadre d'accords de libre-échange régionaux ou globaux. La section 4 traite plus particulièrement des réglementations sanitaires et phytosanitaires. Dans le 2nd chapitre de ce mémoire je présente mon projet de recherche qui fait le lien entre le commerce international et la sécurité alimentaire et nutritionnelle des populations. Enfin, j'ouvre ce projet à la question de la relocalisation des approvisionnements.

1. La mesure de l'impact des politiques commerciales sur le commerce international

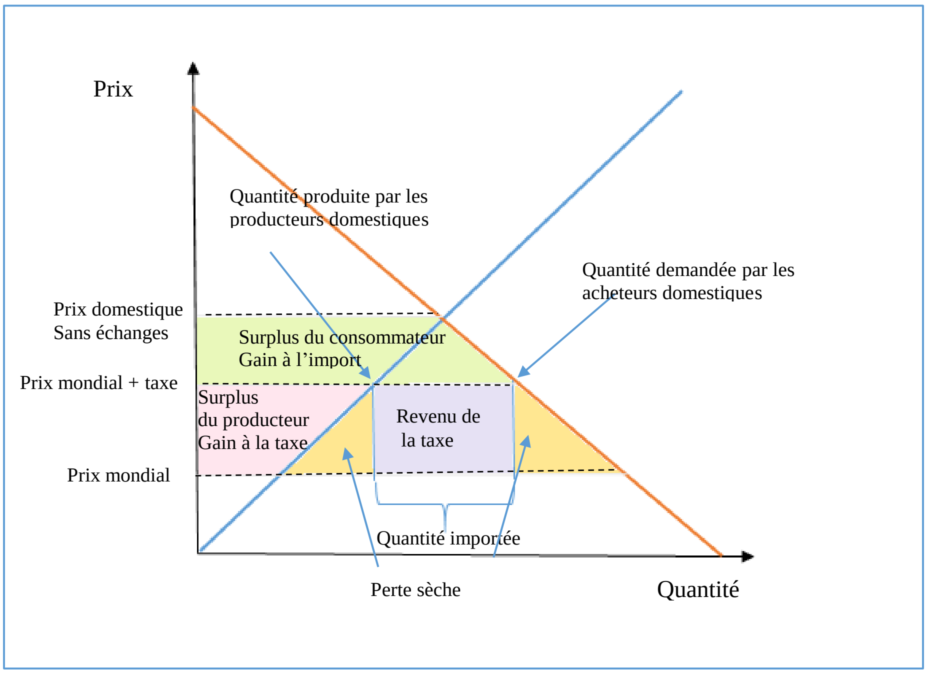
La création de l'OMC le 1er janvier 1995 a marqué la plus grande réforme du commerce international depuis la seconde guerre mondiale. Elle a aussi concrétisé — sous une forme actualisée — l'objectif visé sans succès en 1948 par le projet de création d'une Organisation internationale du commerce. Voilà ce qu'on peut lire sur le site Internet de l'Organisation mondiale du commerce (OMC) dans la partie sur l'histoire de la création de cette organisation internationale. Il est très symbolique que ce soit à l'issue de l'accord de Marrakech au même moment qu'est signé l'Accord sur l'Agriculture que se crée également une « arène » permanente de négociations. Cette conclusion va aussi façonner les 25 dernières années de recherche en économie internationale. En effet, les engagements des nations sur la baisse de la protection commerciale qu'elle soit tarifaire ou non-tarifaire va être à l'origine de nombreux travaux de recherche. Ils vont également donner lieu à un regain d'intérêt pour les modèles multi-marchés et les modèles d'équilibre général calculable. En effet, ces modèles vont permettre de mettre en évidence les interdépendances entre les marchés et les secteurs et de calculer des impacts dans plusieurs pays voire au niveau mondial.

La déclaration ministérielle de Doha adoptée lors de la conférence ministérielle de l'OMC le 14 novembre 2001 insistait sur le rôle majeur que peut jouer le commerce international dans la promotion du développement économique et la réduction de la pauvreté, tout en reconnaissant la « vulnérabilité particulière des pays les moins avancés et les difficultés structurelles spéciales qu'ils rencontrent dans l'économie mondiale. ».

En ce qui concerne l'agriculture, l'objectif à long terme était d'établir un système de commerce équitable et axé sur le marché au moyen d'un programme de réforme fondamentale comprenant des règles renforcées et des engagements spécifiques concernant le soutien et la protection afin de remédier aux restrictions et distorsions affectant les marchés agricoles mondiaux et de les prévenir. L'idée générale étant de supprimer progressivement tous les instruments de politiques commerciales qui créent des distorsions sur les marchés internationaux tels que : les taxes et quotas tarifaires, les subventions.

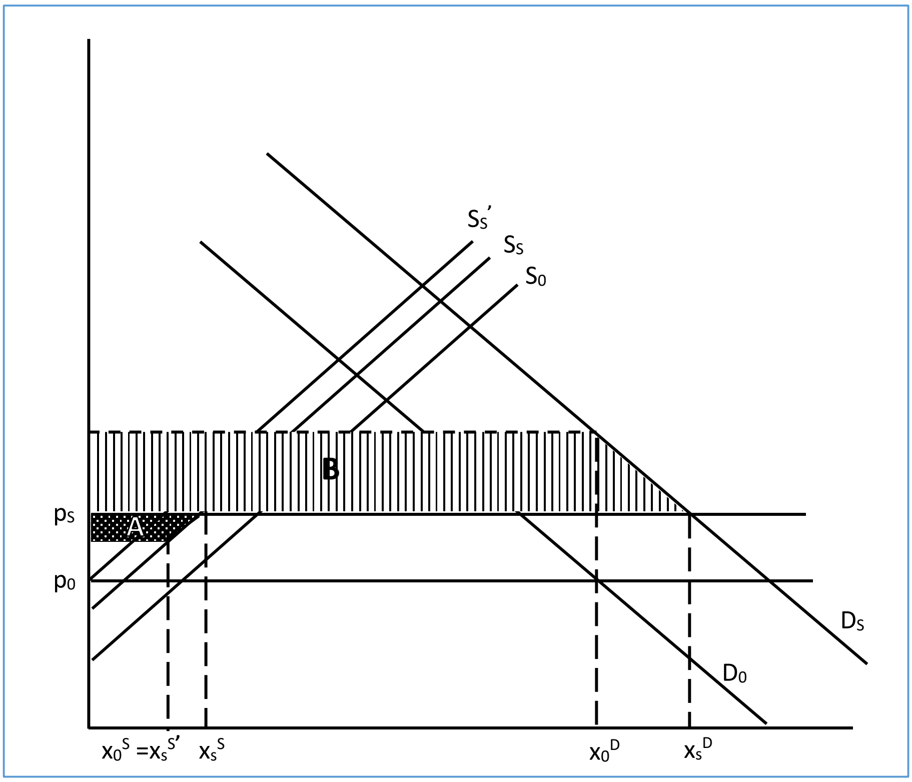
D'un point de vue théorique l'effet d'une taxe par exemple est celui d'une perte sèche (deadweight loss) du fait de la différence entre le prix domestique (qui tient compte de la taxe) et du prix mondial (voir Figure 1).

Figure 1 : Les effets économiques d'une taxe à l'importation



Un autre type d'instruments peut affecter les échanges en créant des distorsions de concurrence, ce sont les normes techniques et/ou les réglementations sanitaires et phytosanitaires. Toutefois, autant la taxe ou les quotas ont un effet négatif sur le commerce autant l'effet des standards techniques ou sanitaires est plus complexe (Marette et Beghin, 2010 ; Santeramo et Lamonaca, 2019). (Swinnen, 2016) montre graphiquement que dans le contexte d'une petite économie ouverte (Figure 2), l'introduction d'un standard peut être un catalyseur de commerce plutôt qu'une barrière aux échanges. Dans la Figure 2, *S* représente l'offre sur le marché domestique, *D* la demande domestique et *P* l'offre du reste du monde qui détermine le prix. L'introduction du standard déplace la courbe d'offre de S0 à SS et la demande domestique de D0 à DD, le prix passe de P0 à PS. Ces déplacements des courbes d'offre et de demande entrainent une augmentation de la demande d'importation qui passe de x0D – x0S à xSD – xSS. Cette norme est donc un « catalyseur » pour le commerce, cet effet serait encore plus important si les coûts de mise en œuvre étaient identiques pour les producteurs nationaux et étrangers puisque dans ce cas la demande d'importation passerait de x0D – x0S à xSD - x0S.

Figure 2 : Efficacité, équité et impact sur le commerce de standards dans une petite économie ouverte



Source : (Swinnen, 2016)

Mes travaux ont porté sur ces deux types d'instruments : les taxes à l'importation (barrières tarifaires) d'une part, les normes et standards (barrières non-tarifaires) d'autre part. Dans les deux 1ères sections de ce mémoire je présente mes travaux sur la mesure de la protection dans le cadre multilatéral et régional. Dans la 3ème section je traite de l'évaluation de l'impact de la baisse des tarifs. Enfin, la 4ème section est consacrée aux barrières non tarifaires au commerce et plus particulièrement aux réglementations sanitaires et phytosanitaires.

1.1. La mesure de la baisse des droits de douane après l'Accord sur l'Agriculture du Cycle de l'Uruguay

Le premier accord de libre-échange multilatéral, ou GATT (*General Agreement on Tariffs and Trade*) a été signé en 1947 avec pour ambition de baisser les droits de douane et de libéraliser le commerce entre les nations signataires. Vont suivre sept cycles de négociations avant que soit conclu un accord qui intègre l'agriculture. Le cycle de l'Uruguay (initié en 1986), qui s'est conclu en 1994 par la signature de l'Accord de Marrakech a modifié significativement les règles commerciales. L'Accord sur l'Agriculture du Cycle de l'Uruguay (AACU) est l'un des textes signés à Marrakech, qui concerne le plus le secteur agricole avec l'Accord sur les mesures sanitaires et phytosanitaires dit accord SPS et l'accord sur les obstacles techniques au commerce dit accord TBT (Bureau, Gozlan et Doussin, 1999). C'est l'AACU qui précise en particulier les nouvelles dispositions en matière d'accès au marché (Encadré 3). A cette époque le secteur agricole se singularisait par des niveaux de protection élevés. En 2001, le taux moyen de protection est de 5,9 % dans l'industrie contre 24 % dans l'agriculture (Bureau, Guimbard et Jean, 2019). A cette époque, nombre de travaux en économie internationale portaient sur la mesure de la protection. Comme les mesures de protection douanière proposées n'étaient pas satisfaisantes, nous avons cherché à les améliorer (**Bureau et al., 2001 [2]**). Nous avons identifié plusieurs sources de difficultés. Il y a celles qui sont liées à la disponibilité des sources statistiques (voir encadré 1) ou aux différences de nomenclature (les nomenclatures douanières sont différentes de celles des bases de données de certaines institutions) et qui rendent périlleux les exercices de pondération (**Drogue et Bartova, 2007 [6]**).

Encadré 1 : Les bases de données utilisées

TARIC est la base administrative qui informe sur les droits de douane qui grèvent tous les produits importés par l'Union européenne pour chaque régime douanier. Dans le système douanier européen les différents produits importés sont codifiés selon une classification appelée nomenclature combinée (NC). Ces codes (ou lignes) comptent jusqu'à 14 chiffres en fonction du degré de détail avec lequel est défini chaque produit et renvoient à un tarif douanier particulier.
Ex. : Le code 01 (quand le code ne comporte que 2 chiffres on parle de chapitre) correspond aux animaux vivants, 0102 …de l'espèce bovine, 010210 …reproducteurs de race pure, 01021010 …Génisses. Le tarif douanier est donné à partir de la ligne tarifaire à 8 chiffres (NC8). Dans le cas de notre exemple le droit NPF[2] est de 0 %. Les chapitres 01 à 24 recouvrent la majeure partie des produits agricoles et agroalimentaires. L'information contenue dans TARIC est brute. Pour pouvoir comparer les tarifs il faut les convertir en équivalents ad-valorem (EAV).

COMEXT est la base de données du commerce extérieur d'EUROSTAT. Elle contient depuis 1995, les valeurs et volumes des flux de commerce pour tous les produits entrant dans ou sortant de l'Union européenne par provenance ou destination. Cette base nous donne au niveau 10 chiffres de la NC, les importations de la Communauté sous quatre régimes : NPF, NPF à droits nuls, Préférentiel, Préférentiel à droits nuls, pour les années 2000 à 2008. Toutefois, aucune information n'est donnée sur

[2] La clause de la nation la plus favorisée (NPF) est un des principes fondateurs du GATT et donc de l'OMC. Il stipule qu'un pays qui adhère à l'Accord sur le commerce ne doit en principe pas favoriser un partenaire commercial par rapport aux autres. Un droit NPF s'applique à tous les pays sans discrimination.

le type de régime préférentiel utilisé : le Système des préférences généralisées (SPG), les accords de Lomé/Cotonou pour la zone Afrique Caraïbes Pacifique ou les accords Euromed qui concernent les pays du pourtour de la Méditerranée etc.

DBTAR est une base de données développée à l'INRA. Elle donne en EAV les tarifs appliqués par l'UE au niveau 10 chiffres de la NC. Les tarifs sont donnés pour les années 2002 à 2004 (Gallezot, 2005a).

TRADEPREF est une base de données développée à l'INRA. Elle offre pour tous les pays bénéficiant d'une préférence et pour l'année 2002, au niveau 10 chiffres de la NC : la valeur du commerce, le régime d'importation dans la Communauté, l'équivalent ad-valorem du tarif appliqué et l'équivalent NPF. Ce travail est basé sur l'exploitation de l'information contenue dans les déclarations en douane (Gallezot, 2005b).

Source : **Drogue et Bartova (2007) [5]**

Il y a également d'autres difficultés liées au problème récurrent de l'endogénéité puisque les niveaux des importations souvent utilisés pour pondérer les taxes sont eux-mêmes dépendant du niveau de la protection douanière. Le cas extrême où les droits de douane sont si élevés qu'ils empêchent toute importation amène à une pondération nulle pour un produit qui, sans protection, aurait peut-être été importé en grandes quantités.

Nous avons utilisé une mesure de la protection qui tient compte de ces difficultés **(Bureau et al., 2001 [2])**. Elle reprend la théorie des nombres indices développée par (Diewert, 1981) et vise à déterminer un droit de douane uniforme dont les effets sont équivalents à ceux de l'ensemble des droits (hétérogènes) en vigueur (voir Encadré 2).

Encadré 2 : Mesure de la protection douanière qui tient compte de l'endogénéité

« Le Trade Restrictiveness Index (TRI) prend comme référence le niveau de bien-être dans l'économie (en l'occurrence le niveau d'utilité). Le TRI est défini comme le facteur scalaire uniforme par lequel les prix de la période 1 (qui correspondent à une politique commerciale donnée) doivent être déflatés pour compenser une perte d'utilité subie par le consommateur par suite du changement de prix (consécutif à une modification des droits de douane) de manière à conserver le niveau d'utilité initial obtenu avec une valeur donnée de la balance commerciale. Ainsi plus ce scalaire est grand, plus le nouveau régime tarifaire peut être considéré comme restrictif.

Le Mercantilistic Trade Restrictiveness Index (MTRI) est conceptuellement proche du TRI, mais prend comme référence le volume des flux commerciaux et non pas le bien-être. Pour cette raison,

il représente davantage l'évolution des restrictions aux échanges. Il repose sur la recherche du droit de douane uniforme qui donne le même volume d'échange que la structure tarifaire originale (Anderson et Neary, 2003) »
Source : **(Bureau et al., 2001 [2], pages 47-48)**

La plupart des études qui ont mesuré le niveau de la protection après la signature de l'AACU montraient que le profil tarifaire agricole et alimentaire variait selon les pays et les produits. Les pays du Nord restaient en moyenne plus protégés que les pays du Sud, de la même façon les produits dits sensibles étaient toujours plus protégés que les autres ; comme la viande ou les céréales. Nos résultats pour l'Union européenne (UE), le Canada et les Etats-Unis montraient d'ailleurs que si ces pays se sont effectivement soumis à leurs engagements de réduction des tarifs de 36 % imposée par l'AACU et de 15 % au minimum sur la plupart des lignes tarifaires, par contre cette réduction a été plus forte sur les produits faiblement protégés. C'est ce que l'on appelle la « dilution des tarifs ». L'analyse en termes de TRI et MTRI montrait que le profil de la réduction tarifaire adopté par les trois pays s'était à la fois traduit par une amélioration du bien-être national et une amélioration de l'accès au marché pour les produits étrangers (**Bureau et al., 2001 [2]**).

Encadré 3 : Les trois piliers de l'AAUR

L'accès au marché, avec la conversion des quotas et d'autres restrictions à l'importation (prélèvements variables, allocation discrétionnaire de licences, etc.) en droits de douane, la consolidation de ces droits de douane (auparavant de nombreux droits n'étaient pas consolidés et pouvaient ainsi être augmentés) et un engagement pour les pays développés de réduire ces droits de 36 % sur une période de 6 ans. Lorsqu'existaient des obstacles non-tarifaires aux importations, l'Accord prévoyait que les pays importateurs offrent un accès minimum de 5 % de la consommation au terme de la période de mise en œuvre, c'est à dire 2000 pour les pays développés.

La limitation des subventions aux exportations, considérées comme déstabilisatrices pour les marchés mondiaux. L'Accord prévoyait une baisse de 21 % des quantités exportées avec des subventions, et de 36 % des dépenses budgétaires consacrées à ces subventions. Les pays signataires peuvent continuer à utiliser leurs programmes existants dans les limites ainsi définies, mais ne peuvent pas en introduire de nouveaux.

La réduction des aides à l'agriculture créant des distorsions sur les marchés internationaux, en incitant à la production et en permettant de vendre en dessous des coûts de revient. Les soutiens à la production devaient être réduits de 20 % sur la période de 6 ans. Le niveau de référence étant défini par une Mesure agrégée de soutien (AMS) dont les modalités de calcul étaient précisées, mais qui comprenait le soutien à la fois par les prix de marchés (transferts du consommateur au producteur) et les aides plus directes (transferts du contribuable au producteur). L'Accord définissait cependant une catégorie de politiques de soutien interne qui n'était pas soumise à cette obligation de réduction, qui étaient les aides entrant dans la « boîte verte » (mesures autorisées), ainsi exclues du calcul de l'AMS. Il s'agissait de soutiens au revenu qui n'ont pas ou très peu d'impact sur le niveau de la production agricole, des aides aux actions destinées à protéger l'environnement, des aides publiques aux mécanismes d'assurance récolte, les soutiens aux actions de conseil et au développement, des programmes d'ajustement structurels, etc. En principe, tous les paiements classés hors de cette boîte verte devaient être réduits. Néanmoins, l'accord bilatéral entre les Etats-Unis et l'UE, largement imposé au reste du monde, spécifiait que les aides conditionnées à un programme de limitation de la production et celles reposant sur des rendements ou surfaces de référence fixes entraient dans une catégorie intermédiaire (la « boîte bleue ») qui les excluait du calcul des AMS (Bureau and Bureau, 1999).

Source : (**Bureau et al., 2001 [2], page 10**)

Nous avons étudié les raisons de ce niveau élevé de protection dix ans après la signature de l'AACU. En analysant le soutien à l'agriculture à travers les trois piliers de l'AACU : l'accès au marché ; les subventions aux exportations et les soutiens internes (**Encadré 3**) on s'apercevait que les obligations de l'AACU n'avaient pas été aussi contraignantes que prévu (**Butault et al., 2004 [79]**). Dans ce chapitre d'ouvrage nous avons décrit l'évolution des soutiens à l'agriculture entre 1986 et 2002 dans les pays de l'Organisation de coopération et de développement économiques (OCDE) et donné un éclairage sur les soutiens à l'agriculture dans les pays d'Europe de l'Est. Ce travail reposait sur l'analyse des déclarations (ou notifications) des pays à l'OMC. Tout en soulignant les limites de l'évaluation des Equivalent soutien au producteur (ESP) de l'OCDE (qui prend pour référence un prix mondial sans tenir compte du fait qu'il peut être soumis à des distorsions du fait de l'existence de politique de soutien), nous montrions l'intérêt de prendre en compte l'inflation ou l'évolution des taux de change dans l'analyse dynamique des soutiens à l'agriculture. De cette analyse il ressortait que dans l'ensemble, les pays avaient respecté leurs engagements dans le cadre de l'AACU, mais qu'ils l'ont fait car cet accord s'est révélé somme toute, peu contraignant. Soit, parce que les pays ont souvent trouvé des « astuces » comme la dilution des taxes pour que cet accord soit effectivement peu contraignant, soit parce que les taux appliqués sont différents des taux consolidés (c'est-à-dire déclarés à l'OMC). Ceci, notamment du fait de l'existence de nombreux accords préférentiels ; le fameux « bol de spaghetti » (**Encadré 4**), représentation caricaturale des imbrications complexes des divers accords régionaux de libre-échange passés entre différentes régions du monde. L'UE est encore un grand « contracteur » d'accords préférentiels. Or, la signature d'accords commerciaux soulève deux questions, la première est celle de la mesure du niveau de la protection, la seconde est celle de l'érosion des préférences face à la signature d'un accord multilatéral. Toutefois, ces questions ne sont plus aussi prégnantes aujourd'hui car une grande partie des droits de douane ont été transformés en droits ad-valorem et surtout le niveau général de la protection dans l'agriculture a beaucoup diminué.

1.2. Les accords commerciaux avec les pays du sud

La plupart des pays taxent leurs importations. Au niveau mondial, ces taxes sont réglementées par des accords de commerce régis par l'OMC. Ces taxes sont fixées selon la clause de la nation la plus favorisée qui stipule que tout avantage commercial accordé par un pays à un autre doit être automatiquement étendu à tous. Toutefois, il existe de nombreuses exceptions à cette clause. Beaucoup de pays ou de régions du monde signent des accords commerciaux préférentiels où ils s'engagent de manière unilatérale ou bilatérale à réduire leurs tarifs par rapport au niveau NPF.

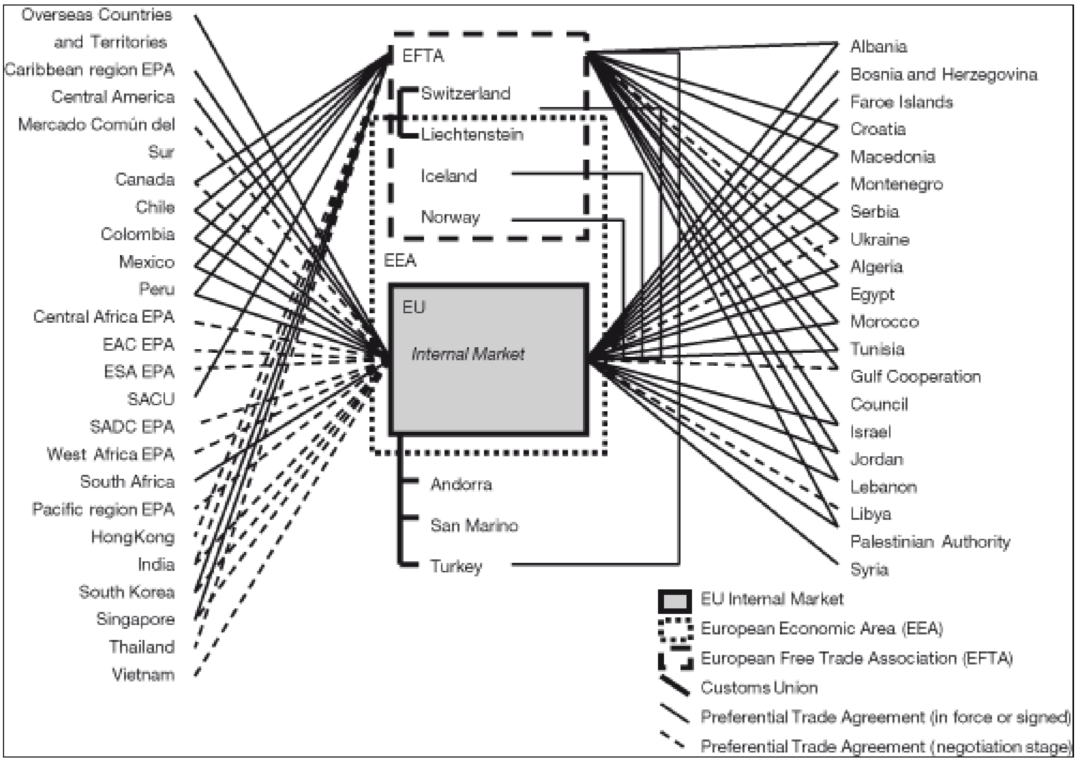
C'est le cas de l'UE qui offre de manière unilatérale des préférences commerciales aux pays en développement dans le cadre de nombreux accords préférentiels régionaux ou bilatéraux qui sont résumés dans la Figure 3. De nos différentes analyses sur les accords préférentiels il ressort que l'UE n'offre que peu de degré de libéralisation aux pays du Sud notamment quand il s'agit de produits agricoles qui pourraient concurrencer l'offre européenne. De plus, il y a débat sur l'efficacité des préférences du fait d'obstacles administratifs ou de règles d'attribution restrictives qui en limitent la portée. Cela bloque souvent les accords avec de grandes puissances commerciales. Par exemple, l'accord avec les pays du Mercosur n'a été conclu qu'en 2019 du fait du blocage agricole (**Drogue, Ramos et Bureau, 2004 [3] ; Drogue et Ramos, 2005 [81]**) et celui envisagé avec la Russie n'a toujours pas été signé (**Drogue, Pyykkönen et Virolainen, 2008 [30]**).

Encadré 4 : Les principaux accord préférentiels de l'UE

Dans le cadre de ses échanges commerciaux avec les pays en développement, l'UE distingue quatre grands groupes : les pays de la triade Afrique-Caraïbe-Pacifique (ACP), les pays méditerranéens, les pays d'Amérique Latine et les pays asiatiques. Les pays ACP occupent traditionnellement la première place dans la hiérarchie des préférences à travers l'Accord de Lomé/Cotonou. Les pays d'Asie et d'Amérique Latine bénéficient d'un accès préférentiel au marché de l'UE depuis 1971 dans le cadre du Système Généralisé des Préférences (SGP). Enfin, les pays les moins développés hors ACP sont soumis au régime « Super ACP » qui leur confère des concessions particulières dont sont exclus les pays qui bénéficient du SGP. ***Le Système Généralisé des Préférences*** a été initié par l'UE en 1971, puis adopté par les autres pays. Il offre aux pays en développement des conditions avantageuses pour accéder au marché européen.

La Convention de Lomé de 1957 accorde des préférences unilatérales pour l'accès au marché européen aux pays ACP. A ce titre, elles sont incompatibles avec les principes de l'OMC, d'une part, parce qu'elles sont limitées à un groupe de pays, et d'autre part, parce qu'elles sont unilatérales. Il faut toutefois signaler que la Convention de Cotonou a apporté des modifications importantes, en décidant notamment que les préférences accordées d'une manière unilatérale seront maintenues jusqu'en 2007, date à laquelle les pays signataires devront, soit conclure des accords d'association économique réciproques pour l'essentiel de leurs échanges, soit opter pour le Système Généralisé des Préférences. L'UE a également conclu de nombreux ***autres accords préférentiels***. C'est ainsi qu'en 1999, elle a signé avec l'Afrique du Sud, qui ne bénéficie plus de l'Accord de Lomé, un accord commercial prévoyant la libéralisation totale des échanges en 2012 et incluant 60 % des produits agricoles. D'autres accords ont été conclus avec les pays balkaniques et avec l'ex-république yougoslave. Le dernier en date est le CETA conclu avec le Canada en 2017.

Figure 3 : Les accords commerciaux avec l'Union européenne en 2010



Source : (Koopmann et Wilhelm, 2010)

La signature d'accords préférentiels n'a pas contribué à rendre la structure tarifaire d'un pays plus transparente. En particulier, la mise en place de restrictions quantitatives ou de tarifs spécifiques rend plus difficile la quantification des effets de réduction de droits de douane. La traduction de droits spécifiques en droits ad-valorem constitue le premier pas dans la construction d'une base de données directement utilisable. Non seulement elle permet d'utiliser directement ces tarifs dans un modèle mais également de construire des scénarios. Nombre de mes travaux ont porté notamment sur la mesure des concessions douanières accordées par l'UE à ses nombreux partenaires commerciaux (**Chahed et Drogue, 2003 [86]**, **DeMaria, Drogue et Matthews (2008) [15]** ; **DeMaria, Drogue et Rau (2015) [45]**).

a. Les accords Euromed

Les pays signataires de l'AACU ont dû réduire les droits sur leurs importations de produits agricoles, en application de la clause de la nation la plus favorisée. Or, nombre de ces pays avaient conclu des accords commerciaux bilatéraux leur permettant de bénéficier de préférences tarifaires. C'est le cas des pays méditerranéens avec l'UE, dans le cadre notamment des accords Euromed. Ces accords ont été signés entre l'UE et dix autres pays riverains de la Méditerranée à l'issue du processus de Barcelone institué en 1995 à l'initiative de l'UE. La baisse des tarifs NPF, initiée par l'AACU, induisait pour ces pays une érosion de leurs préférences qui pouvait avoir une répercussion négative sur leurs exportations agricoles.

En 2003, dans (**Chahed et Drogue, 2003 [86]**) nous avons mesuré pour plusieurs produits agricoles et pays méditerranéens, les préférences offertes par l'UE. L'objectif était d'évaluer à quel point les accords Euromed avaient ouvert le marché européen aux produits de la rive sud de la Méditerranée et les conséquences qu'une détérioration de ces préférences, consécutive à une plus grande libéralisation, aurait pu avoir sur le commerce agroalimentaire de ces pays avec l'UE. La méthodologie reposait sur le croisement de plusieurs indicateurs tels que la marge préférentielle[3] et des indicateurs de performance ou compétitivité : l'avantage comparatif révélé, l'indice de spécialisation des exportations et l'intensité relative des flux (voir **Drogue, Ramos et Bureau (2004) [3]** pour plus de détails sur ces indicateurs). Les conclusions étaient contrastées selon les pays et les produits analysés. Il ressortait de ce travail que le marché européen ne s'ouvrait pas vraiment aux produits phare des pays méditerranéens tels que les fruits et légumes ou l'huile d'olive (exception faite de la Tunisie, voir Encadré 5). De fait, les risques de détournement des échanges avec l'UE au détriment des pays méditerranéens par suite de l'érosion de leurs marges préférentielles, paraissaient limités.

[3] La marge préférentielle est la différence entre le droit de douane MFN et le droit de douane préférentiel. En multipliant cette marge par la valeur du commerce on obtient la valeur de la marge préférentielle.

Encadré 5 : l'huile d'olive un produit très protégé sur le marché de l'UE

Dans le cadre du programme de travail « décrire et quantifier les régimes de protection de l'UE pour les fruits et légumes et l'huile d'olive » du projet FP6 EUMED-AGPOL coordonné par le Centre International des Hautes Etudes Agronomiques Méditerranéennes et l'Institut Agronomique Méditerranéen (CIHEAM-IAM) de Montpellier, j'ai mesuré le régime de protection européen de l'huile d'olive (**Drogue, 2005 [4]**). L'huile d'olive depuis la création en 1966 de l'Organisation commune de marché (OCM) pour les huiles et matières grasses est un secteur très soutenu par la Politique agricole commune (PAC) (**Drogue, 1998 [78]**). Les ESP que j'ai calculés pour l'huile d'olive entre 1995 et 2003 représentaient en moyenne, 42 % de la valeur de la production. Ces résultats étaient proches de ceux obtenus par d'autres auteurs mais ont été calculés à partir d'un prix de référence mondial différent. En effet, prendre comme référence pour le prix mondial, la valeur unitaire des importations extra-UE par exemple, introduit un biais dans la mesure où la plupart des importations européennes sont stimulées par les préférences que l'UE accorde à certains de ses partenaires, notamment la Tunisie. J'ai donc utilisé la valeur unitaire des importations des Etats-Unis en provenance de la Turquie comme référence de prix mondial. Dans une seconde partie j'ai mesuré le niveau de protection de ce produit au niveau 8 chiffres du système de codification douanière de l'UE. Les résultats montraient que les droits de douane étaient très élevés (supérieurs à 50 % en équivalent ad-valorem) et que, à part pour la Tunisie, les préférences accordées par l'UE étaient très limitées au vu de la taille des quotas.

b. L'accord avec les pays du Mercosur

Parallèlement, des négociations entre l'Union européenne et le Mercosur visant à créer la plus grande zone de libre-échange au monde ont été entamées en 2000. L'accord définitif a été conclu en juin 2019 mais est toujours en suspens car la France s'oppose à cet accord. Pendant de nombreuses années, cet accord a achoppé à cause de l'offre mercosuline en matière de services et de marchés publics du côté européen et de l'offre agricole européenne, côté mercosulin. Le volet agricole a tenu une place importante dans les discussions. Une ouverture plus importante des marchés de l'UE aux pays latino-américains risquait de mettre en péril les fondements même de la Politique agricole commune (PAC) et de bouleverser l'équilibre laborieusement trouvé pour assurer aux producteurs européens une perspective stable. En effet, les pays du Mercosur et notamment les deux « géants » Brésil et Argentine étaient en mesure de concurrencer les produits européens, sur leur propre marché et ce malgré des niveaux de protection qui restaient assez élevés. Et donc, bien que classés parmi les pays en développement, les pays du Mercosur n'ont jamais bénéficié des avantages généralement accordés par l'UE à ces pays, en matière d'accès à son marché.

Nous avons analysé cinq filières agricoles : maïs, blé, sucre/éthanol, viandes et produits laitiers grâce à des indicateurs de compétitivité de court et long terme (**Drogue et al., 2004 [3]**). Ces travaux montraient que le bloc mercosulin bénéficiait d'une compétitivité-prix très avantageuse par rapport à son concurrent européen sur toutes ces filières et si jusqu'alors les taxes aux importations réussissaient à faire la différence, l'ouverture de plus larges quotas aux agriculteurs et éleveurs du Mercosur risquait de mettre en difficulté leurs homologues européens. En effet, malgré une faiblesse structurelle dans la productivité des facteurs (terre, travail, capital), le Mercosur tirait son épingle du jeu grâce à sa compétitivité coût des facteurs notamment de la main d'œuvre (**Drogue et Ramos, 2005 [81]**).

c. Le système des préférences généralisé

Le système des préférences généralisé (SGP) a été adopté par l'UE en 1971 pour offrir des préférences tarifaires aux pays en développement. Ce système est renouvelé tous les 10 ans. Il comporte 3 volets un accord « général » (SPG), des accords dits « spéciaux » (SPGE) pour la protection des droits des travailleurs, pour la protection de l'environnement et pour la lutte contre la production de drogue et un accord pour les pays les moins avancés (PMA) appelé aussi initiative « Tout sauf les armes » (désigné par SGPA) introduit en 2001. En mobilisant les bases de données disponibles sur les tarifs et le commerce (voir Encadré 1), nous avons réalisé 2 analyses de « l'intérêt » pour les pays bénéficiaires des préférences accordées par les SPG (**DeMaria, Drogue et Mathews 2008 [88] ; DeMaria, Drogue et Rau 2015 [45]**). Nous avons étudié l'impact du SPG entré en vigueur en 2006 et de celui entré en vigueur en 2014. Ces 2 analyses reposent sur des calculs d'EAV et de marge préférentielle. Bien que des efforts aient été accomplis par l'UE pour offrir un accès privilégié à ses marchés aux pays en développement, le constat reste mitigé.

Lorsqu'on analyse les données commerciales, les pays en développement semblent avoir réussi à tirer parti de l'amélioration de l'accès au marché offerte par les préférences de l'UE. La valeur des importations agroalimentaires en provenance des pays bénéficiaires et ayant bénéficié du SPG européen a considérablement évolué entre 2004 et 2013 (voir Tableau 2). Pour les pays SPG, elle est passée de 35 à 64 milliards d'euros. Pour les pays du SPGE, ces importations ont doublé. Seuls les pays SPGA n'ont pas vu leurs exportations agroalimentaires vers l'UE augmenter énormément. Quand on s'intéresse au classement des pays en fonction de la valeur de leurs exportations agroalimentaires vers l'UE, on s'aperçoit que ce sont les pays émergents qui sont les grands bénéficiaires de ce régime préférentiel.

Il y a plusieurs raisons à cela : (i) les coûts de participation aux régimes respectifs empêchent les exportateurs des petits pays en développement en particulier de bénéficier des préférences disponibles. Les coûts de participation sont liés à l'administration, au suivi et aux règles d'origine, mais aussi aux exigences en matière d'importation ; (ii) certains bénéficiaires du SPG peuvent choisir de négocier une préférence dans le cadre d'un accord de libre-échange (ALE), et ils peuvent préférer cette alternative dans certains cas.

Nos résultats montraient que les régimes SPG n'apparaissaient pas toujours comme les régimes préférés et les plus avantageux. L'analyse des marges préférentielles sur les 3 années étudiées (2004, 2006 et 2013) a montré que, bien que le droit SPG moyen n'ait pas beaucoup changé entre ces trois périodes, les importations, et donc la valeur de la marge globale, en provenance des pays bénéficiaires avaient évolué favorablement, quel que soit le régime adopté (SPG, SPGE ou SPGA). Ces évolutions étaient dues à l'augmentation du volume des importations mais aussi à un changement dans leur composition. Cette évolution était cependant à nuancer en fonction des pays bénéficiaires. Le nouveau SGP confirmait la présence en tête de pays émergents tels que la Chine, le Brésil, l'Argentine, l'Inde ou l'Afrique du Sud, mais il voyait apparaître de nouveaux venus comme la Thaïlande, le Vietnam ou la Russie parvenus à tirer parti des préférences offertes par l'UE (voir **Tableau 2**).

Tableau 1 : Valeur des importations agroalimentaires de l'UE des pays bénéficiant du SPG et taux d'utilisation des préférences accordées par l'UE (toutes préférences confondues).

	Importations agroalimentaires UE de pays bénéficiant du SPG (€ million)	**MFN non-0 (%)**	**MFN-0 (%)**	**Pref-0 (%)**	**Pref non-0 (%)**	**Taux d'utilisation (%)**
SPGA						
2013	3,576	2.30	32.42	65.28	0.00	97
2006	2,510	2.37	35.50	61.90	0.23	84
2000-2005	2,289	6.14	29.66	63.97	0.22	87
SPG						
2013	64,577	18.07	46.24	21.58	14.12	88
2006	43,202	22.67	40.43	16.76	20.14	77
2000-2005	35,704	27.58	41.39	16.89	14.13	84
SPGE						
2013	10,590	18.62	33.98	38.11	9.28	92
2006	7,139	29.85	30.73	32.14	7.28	87
2000-2005	5,209	37.51	29.26	26.17	7.05	85

Source: **DeMaria, Drogue et Mathews 2008 [88] ; DeMaria, Drogue et Rau 2015 [45]**

Tableau 2 : Valeur des importations agroalimentaires de l'UE des 10 premiers pays en développement qui perdent leur statut SPG au 01/01/2014, par groupe de préférence en 2013.

SPGA	Valeur du commerce sous préférence (million €)	SPG	Valeur du commerce sous préférence (million €)	SPGE	Valeur du commerce sous préférence (million €)
2013					
Bangladesh	324,75	Chile	2289,19	Ecuador	1,454.42
Tanzania	228,57	China	1970,11	Peru	1,117.34
Madagascar	223,43	Morocco	1942.71	Costa Rica	696,21
Senegal	209,90	South Africa	1586.05	Colombia	661.09
Mozambique	192,98	India	1400.59	Guatemala	343.66
Malawi	181,26	Thailand	1167.20	Honduras	165.08
Ethiopia	169,42	Argentina	1099.83	Sri Lanka	119.10
Cambodia	161,89	Cote d'Ivoire	1075.57	Nicaragua	113.15
Uganda	133,51	Vietnam	836.62	Georgia	91.75
Mauritania	114,57	Kenya	703.21	El Salvador	69.00
2006					
Bangladesh	133,12	China	1252.33	Ecuador	755.43
Senegal	87,14	Argentina	1065.39	Peru	461.70
Tanzania	81,25	India	732.04	Costa Rica	380.31
Mauritania	49,02	Brazil	596.69	Colombia	375.04
Maldives	44,28	Thailand	588.23	Guatemala	130.88
Uganda	43,07	South Africa	564.88	Sri Lanka	104.66
Ethiopia	33,01	Vietnam	479.37	Panama	92.13
Yemen	32,01	Ukraine	404.79	Honduras	88.24
Zambia	26,56	Indonesia	277.48	Venezuela	68.05
Madagascar	22,49	Russian Fed.	263.75	Georgia	58.13
2004					
Bangladesh	120,31	China	678.12	Ecuador	473.40
Tanzania	91,72	Argentina	603.82	Peru	316.95
Senegal	90,74	India	529.05	Colombia	198.24
Uganda	37,39	South Africa	448.02	Guatemala	118.57
Mauritania	36,44	Brazil	299.53	Costa Rica	91.42
Madagascar	29,67	Indonesia	265.73	Pakistan	73.42
Malawi	29,10	Iran	226.24	Honduras	71,40
Maldives	25,94	Malaysia	153.78	Venezuela	69,90
Yemen	23,46	Ukraine	149,56	Panama	45,71
Ethiopia	16,16	Cuba	137,72	El Salvador	31,72

Source : **DeMaria, Drogue et Mathews 2008 [88] ; DeMaria, Drogue et Rau 2015 [45]**

Ces évolutions commerciales ont eu pour effet que la réforme du SPG de 2013 allait affecter surtout les pays qui ne bénéficient que des régimes SPG et/ou qui se sont spécialisés dans des produits gradués des préférences. C'est le cas de certains pays émergents, comme le Brésil et la Russie, qui ont perdu leur statut SPG pour exporter vers l'UE. En tant qu'acteurs importants du commerce international, on peut toutefois s'attendre à ce que ces pays soient compétitifs sur le marché mondial ainsi que sur le marché de l'UE. La Chine conserve son statut SPG mais a perdu ses conditions préférentielles d'accès au marché pour de nombreux produits agroalimentaires. On peut donc s'attendre à ce que les pays en développement qui perdent leur statut SPG concluent davantage d'accords de libre-échange[4], y compris des accords de partenariat économique (APE), avec l'UE pour maintenir leur accès préférentiel à ce marché.

Dans un contexte de globalisation de l'économie, un certain nombre d'interrogations et de préoccupations concernant les effets potentiels de la libéralisation des échanges ont émergé du côté des producteurs comme des consommateurs. Il ne s'agissait plus de mesurer le niveau de la protection mais d'évaluer son impact. Les travaux de quantification de l'impact des politiques commerciales sur les échanges, les prix ou le bien-être sont au cœur des démarches d'aide à la décision publique dans ce domaine. Ces sujets ouvrent nombre de questions de recherche empiriques et méthodologiques. La section suivante est consacré à mes travaux en lien avec la mise en œuvre des politiques commerciales. Je présente trois points méthodologiques : la prise en compte des quotas tarifaires et de la concurrence imparfaite dans les modèles

1.3. Exemple de simulation de scénarios de libéralisation commerciale et points méthodologiques

a. La prise en compte des quotas tarifaires

La plupart de mes travaux en commerce international ont été également des exercices de simulation d'accord de libre-échange réalisés avec des modèles d'équilibre général calculable (EGC). Ces modèles EGC sont devenus un instrument standard dans l'analyse de l'impact des négociations commerciales. Parmi les projets qui ont eu le plus de succès, le modèle Global Trade Analysis Project (GTAP) s'est révélé un instrument utile pour les modélisateurs du commerce international partout dans le monde. L'intérêt et la force de GTAP est que c'est à la fois un modèle mais aussi une base de données mondiale. Dans **Ramos et Drogue (2005) [29]** nous avons utilisé GTAP pour simuler les effets de la création d'une zone de libre-échange entre l'UE et le Mercosur. Notre objectif était d'évaluer l'impact de ce plus large accès aux marchés de l'UE pour des produits agroalimentaires du Mercosur ; pour l'UE, le Mercosur et les partenaires commerciaux de l'UE. Comme l'offre européenne était construite en termes de quotas tarifaires (TRQ), nous avons utilisé la méthodologie et le programme de (Elbehri et Pearson, 2000) pour introduire des quotas dans le modèle GTAP. Nous avons ajouté un bloc de variables et d'équations

[4] L'Equateur a signé un accord de libre-échange avec l'UE en 2014 pour garantir ses préférences.

pour tenir compte de cet instrument de politique commerciale, puis effectué des simulations en suivant le scénario des négociations. Cette proposition concerne l'ouverture de TRQ pour le bœuf, la volaille, le blé, le maïs, et les produits laitiers.

Les résultats montraient que la mise en œuvre de ces propositions aurait entraîné une perte globale de bien-être de 5 millions de US$. Sans surprise, dans ce scénario, l'UE est la principale perdante et le Mercosur le principal gagnant. Ces gains et pertes sont essentiellement dus aux changements dans les termes de l'échange et aux transferts de rentes de quotas[5]. Dans l'hypothèse où toutes les rentes de quotas sont captées par les exportateurs, le Mercosur gagnerait 75 % de son bien-être par transfert de rentes. Il semble que dans les pays du Mercosur il y ait une sorte de concurrence sectorielle sur les facteurs qui entraînerait une redistribution des ressources de tous les autres secteurs vers ceux de la volaille et du bœuf. Globalement, la redistribution des ressources induirait des gains positifs de bien-être, mais le fait que ces ressources soient dirigées vers un nombre réduit de secteurs entrainerait des inefficacités techniques du fait de la perte de valeur ajoutée dans les services et l'industrie. Cependant, contrairement à ce qu'on aurait pu prévoir, les détournements de commerce au détriment des principaux partenaires commerciaux de l'UE auraient été limités et auraient affecté surtout les principaux fournisseurs de viande. Une intégration plus profonde entre l'UE et le Mercosur aurait affecté certainement les agriculteurs européens, en particulier si cette plus large intégration comprenait les produits agroalimentaires parmi les plus protégés en Europe, qui sont également parmi le plus compétitifs dans le Mercosur. Dans ce document nous avions fait l'hypothèse que 100 % des rentes de quotas étaient transférés aux exportateurs. Il en ressortait que, l'administration des licences de quotas semblait à cette époque l'obstacle principal des négociations entre l'UE et le Mercosur.

b. Modèle CGE et concurrence imparfaite

Un autre modèle est venu « concurrencer » GTAP, c'est le modèle MIRAGE du Centre d'études prospectives et d'informations internationales (CEPII) (voir Encadré 6). Ce modèle développé par le CEPII très utilisé pour simuler les propositions de négociations de la France et de la Commission européenne présentait deux innovations par rapport à GTAP. La 1ère était l'introduction de l'hypothèse de concurrence imparfaite *à la* Krugman (Krugman, 1995) et la 2nde était l'utilisation de la base de données sur les droits de douane MacMaps (Market Access Maps). C'est ce modèle que j'ai utilisé pour simuler un accord de libre-échange entre l'UE et la Russie (**Drogue, Pyykkönen et Virolainen, 2008 [30]**). L'objectif

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[5] Un quota tarifaire est une restriction quantitative au commerce (à l'intérieur du quota le droit de douane est inférieur au droit NPF voire nul et égal au droit NPF à l'extérieur du quota). Contrairement à un droit de douane qui s'applique à tous, le quota est administré par le partenaire commercial qui peut donc choisir quelle entreprise pourra bénéficier de la préférence. La rente de quota est le bénéfice que l'exportateur retire de sa marge préférentielle « in-quota ».

était d'évaluer l'impact des différents niveaux d'un accord commercial entre la Fédération de Russie et l'Union européenne.

Encadré 6 : le modèle Mirage
« MIRAGE (Modelling International Relationships in Applied General Equilibrium) est un modèle d'équilibre général calculable multi-sectoriel et multi-régional, destiné à l'analyse des politiques commerciales. Il incorpore des éléments de concurrence imparfaite, de différenciation des produits par variétés et par gamme de qualité, et d'investissement direct à l'étranger, dans un cadre dynamique séquentiel où le capital installé est supposé immobile. Les inerties d'ajustement y sont liées à la réallocation du stock de capital. MIRAGE s'appuie sur une mesure bilatérale très détaillée des barrières aux échanges et de leur évolution sous différentes hypothèses, grâce à la base MAcMap. »
Source : http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=14

Les scénarios calculés tenaient compte de trois niveaux d'accord entre la Fédération de Russie et l'Union européenne : un accord « minimum », une libéralisation totale sauf pour les produits sensibles et la création d'une zone de libre-échange (ZLE) avec suppression de toute protection entre les deux blocs. Dans tous les scénarios, la réduction tarifaire était mise en place en 2010 sans période de transition. En plus, différents contextes de l'environnement international étaient pris en compte tels que la conclusion de l'accord du cycle de Doha (ci-après appelé PDD pour le programme de Doha pour le développement) et l'adhésion de la Russie à l'OMC. Les différentes combinaisons conduisent à dix scénarios : (i) accord minimal entre l'UE et la Russie, (ii) libéralisation totale des biens et services, sauf pour certains produits sensibles, (iii) création d'une ZLE, (iv) Accord du Cycle de Doha + « Accord minimum », (v) PDD + libéralisation à l'exception des produits sensibles, (vi) PDD + ZLE, (vii) adhésion à l'OMC + libéralisation sauf pour les produits sensibles, (viii) adhésion à l'OMC + ZLE, (ix) adhésion au PDD+OMC + libéralisation sauf pour les produits sensibles, (x) ADD + adhésion à l'OMC + ZLE.

Plusieurs conclusions ont pu être tirées. Comme la protection initiale des deux côtés est plutôt faible, les impacts simulés sont plutôt faibles, pour les deux économies en moyenne en termes relatifs. Toutefois, les résultats ne sont pas négligeables en termes absolus, en particulier lorsqu'une libéralisation multilatérale parallèle est envisagée. Cela profite en particulier à l'UE et au secteur industriel.

Au départ, la Russie est plus protégée que l'UE et l'UE est le principal partenaire commercial de la Russie. La création d'une zone de libre-échange sans autre processus de libéralisation conduit la Russie à souffrir des effets de diversion commerciale. Un accord de libre-échange UE-Russie a des effets négatifs sur les termes de l'échange pour la Russie. Toutefois, ils sont largement compensés par des gains d'allocation. En fait, dans tous les cas, la Russie expérimente un gain de revenu réel. Du côté de l'UE, le commerce avec la Russie ne représente que 3 % du total des exportations de l'UE, ce qui entraîne en tout état de cause de faibles gains en points de pourcentage. Les termes de l'échange étant favorables à l'UE, les variations de revenus sont toujours positives.

Ensuite, les résultats sont contrastés. Un accord de libre-échange entre l'UE et la Russie entraîne une perte de bien-être pour la Russie, même s'il s'accompagne d'une libéralisation commerciale multilatérale en raison de termes de l'échange défavorables. Mais cet ALE est toujours bénéfique pour les échanges entre les deux partenaires et en particulier pour la Russie, où la protection initiale est plus élevée et grâce à la dépréciation de son taux de change réel.

Ces résultats sont également contrastés selon les secteurs. Le secteur industriel étant de loin le plus important dans la composition des échanges de ces deux économies, c'est aussi le secteur qui concentre la plupart des gains. En ce qui concerne l'agroalimentaire, les gains sont plus modestes en termes absolus, mais les augmentations du commerce en termes relatifs sont significatives pour les produits laitiers, les viandes, les céréales, la pêche et l'alimentation pour la Russie ; les viandes, les produits laitiers et autres cultures pour l'UE.

c. La différentiation des produits

Un enjeu important dans la mesure des impacts de la libéralisation des échanges est la prise en compte de la qualité. Dans le secteur agricole en particulier, on a observé un développement de l'échange de produits différenciés, résultant par exemple, de la multiplication des variétés de produits frais et des exigences en termes de sécurité des aliments. Cet état de fait pose la question de la quantification du bien-être des consommateurs dans un contexte où la qualité et la variété comptent pour les producteurs et les consommateurs. Beaucoup de modèles empiriques considèrent que les produits agricoles sont des biens homogènes, hypothèse utilisée du fait du manque de données détaillées. La disponibilité des données, comme vu précédemment, est souvent un facteur limitant dans l'estimation des courbes de demande ou des élasticités. Or le manque de précision dans les données peut constituer un problème dans l'évaluation du bien-être. En partant de ce constat, dans **Drogue, Ramos et Marette, 2004 et 2005 [27 et 28]** nous avons étudié l'impact sur la mesure du bien-être de la prise en compte de la qualité dans un modèle de demande. Pour ce faire, nous avons comparé des résultats en termes de bien-être entre deux spécifications d'un modèle de demande pour un produit. Nous avons repris la structure du modèle de (Spence, 1976) concernant les caractéristiques de la demande. Nous avons fait l'hypothèse que pour un même produit, il pouvait y avoir des productions de qualité haute ou de qualité basse et donc des demandes pour les deux qualités. Nous avons appliqué ce modèle dans un cadre de concurrence parfaite qui correspond mieux au secteur agricole. Nous avons calibré ce modèle à partir de données « théoriques ». Nous avons ensuite agrégé les quantités et les prix pour obtenir un seul produit homogène et une seule demande. Quand on effectue des mesures de bien-être en faisant varier les paramètres du modèle nous trouvons que l'estimation du bien-être pouvait être inférieure ou supérieure en présence de différenciation à celle pour le produit considéré comme homogène. Nous avons ensuite appliqué ce modèle au cas particulier de la demande de viande de bœuf aux Etats-Unis à partir des données de (Lusk et al., 2001). Ce marché avait été choisi car la qualité et les prix des qualités sont importants pour les consommateurs de viande américains. Cette estimation empirique corrobore complètement les résultats théoriques. Elle montre que les gains de bien-être dans l'agriculture pourraient être largement sur ou sous-estimés (+ ou -30 % dans notre exemple) si on ne tient pas compte des différences de qualité des produits. Ces résultats appellent donc à plus de circonspection quand on analyse des résultats de simulation ou que l'on conduit des travaux de quantification. Ils suggèrent que des biais significatifs peuvent venir de l'absence de données précises.

d. Le calibrage des élasticités

Une autre limite importante à laquelle se heurtent les exercices de modélisation est le manque ou l'absence d'information sur les élasticités nécessaires au calibrage ou paramétrage du modèle. Dans **Beghin, Bureau et Drogue, 2004 [2]** nous avons repris la méthodologie développée dans (LaFrance et al., 2002; LaFrance, 2004; LaFrance and Hanemann, 1989) permettant de retrouver la structure des préférences à partir d'un système de demande incomplet et nous l'avons adaptée à des exercices de calibrage des systèmes de demande partiels. Nous proposons une technique de calibrage flexible des systèmes de demande quand on ne dispose d'information que sur les élasticités-prix propres ou quand ne sont disponibles qu'une partie des élasticités-prix croisées. Cette technique est basée sur les développements récents des systèmes de demande incomplets (LaFrance, 1998). Elle s'adapte à divers niveaux de connaissance sur les élasticités-prix croisées, satisfait les conditions de courbure et permet une mesure exacte du bien-être pour l'analyse économique. Le calibrage est ici effectué de manière séquentielle. Tout d'abord, une estimation des dérivées des demandes du système par rapport au revenu est obtenue à partir des élasticités-revenu. Les paramètres obtenus sont introduits dans les équations du système de demande marshallienne et dans les équations des élasticités prix propres. A partir de ces équations on peut retrouver les réponses en prix grâce aux élasticités disponibles. En utilisant ces réponses en prix, les conditions d'intégrabilité, et les niveaux de demande observés on retrouve les paramètres du modèle. Il convient de souligner que comme on peut recalculer tous les paramètres du modèle, une mesure exacte du bien-être est possible et donc cette technique peut être utilisée dans une analyse de politique économique.

Nous illustrons cette approche par un système de demande partiel pour la consommation alimentaire en Corée pour différents niveaux de connaissance des effets-prix croisés. Nous mesurons l'impact d'une libéralisation commerciale des biens agricoles et alimentaires sur le bien-être des consommateurs. Les résultats obtenus ne sont pas sensibles à l'inclusion ou à l'exclusion des effets prix croisés disponibles.

La libéralisation du commerce et la baisse progressive des niveaux de taxes dans tous les secteurs et dans tous les pays ont, au cours des années qui ont suivi la signature de l'AACU[6], motivé l'émergence d'une littérature théorique et empirique en commerce international qui s'est intéressée moins aux tarifs qu'aux réglementations susceptibles de freiner à leur tour le commerce.
Avec la signature de l'AAUR ont aussi été signés deux autres accords. L'Accord sur l'application des mesures sanitaires et phytosanitaires (SPS) a trait à l'application des réglementations concernant l'innocuité des produits alimentaires, ainsi que la protection de la santé des animaux et la préservation des végétaux. L'Accord sur les obstacles techniques au commerce (OTC) concerne les règlements techniques, les normes et les procédures d'évaluation de la conformité. Ces deux accords visent à faire en sorte que les deux types de réglementations soient non discriminatoires et ne créent pas d'obstacles non nécessaires au commerce. Ils ont également favorisé l'émergence d'un corpus en commerce international. Dans la section suivante je présente mes travaux sur les réglementations sanitaires et phytosanitaires et notamment celles concernant les limites maximales de résidus de pesticides, leurs déterminants et leur impact sur le commerce.

1.4. Les standards de sureté alimentaire : barrière au commerce ou mesure de santé publique ?

Le caractère restrictif pour le commerce des réglementations techniques et sanitaires et phytosanitaires nationales a fait l'objet d'une grande attention au cours des 20 dernières années en raison de la crainte que de telles mesures soient utilisées comme du protectionnisme déguisé visant à compenser les effets de la baisse des tarifs. La création en 1995 de l'OMC dotée d'un organe de règlement des différends (ORD) et de deux accords spécifiques favorisant l'harmonisation internationale des standards nationaux (l'accord SPS en vigueur à partir de cette date et l'accord OTC de 1979) avait suscité de grands espoirs quant à l'émergence d'un cadre multilatéral mettant en cause la « restriction inutile au commerce ». En effet, la nécessité d'une évaluation scientifique des risques (qui renforce la légitimité des réglementations restrictives pour le commerce dans le cadre de l'accord SPS) et d'une cohérence des réglementations (veiller à ce que les produits présentant un niveau de risque comparable soient soumis à des réglementations similaires) ont conduit l'ORD à dénoncer certaines réglementations manifestement protectionnistes.

[6] Un article récent (Bureau, Guimbard, and Jean, 2019) montre que ces réductions de tarifs ne se sont pas faites forcément dans le cadre multilatéral de l'OMC.

Ce cadre a également eu des répercussions positives sur la transparence des diverses exigences des pays en matière d'importation (par le biais du système de notification aux comités SPS et OTC). Toutefois, malgré les tentatives récentes de répondre aux besoins des pays en développement dans le cadre du Cycle de Doha pour le développement, de nombreuses études ont montré que ces derniers continuent d'éprouver des difficultés récurrentes à satisfaire aux prescriptions SPS et aux prescriptions techniques pour exporter vers les pays développés, notamment dans les secteurs agricole et agroalimentaire (Disdier, Fontagné et Mimouni, 2008 ; Keiichiro, Otsuki et Wilson, 2015). Dans ce contexte, une grande partie de mes travaux de recherches ont porté sur l'impact des réglementations SPS sur le commerce. J'ai plus particulièrement étudié celles qui concernent les limites maximales de résidus de pesticides (voir Encadré 7).

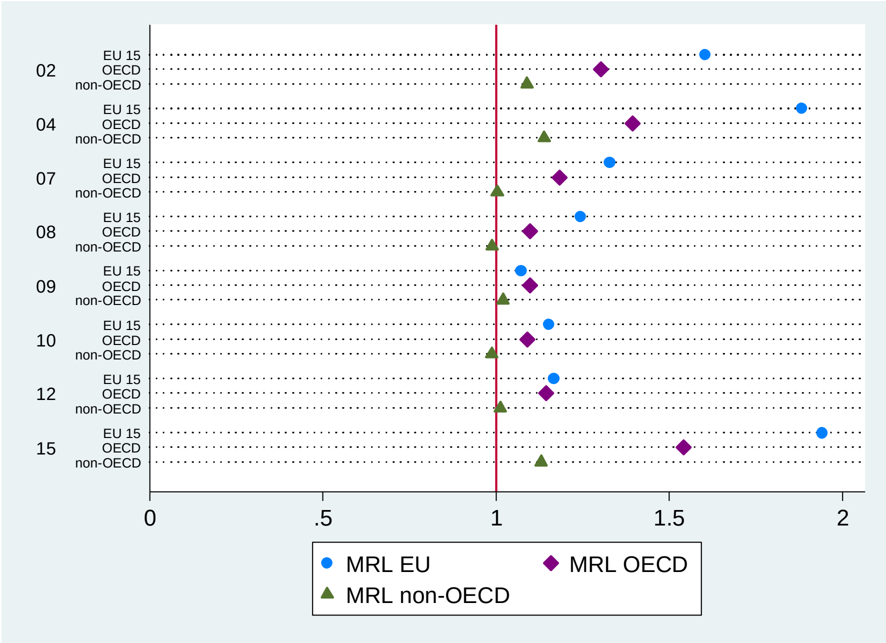
Encadré 7 : Les limites maximales de résidus de pesticides

La limite maximale de résidus (LMR) est la quantité maximale légalement autorisée d'un résidu (d'une substance) dans les produits alimentaires. Les LMR de pesticides visent à protéger la santé des consommateurs et à assurer l'adoption de bonnes pratiques par les agriculteurs.

Selon les règles de l'OMC, les mesures SPS devraient être fondées sur (i) des normes internationales telles que celles du Codex Alimentarius, (ii) la science, y compris l'évaluation des risques, (iii) un principe provisoire de précaution en l'absence de normes internationales ou de preuves scientifiques. Les pays sont libres d'établir leurs propres normes basées sur la science, et chaque pays établit des LMR de manière autonome sur la base des conditions nationales et des bonnes pratiques agricoles. Le processus d'approbation dans un pays est basé sur des études de terrain de la quantité de résidus qui pourraient rester dans le produit après la récolte dans le pire des cas. Par conséquent, le nombre de substances réglementées et leur LMR peuvent différer d'un pays à l'autre et un pesticide autorisé dans un pays peut être non réglementé dans un autre.

(Curzi et al., 2018) montrent empiriquement que le manque d'harmonisation des normes alimentaires affecte le commerce international des produits agroalimentaires entre l'UE et le reste du monde. Suivant la méthodologie développée par (Li et Beghin, 2014), ils comparent le caractère restrictif des normes d'un pays donné avec celui imposé par le Codex Alimentarius en calculant un « score » synthétisant le niveau moyen des LMR. Comme le montre la Figure 4, l'UE établit des normes restrictives plus élevées par rapport aux autres pays. La ligne verticale est définie à la valeur 1, ce qui représente la norme mentionnée dans le Codex. Dans tous les secteurs considérés dans l'analyse, l'UE affiche en moyenne un score plus élevé que les pays de l'OCDE et les pays non membres de l'OCDE, sauf le café, le thé et les épices, où la note moyenne est légèrement inférieure à celle des pays de l'OCDE. Les scores des pays de l'OCDE sont, en moyenne, plus élevés que ceux des pays non membres de l'OCDE dans tous les secteurs.

Figure 4: Niveau moyen des LMR UE *vs* pays de l'OCDE *vs* pays non-membres de l'OCDE



Source: (Curzi et al., 2018)

a. La mesure des réglementations sanitaires et phytosanitaires

La mesure des normes de LMR et de l'hétérogénéité des réglementations entre les pays a fait l'objet d'un courant de recherche récent en commerce international. La manière la plus simple de prendre en compte les exigences sanitaires, phytosanitaires et techniques consiste simplement à prendre en compte la présence ou l'absence de normes. Les mesures quantitatives simples trouvées dans la littérature sont les ratios de couverture et de « fréquence » (Disdier, Fontagné et Mimouni, 2008 ; Fontagne, Mimouni et Pasteels, 2005 ; de Frahan et Vancauteren, 2006 ; Moenius, 2004) ou leurs équivalents ad valorem (Beghin and Bureau, 2001; Carrère and de Melo, 2011). Une autre méthode consiste à évaluer la rigueur des normes et réglementations par le niveau absolu de la réglementation (Otsuki, Wilson et Sewadeh, 2001a, 2001b).
Des indicateurs plus sophistiqués ont été élaborés dans le but d'obtenir des mesures plus précises du niveau de similitude des réglementations pouvant affecter le commerce, partant du principe que ce qui affecte le commerce international ce n'est pas tant le niveau de sévérité intrinsèque mais l'hétérogénéité ou la distance réglementaire (**Zezza et al.,2018 [13]**). Une grande partie de mes travaux a porté sur le développement d'indicateurs permettant de mesurer cette hétérogénéité.

Dans le cadre du projet européen NTM-Impact (**Drogue et DeMaria, 2012, [91]**) nous avons construit un indice basé sur le coefficient de corrélation de Pearson qui mesure la différence (ou distance) entre les normes LMR sur les pesticides pour les pommes et les poires. Cet index est calculé comme suit :

$$SIM_{ijk} = 1 - \left(\frac{1}{N}\sum_{p=1}^{n}\left(\frac{LMR_{ip}^{k} - \overline{LMR}_{i}^{k}}{\sigma_{i}^{k}}\right)\left(\frac{LMR_{jp}^{k} - \overline{LMR}_{j}^{k}}{\sigma_{j}^{k}}\right)\right) \textit{Équation 1}$$

où *N* est le nombre total de pesticides enregistrés, LMR_{ip}^{k} est la LMR du pays exportateur *i (resp. j)* pour le pesticide *p* et le produit *k*, $\overline{LMR}_{i}^{k}$ est la moyenne de l'échantillon pour le pays *i (resp. j)* et le produit *k.* σ_{i}^{k} est l'écart-type de l'échantillon pour le produit k dans le pays *i (resp. j)*. Le coefficient de corrélation de Pearson est un moyen très classique de mesurer la proximité entre vecteurs de variables. Sa valeur se situe entre [-1, 1], la distance correspondante se situe entre [0, 2]. Une valeur de SIM_{ijk} égale à 0 signifie que les deux échantillons comparés sont similaires alors qu'une valeur de 2 indique le contraire.
Par la suite en nous inspirant des travaux de (Li et Beghin, 2014), nous avons comparé la réglementation du secteur de l'alimentation infantile entre l'UE et ses principaux partenaires commerciaux (**DeMaria et Drogue (2017), [95]**).
(Li et Beghin, 2014) ont proposé un indice pour mesurer la sévérité d'un pays en termes de LMR pour un produit donné où le terme de référence est le Codex. Plus le score est élevé, plus la réglementation est stricte. Ils utilisent ce score pour évaluer le protectionnisme des réglementations nationales en partant du principe que celles qui sont plus sévère que le Codex sont instaurées pour des raisons de protection des marchés intérieurs. Leur indicateur s'écrit :

$$S_{ij} = \frac{1}{K_{(j)}}\left(\sum_{k(j)=1}^{K(j)}\frac{LMR_{codex,jk(j)} - LMR_{ijk(j)}}{LMR_{codex,jk(j)}}\right) \textit{Équation 2}$$

Où $LMR_{ijk(j)}$ est la LMR adoptée par le pays *i* pour le produit *j* et ciblant le pesticide *k* $LMR_{codex,jk(j)}$ est la LMR fixée par le Codex Alimentarius. Le score S_{ij} mesure l'écart entre la réglementation intérieure et le Codex par opposition à la différence de LMR entre les partenaires commerciaux.

Dans (**DeMaria et Drogue (2017), [95]**) nous nous sommes inspirés de cet indicateur pour construire une métrique qui mesure la « distance » réglementaire entre l'UE et ses partenaires commerciaux pour les produits d'alimentation infantile. En effet, les LMR sont établies notamment en fonction du poids du corps pour un adulte pesant 60kg. Or, les enfants de moins de 3 ans de par leur faible masse corporelle sont plus sensibles à la toxicité des produits. L'UE a donc établi des mesures spécifiques pour les produits destinés à l'alimentation infantile. Dans le but de mesurer l'impact de cette spécificité européenne sur le commerce, nous avons construit un indicateur de « sévérité » de la réglementation sur les LMR de pesticide pour les produits de l'alimentation infantile de l'UE par rapport à ses partenaires commerciaux ; S_{EU-ROW}^{k} est défini comme suit :

$$S_{EU-ROW}^{k} = \frac{1}{N}\left(\sum_{p=1}^{N} I_{(LMR_{EUp}^{k} < LMR_{ROWp}^{k})} * exp\left(\frac{LMR_{ROWp}^{k} - LMR_{EUp}^{k}}{LMR_{MAX}^{k}}\right)\right) \quad \text{Équation 3}$$

LMR_{EUp}^{k} est la LMR de l'UE pour le pesticide *p* et le produit *k*. LMR_{ROWp}^{k} est la LMR du reste du monde pour le pesticide *p* et le produit *k.* LMR_{MAX}^{k} est la valeur maximale de la LMR du pesticide *p* pour le produit *k* dans toutes les réglementations. $I_{(LMR_{EUp}^{k} < LMR_{ROWp}^{k})}$ est une fonction égale à 1 si la LMR européenne est plus faible que celle de ses partenaires et à 0 dans le cas contraire.
On obtient un score normalisé variant entre 1 et e=2,72. Un score égal à 1 pour les pays les moins exigeants et à 2,72 pour les plus exigeants. L'exponentielle permet de rendre compte de la convexité des réglementations, c'est-à-dire que l'augmentation du coût de mise en conformité est plus que proportionnelle à l'augmentation des exigences SPS.

Mais les réglementations SPS ne sont pas toujours disponibles sous la forme de données quantitatives comme dans le cas des LMR. Dans le cadre du projet ANR Sustain'apple nous avons construit un score pour traduire de façon quantitative des données réglementaires sur la gestion des risques phytosanitaires (**DeMaria, Lubello, Drogue, 2018 [98]**). Notre démarche a été d'abord de faire une compilation exhaustive des exigences phytosanitaires auxquelles sont confrontés les exportateurs de pommes fraîches. Ces réglementations ont été classées selon leur niveau d'exigence et une note leur a été attribuée (voir **Tableau 3**).

Tableau 3: Evaluation de la sévérité des exigences réglementaires dans la gestion des risques sanitaires à l'export des pommes fraîches

Dimension	Values
Restriction territoriale / QO Restriction	0 (Pas de restriction) 1 (Restriction) 2 (Ban)
Accord bilatéral	0 (Pas d'accord nécessaire) 1 (Accord en pre-listing) 2 (Accord révisé chaque année) 3 (Ban)
Permis d'importation (PI)	0 (Pas de PI nécessaire) 1 (Le PI a été négocié) 2 (Le PI n'a pas été négocié) 3 (Ban)

Certificat Phytosanitaire (CP)	0 (Pas de CP) 1 (Le CP a été négocié) 2 (Le CP est en négociation) 3 (Le CP est non officiel) 4 (Ban)
Pre-inspection	0 (Pas de pre-inspection) 1 (Pre-inspection nécessaire) 2 (Ban)
Pre-clearance	0 (Pas de pre-clearance) 1 (Pre-clearance nécessaire) 2 (Ban)
Pre-traitement au froid/fumigation	0 (Pas de traitement requis) 1 (Traitement requis) 2 (Ban)
Traitement au froid	0 (Pas de traitement au froid) 1 (Traitement en transit) 2 (Traitement à l'arrivée) 3 (Ban)
Inspection à l'arrivée	0 (No inspection at arrival) 1 (Inspection at arrival) 2 (Ban)
Total Requirements	**24 (maximum requirements)**

Source: **DeMaria, Drogué, Lubello (2018), [98]**

Puis nous avons synthétisé ces notes dans un score appelé *Phytosanitary Score (PS)* :

$$PS_{ij} = \frac{1}{N}\left[\sum_{t=1}^{N} exp\left(\frac{Phyto_{ijN} - minPhyto_N}{maxPhyto_N - minPhyto_N}\right)\right] \textit{Équation 4}$$

où *i* désigne le pays exportateur et le pays importateur, $Phyto_{ijN}$ est la note attribuée à chaque niveau d'exigence dans la dans la dimension *N* imposée par le pays *j* au pays *i*; $maxPhyto_N$ est la note la plus élevée dans la dimension *N*; $minPhyto_N$ est la note la plus basse dans la dimension *N*. Chacun des pays de l'échantillon (une centaine environ) a obtenu un score normalisé variant entre 1 et e=2,72. Un score égal à 1 pour les pays les moins exigeants et à 2,72 quand les importations de pommes sont interdites par le partenaire. Ce score est intéressant car : (i) il synthétise des informations qualitatives dans une métrique qui est ensuite utilisée dans l'analyse quantitative ; (ii) il rend compte de la convexité des réglementations grâce à l'exponentielle.

b. L'impact sur les commerce des réglementations SPS

L'impact commercial des normes n'est pas seulement conceptuellement complexe ; il est également difficile à mesurer empiriquement. Dans le domaine empirique de la littérature sur les normes et le commerce, (Beghin, 2017) distingue deux grands domaines méthodologiques : l'un utilisant des modèles de gravité pour étudier l'impact de l'hétérogénéité des réglementations entre différentes régions ou pays ; l'autre utilisant des méthodes plus micro-économiques.

L'approche de l'équation de gravité a été largement utilisée et avec succès pour expliquer le commerce bilatéral entre deux pays. Le commerce est supposé être proportionnel à l'activité économique (PIB, ou production de l'industrie exportatrice) et à la diminution des coûts commerciaux entre les deux pays. Les coûts commerciaux comprennent la distance, l'éloignement linguistique et culturel, les obstacles et les autres coûts de transaction avec divers degrés de sophistication (Feenstra, 2015). Cependant, les résultats des estimations de gravité doivent être interprétés avec prudence. En général, la littérature utilisant les modèles gravitaires pour étudier l'impact des mesures non tarifaires montre des résultats positifs ou négatifs en fonction de la direction des flux commerciaux, du type d'industries, de la nature des normes et de la méthodologie utilisée pour l'analyse (pour un excellent aperçu, voir la méta-analyse par (Li et Beghin, 2016). C'est cette méthodologie que j'ai mobilisée dans la plupart de mes travaux sur les effets des LMR de résidus de pesticide sur le commerce.

L'hypothèse fréquemment admise était que les mesures non tarifaires pouvaient être instaurées dans un but protectionniste et donc qu'elles avaient un impact négatif sur le commerce. Dans (**Drogue et DeMaria, 2012 [91]**) nous montrons qu'en ce qui concerne le commerce de pommes et poires fraîches et transformées, l'impact sur le commerce des LMR de pesticides pouvait être positif ou négatif en fonction des pays. L'originalité de ce travail était, comme expliqué précédemment, qu'au lieu de prendre en compte le niveau absolu de la réglementation elle introduit dans l'équation gravitaire une mesure de la « distance réglementaire » ou de la similarité réglementaire entre les deux pays. L'hypothèse sous-jacente étant que des pays ayant des réglementations similaires auront des coûts d'adaptation moins élevés que les autres et donc un commerce qui sera favorisé (voir le cadre théorique proposé par Swinnen et détaillé dans le chapitre 1). C'est la même hypothèse que nous avons utilisée pour (**DeMaria et Drogue, 2017 [95]**). Nous montrons que dans le cas particulier de l'alimentation infantile (avec des consommateurs européens plus sensibles pour leurs enfants que pour eux à l'innocuité de l'alimentation), l'effet de la sévérité des LMR européennes n'affectent pas le commerce et aurait plutôt tendance à le dynamiser. L'originalité de ce travail tient au fait que nous appliquons cette « mesure de distance » à un produit transformé ce qui n'avait pas été fait dans la littérature.

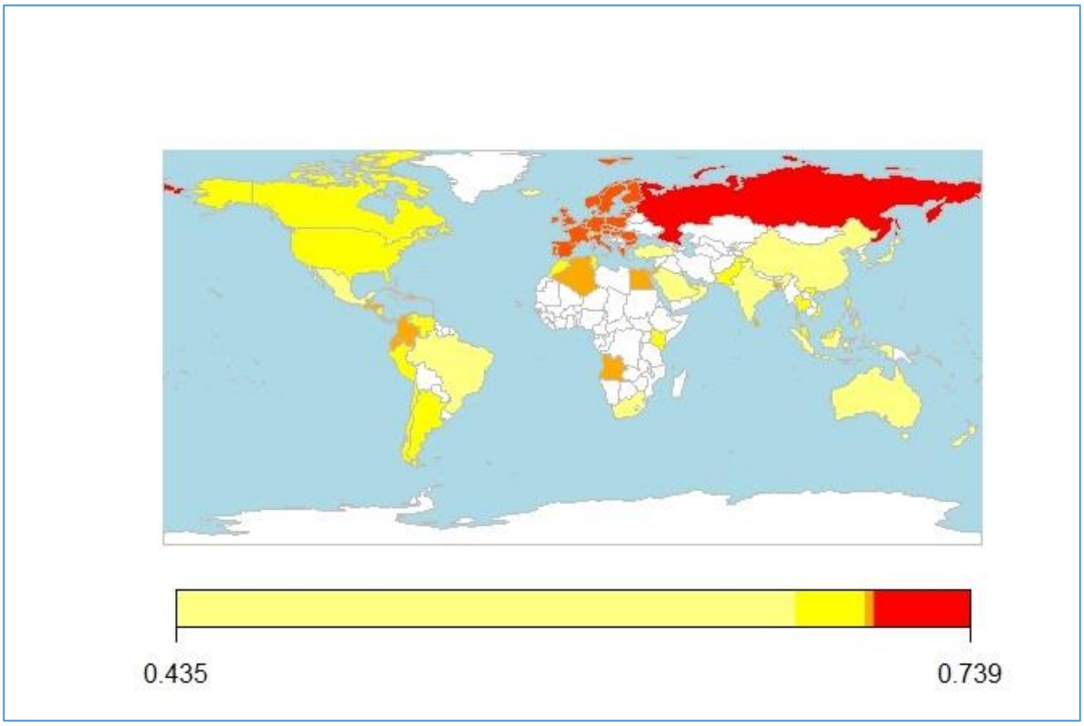
Enfin, nous nous sommes aussi intéressés dans le cadre du projet ANR Sustain'Apple à d'autres forme de mesures non tarifaires que sont les réglementations de gestion des risques sanitaires et phytosanitaires sur les pommes (**DeMaria, Drogue et Lubello, 2018 et à venir [85, 106]**). Là aussi les résultats économétriques montrent que l'impact des réglementations SPS peut être différent selon les pays.

c. *Les réglementations sur les LMR : barrières au commerce ou mesure de santé ?*

Dans la littérature, les standards SPS sont classiquement considérés comme des obstacles au commerce et même si les résultats empiriques et théoriques ont pu montrer, comme nous l'avons vu dans le cadre des LMR de pesticides, que leur impact pouvait dans certaines circonstances se révéler positif, la position défendue est celle d'une harmonisation des standards afin de faciliter le commerce (**Zezza et al., 2018 [13]**). Si une grande partie de la littérature a été consacrée à mesurer les impacts des standards de sureté sanitaire, les recherches sur les déterminants de ces standards sont plus rares. (Li, Xiong et Beghin, 2016) ont analysé l'élaboration d'une politique de normes de sécurité des aliments, montrant que les pays à revenu élevé et à forte population ont tendance à adopter des LMR plus strictes. En outre, des LMR plus strictes seraient établies pour protéger les secteurs stratégiques et compétitifs. Enfin, ils concluent que les LMR et les taxes à l'importation se comporteraient comme des instruments substituables. Leur conclusion tendrait à prouver que ces normes seraient fixées pour des motifs de protection commerciale.

Dans (**Carrere, DeMaria et Drogue., 2018 [98]**) nous analysons les déterminants des LMR de pesticides. Notamment, la question que nous posons est de savoir si les LMR de pesticides sont déterminées par des « objectifs légitimes de précaution » et quelles sont les causes des divergences nationales. À cette fin, en croisant la valeur des LMR et le niveau des effets santé à long terme (ELT) de ces substances sur la santé, nous calculons un « score de santé » capable de déterminer si un pays peut être considéré comme plus prudent que d'autres (voir Figure 5). Cette carte fournit une description du niveau de précaution au niveau mondial. Sur notre carte plus le score est élevé plus les pays ont un niveau de LMR sévère pour des substances ayant des effets de long terme élevés.

Figure 5 :Distribution mondiale du score santé



Source : **Carrere, DeMaria et Drogue., 2018 [98]**

Nous avons construit un modèle empirique (logistique) basé sur le modèle théorique d'économie politique de (Swinnen and Vandemoortele, 2009 et 2011) pour identifier les déterminants du score. Contrairement aux études similaires et notamment au travail de (Li, Xiong et Beghin, 2016) ,nous n'avons pas trouvé de lien significatif entre le score et le niveau de richesse, par contre dans notre modèle c'est le niveau des dépenses publiques de santé qui est déterminant. De même, ce n'est pas la perception par les consommateurs de la qualité des institutions mais la forme du régime qui influence le score. Plus le gouvernement sera autocratique plus faible est le score. Enfin, les déterminants économiques ont un impact sur le niveau du score tels que la compétitivité du secteur (négatif) ou la libéralisation du commerce (positif). Nos résultats sembleraient montrer que plus une nation investit dans la santé publique plus les règles qu'elle instaure sont protectrices du consommateur.

Mes travaux en commerce international particulièrement ceux sur les réglementations sur les résidus de pesticide m'ont amené à approfondir l'étude des liens entre commerce international et santé publique. Ils m'ont par exemple amené à m'interroger sur la légitimité des mesures de santé publique (comme les limites de résidus de pesticides) au regard du commerce international (**Carrere, DeMaria et Drogue., 2018 [98]**).

Ma rencontre avec une équipe de chercheurs en nutrition publique et épidémiologie de la nutrition et subséquemment leur intégration dans l'UMR MOISA m'a permis d'envisager des collaborations interdisciplinaires très stimulantes sur l'étude des liens entre l'approvisionnement alimentaire et la santé. En effet, l'état nutritionnel des individus et par voie de conséquence leur santé, dépend de ce qu'ils consomment en quantité et en qualité et donc du type d'aliments disponibles et de leurs capacités d'accès à ces aliments. Il faut notamment que les aliments auxquels les individus ont accès soient « sûrs, sains et conformes aux normes de salubrité, de manière à améliorer la sécurité sanitaire des aliments et la sécurité de la nutrition » https://www.who.int/foodsafety/areas_work/nutrition/fr/. Jusqu'à récemment les travaux des économistes dans le domaine de la sécurité alimentaire et nutritionnelle ont surtout porté sur le côté demande (théorie du consommateur et modèles de demande). Ce n'est qu'assez récemment que des recherches systématiques ont été produites sur le côté offre (Etilé et Oberlander, 2019). L'une des conclusions de ces recherches étant que l'ouverture commerciale d'un pays a une influence plutôt négative sur la qualité de l'alimentation et la nutrition (Costa-Font et Mas, 2016 ; Dithmer et Abdulai, 2017 ; Dreher, 2006 ; Oberlander, Disdier et Etilé, 2017). Mes travaux en modélisation et en commerce international m'ont amené à développer une analyse de l'adéquation entre les approvisionnements alimentaires et la sécurité alimentaire et nutritionnelle des populations. Dans mon projet de recherche je vais m'interroger sur l'enjeu lié à la relocalisation de l'alimentation. L'idée est de voir s'il est faisable est souhaitable de raccourcir les distances de l'approvisionnement alimentaire tout en maintenant ou en améliorant la sécurité alimentaire et nutritionnelle des populations. Je m'intéresserai à deux terrains très contrastés : celui des Antilles françaises et celui de la Métropole de Montpellier. C'est ce qui fera l'objet de la seconde partie de ce mémoire.

2. Projet de recherches : Adéquation entre approvisionnement et sécurité alimentaire et nutritionnelle des populations

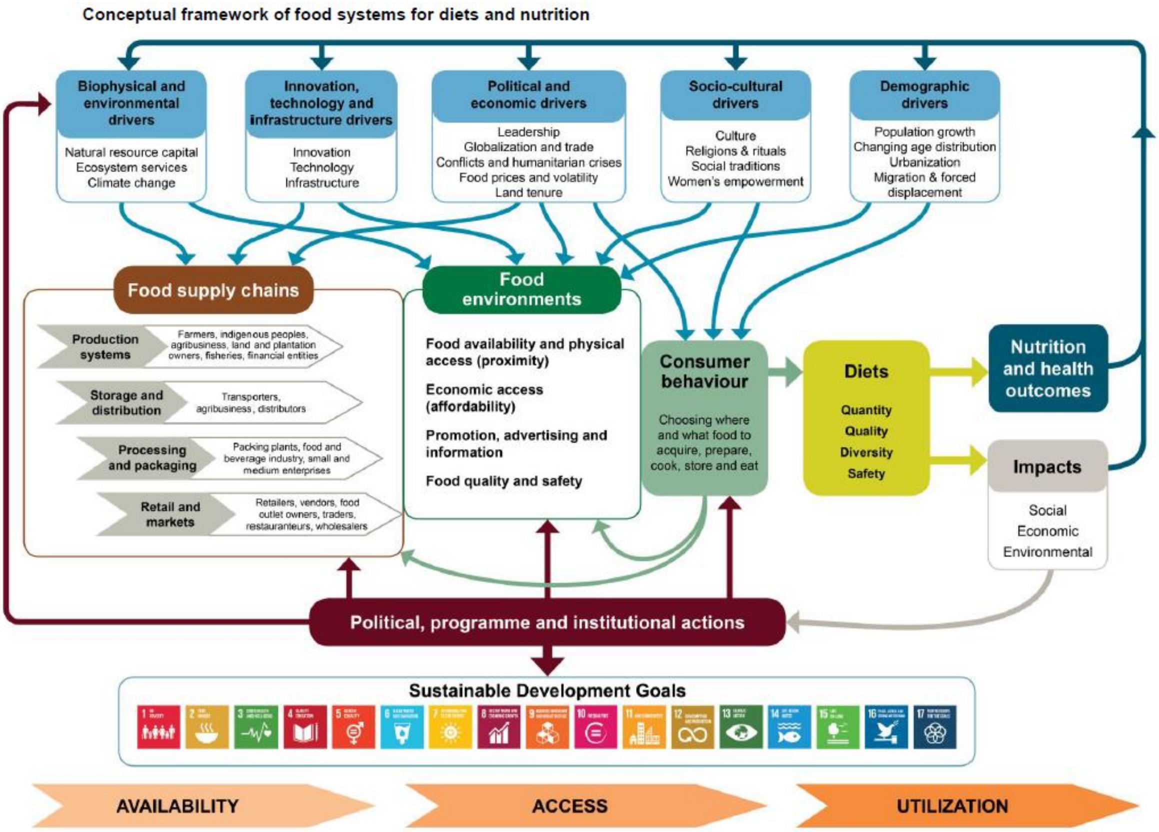
La sécurité alimentaire et nutritionnelle « existe lorsque tous les êtres humains ont, à tout moment, un accès physique, social et économique à une nourriture en quantité suffisante et de qualité appropriée en termes de variété, de diversité, de teneur en nutriments et de sécurité sanitaire pour satisfaire leurs besoins énergétiques et leurs préférences alimentaires et peuvent ainsi mener une vie saine et active, tout en bénéficiant d'un environnement sanitaire et de services de santé, d'éducation et de soins adéquats » (déclaration au Sommet mondial de l'alimentation, 1996). Un enjeu majeur pour nos sociétés est donc d'atteindre l'objectif de sécurité alimentaire et nutritionnelle des populations en s'appuyant sur des systèmes alimentaires durables, c'est-à-dire l'ensemble des éléments (environnement, individus, apports, processus, infrastructures, institutions, etc.) et des activités liées à la production, à la transformation, à la distribution, à la préparation et à la consommation des denrées alimentaires, ainsi que le résultat de ces activités, capables d'apporter des bénéfices en matière de nutrition et de santé des populations en intégrant les impacts environnementaux, socio-économiques et socioculturels de l'alimentation. Le rapport « Nutrition et Systèmes Alimentaires » du Groupe d'experts de haut niveau sur la sécurité alimentaire et la nutrition (HLPE, 2017) recense, au sein de ces systèmes, trois composantes qui interagissent et influent sur la capacité des consommateurs à adopter des régimes alimentaires durables et par conséquent ont des répercussions sur la santé nutritionnelle des populations : (i) les chaînes d'approvisionnement alimentaire, (ii) les environnements alimentaires et (iii) le comportement des consommateurs (**Figure *6***).

Par chaîne d'approvisionnement alimentaire on entend les activités et les acteurs qui accompagnent les aliments depuis leur production jusqu'à leur consommation et l'élimination des déchets (Hawkes et Ruel, 2012). La chaîne d'approvisionnement alimentaire est articulée autour des étapes suivantes : production ; entreposage et distribution ; transformation et conditionnement ; vente au détail et marchés

L'environnement alimentaire désigne le contexte, les possibilités et les conditions physiques, économiques, politiques et socioculturels qui créent des sollicitations quotidiennes, déterminant les préférences et les choix alimentaires des personnes ainsi que leur état nutritionnel (Panel, 2017). Il fait office d'interface permettant aux consommateurs de se procurer des produits alimentaires dans le cadre général du système alimentaire.

Le comportement des consommateurs est constitué de l'ensemble des choix et des décisions des consommateurs concernant, au niveau individuel ou au niveau du ménage, les aliments à acheter, à stocker, à préparer, à cuisiner et à consommer, et la répartition de ces aliments au sein du ménage (notamment entre les hommes et les femmes et entre les adultes et les enfants).

Figure 6 : Cadre conceptuel des systèmes alimentaires pour la nutrition et les régimes alimentaires



Source : *(HLPE, 2017)*

Dans ce contexte, **mon projet pour des recherches futures est d'analyser l'adéquation entre les approvisionnements alimentaires et la sécurité alimentaire et nutritionnelle des populations.** Dans un univers néoclassique, la réponse à cette question pourrait se réduire à l'analyse du processus d'ajustement entre l'offre et la demande par les prix. La demande des individus dépendant des prix des biens, de leur revenu et d'un ensemble de caractéristiques qui reflètent leurs préférences. Des individus rationnels devraient avoir une préférence pour un panier alimentaire nutritionnellement adéquat. Or, la rationalité des individus est un arbitrage entre plaisir hédonique de court terme et l'objectif de long terme de préservation de la santé. Les besoins des populations en produits favorables à la santé ne se traduisent donc pas toujours dans leurs préférences alimentaires puisque les chercheurs en nutrition ont mis en évidence une plus grande appétence pour des produits gras, salés et/ou sucrés qui sont aussi défavorables à la santé (Drewnowski, 1997 ; Drewnowski et Greenwood, 1983). Face à une offre de produits alimentaires caloriquement denses, riches en graisses saturées, sucres et sel et pauvre en fibres cela se traduit par une augmentation du taux d'obésité et de prévalence des maladies cardio-vasculaires.

Désormais, la question de la disponibilité n'est plus simplement une question de quantité mais aussi une question de qualité. Savoir si le système alimentaire que l'on étudie a les capacités physiques de répondre aux besoins des populations plutôt qu'à la demande est une question à ne pas négliger particulièrement si le système est contraint ou si l'objectif est la relocalisation du système. Mais avant de présenter mon projet de recherche que j'illustrerai à l'aide de projets en cours, je préciserai ce que ces travaux nécessairement pluridisciplinaires voire interdisciplinaires impliquent en matière d'établissement d'un cadre conceptuel et de production de données.

2.1. Une recherche nécessairement pluridisciplinaire : le besoin d'un cadre conceptuel

Les recherches pluridisciplinaires ont besoin de se fonder sur des cadres conceptuels car ils permettent de clarifier et de fluidifier les échanges entre des disciplines qui peuvent utiliser des langages et des méthodes différentes mais surtout qui peuvent utiliser des méthodes et des termes identiques mais dont la sémantique est différente. Le cadre conceptuel est en ce sens un outil stratégique. A cet égard, on notera que celui développé par le HLPE (voir Figure 6) a permis de clarifier la notion de système alimentaire associé aux objectifs du développement durable.
Celui développé dans le cadre du projet ANR MEDINA sur la Tunisie (**Verger et al., 2018 [97]**) est une approche « de la fourchette à la fourche » multi échelle originale (voir Figure 7).

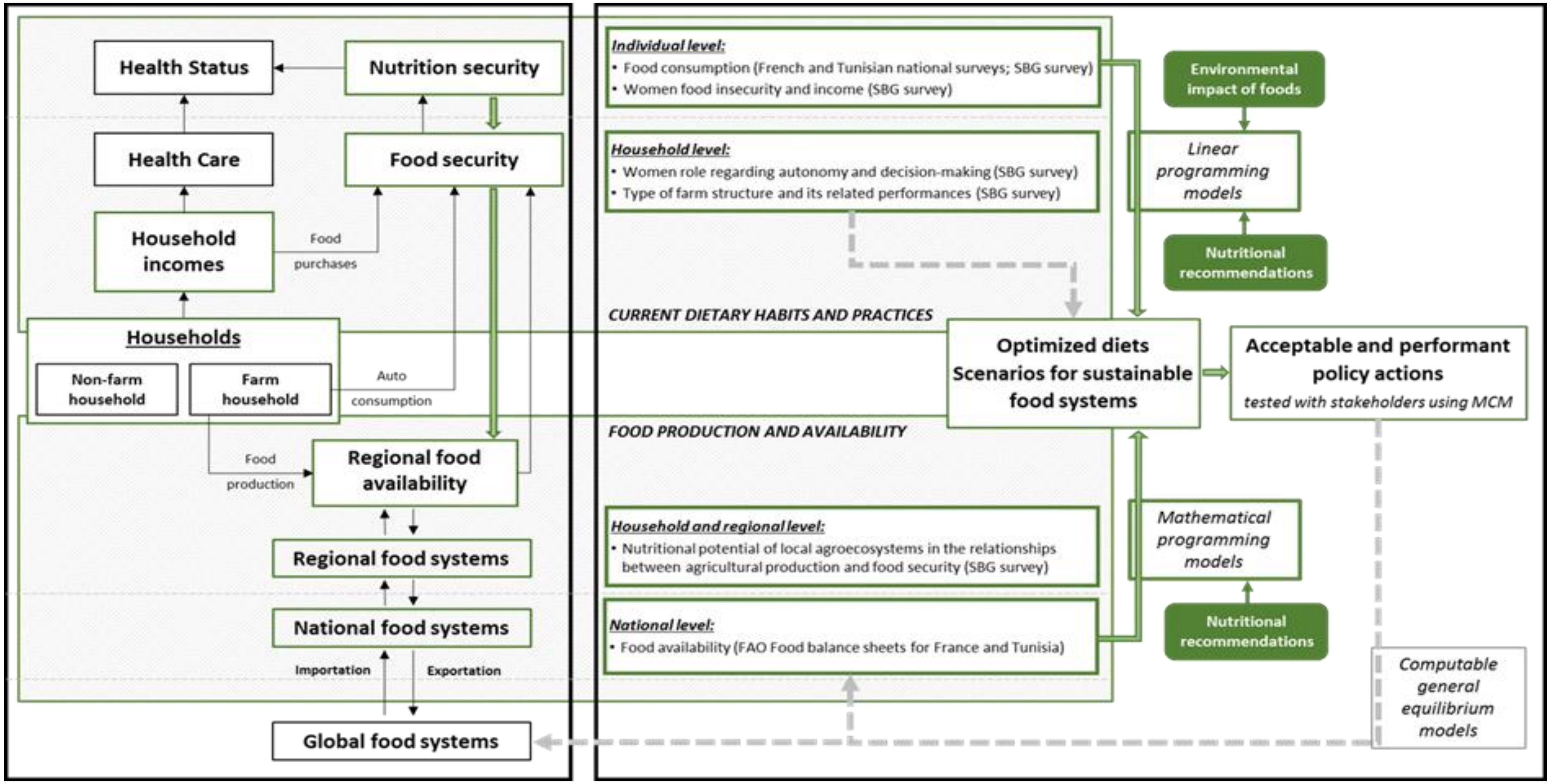
i) une échelle spatiale large (globale et ses déclinaisons régionales) et une échelle temporelle longue pour définir les grandes tendances d'évolution des environnements et des comportements alimentaires dans des contextes de transition. Il s'agit d'évaluer les trajectoires des grandes régions/pays à partir d'une meilleure connaissance de leurs déterminants démographiques, socio-culturels, économiques, environnementaux.

ii) une échelle spatiale plus locale (territoire) et une échelle temporelle plus courte pour identifier les dynamiques d'interactions entre environnements et comportements. Il s'agit d'identifier et de prendre en compte d'autres déterminants, et notamment ceux d'ordres politiques et socio-culturels, les facteurs liés à l'innovation, qui, combinés aux déterminants précédents, permettent de comprendre les interactions entre environnements et comportements et leurs effets sur les régimes alimentaires. C'est aussi à cette échelle plus fine que s'exprime le mieux l'enjeu d'accès à l'alimentation. L'échelle des territoires, vus comme des espaces privilégiés des interactions producteurs-consommateurs, renouvelle la réflexion sur les systèmes alimentaires. La prise en compte des caractéristiques spécifiques de la diversité des situations territoriales en matière de ressources matérielles et immatérielles mais aussi de formes de production, de distribution et de consommation amène à travailler sur cette échelle territoriale.

iii) Une échelle au niveau individuel ou du ménage pour évaluer les comportements non seulement de consommation mais aussi les stratégies d'approvisionnement en lien avec son environnement alimentaire.

Outre le besoin de cadres renouvelés, la recherche pluridisciplinaire a aussi besoin de nouvelles données qui reflètent la complexité et les enjeux de cette recherche.

Figure 7 : Le cadre conceptuel développé par le groupe d'étude MEDINA vise à apporter un soutien solide aux directives nutritionnelles révisées compatibles avec des systèmes alimentaires durables.



Le côté gauche du cadre représente en partie les voies d'impact entre les systèmes alimentaires et la nutrition et la santé, avec l'approche "de la fourche à la fourchette" (flèches noires) et l'approche "de fourchette à la fourche" utilisée dans le projet de recherche MEDINA (flèches vertes). Le côté droit du cadre représente l'approche de modélisation utilisée pour proposer des lignes directrices garantissant une bonne nutrition et la durabilité, avec les modèles actuellement appliqués dans le projet de recherche MEDINA (flèches et encadrés verts) et les modèles considérés comme perspectives de recherche (flèches et encadrés gris). Les deux côtés du cadre envisagent différentes échelles (individuelle, familiale, régionale et nationale) en utilisant différentes bases de données. SBG signifie Gouvernorat de Sidi Bouzid.

2.2 Une recherche nécessairement pluridisciplinaire : le besoin de bases de données renouvelées qui répondent aux principes « FAIR »

L'évaluation des politiques publiques dans le domaine agricole et alimentaires se fait principalement en termes monétaires (ex. évaluation des surplus des consommateurs et/ou producteurs). En ce qui concerne la sécurité alimentaire, l'évaluation se fait essentiellement en termes de quantité de nourriture ou d'apport calorique, ventilée en fonction des principaux composants (protéines, graisses, glucides) ; mais l'analyse de la disponibilité nationale des (micro) nutriments est rarement effectuée. Mes recherches précédentes en commerce international m'avaient amené à produire des bases de données originales à partir de l'appariement de bases de données de diverses provenances, c'était le cas pour mes travaux portant sur l'impact et les déterminants des réglementations sanitaires (**Carrere, DeMaria, Drogue, 2018 [96] ; DeMaria et Drogue, 2017 [95]**).

Mes travaux se poursuivent aujourd'hui avec un besoin de données renouvelées. Par exemple, en 2015 j'ai obtenu un soutien du Métaprogramme INRA GloFoodS pour construire une base de données qui apparient la nomenclature du système harmonisé et la table de composition nutritionnelle des aliments de l'ANSES. Cette base de données Reconcil permet de mesurer la qualité nutritionnelle des flux d'échanges et est utilisée dans le cadre de mes recherches sur l'impact et les déterminants des approvisionnements alimentaires (**Drogue et al. 2019 [15] ; Drogue et al., 2020 [105]**).

Ces échanges entre les disciplines ne s'arrêtent pas à la nutrition car une alimentation de qualité est aussi une alimentation qui répond à des objectifs de durabilité environnementale. Une collaboration avec des chercheurs en science de l'environnement a permis la construction d'une base de données sur le contenu en eau des aliments consommés en Tunisie et dans le sud de la France. Ces données tiennent compte notamment de l'origine des produits consommés. Elle est le fruit d'une démarche originale entre chercheurs en nutrition, en sciences de l'environnement et en commerce international (**Sinfort et al., 2019 [103] ; Perignon et al., 2019 [101]**).

Récemment, j'ai obtenu un projet de recherche pour un soutien financier de la fondation Olga Triballat. Ce projet se fonde sur l'existence d'un appariement entre la base de donnée Kantar WordPanel 2014 et des données de composition nutritionnelle des aliments Ciqual 2014. L'objectif de ce projet est d'évaluer l'impact de l'introduction d'aliments bio sur le budget minimal nécessaire pour se procurer un panier alimentaire nutritionnellement adéquat. Le projet BIOCOST vise également à évaluer les modifications, en matière de choix alimentaires, par rapport à la composition du panier moyen observé en France pour respecter les préconisations du PNNS 4 qui « *intègrent la question du développement durable en conseillant d'aller vers des aliments de producteurs locaux, des aliments de saison et, si possible, des aliments bio* » (Sante Publique France, 2019a, 2019b). Ces nouvelles données sont construites pour répondre (dans la mesure du possible) aux principes FAIR (*Findable, Accessible,* *Interoperable, Reusable)* de l'initiative GOFAIR sur laquelle s'inscrit INRAE à travers le réseau de mise en œuvre Food Systems.

2.3 Commerce international et sécurité alimentaire et nutritionnelle

L'importance des flux commerciaux en quantité et en qualité ont des effets sur la disponibilité, la qualité, la diversité, la variété et la durabilité de l'offre disponible à l'échelle d'un territoire. La concurrence entre les divers modes d'approvisionnement circuits courts/longs, bio, conventionnel etc. détermine également l'offre disponible au niveau des consommateurs. La structure de l'offre va donc influencer celle de la diète. Les systèmes alimentaires ont été fortement modifiés par la mondialisation et le commerce international (Kennedy, Nantel et Shetty, 2004). Le progrès technique et la baisse des droits de douane ont fait baisser les coûts de transport. Tout comme les investissements directs à l'étranger, ils ont eu des effets sur les prix des produits alimentaires, ainsi que sur la quantité, la variété et la diversité des produits. La gamme des produits alimentaires disponibles auprès des consommateurs s'est élargie considérablement depuis les années 1960 et elle a souvent été accompagnée d'une baisse de leur qualité nutritionnelle c'est-à-dire par une baisse de la part des produits bruts au profit de produits transformés et ultra-transformés défavorables à la santé (Cuevas García-Dorado et al., 2019).

À l'échelle mondiale, les pratiques alimentaires connaissent une évolution rapide depuis les dernières décennies. Sous l'effet de la mondialisation, de l'urbanisation et de la croissance des revenus, de nouveaux environnements alimentaires se font jour, propices à un élargissement des choix alimentaires et à une diversification des modes d'alimentation dont les effets peuvent être aussi bien positifs que négatifs. La transition nutritionnelle renvoie à l'évolution du mode de vie et des modes d'alimentation attribuables à l'urbanisation, à la mondialisation et à la croissance économique, ainsi qu'aux effets de cette évolution sur la nutrition et la santé (Popkin et Ng, 2007). En particulier, l'inversion des tendances de consommation d'aliments d'origine animale dans les pays à revenu intermédiaire et à fort revenu demeure un enjeu actuel majeur, en raison des défis que pose l'approvisionnement en aliments d'origine animale en matière de développement durable, compte tenu de la complexité des incidences de ces aliments sur la santé, l'état nutritionnel et l'environnement.

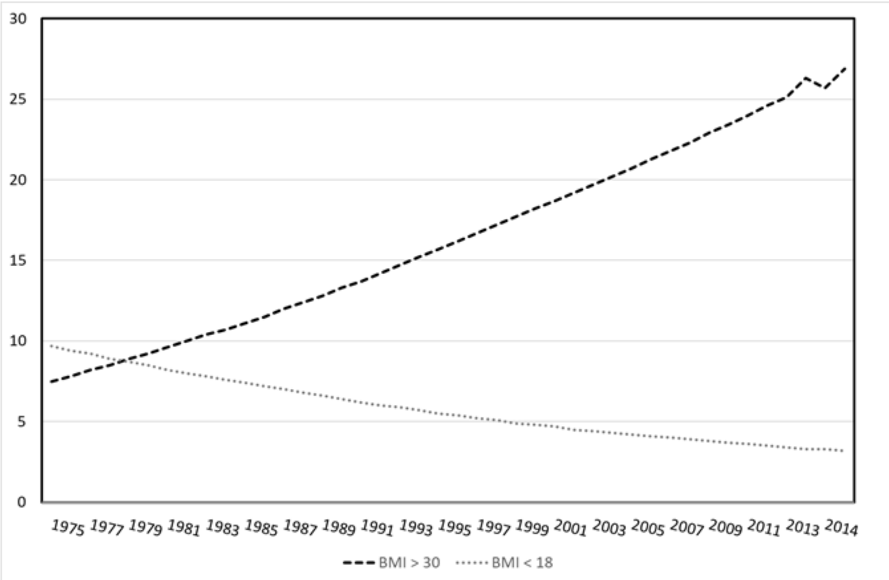
Dans mon projet de recherche, je souhaite appréhender ces modifications à différentes échelles.

a. Echelle nationale

Dans certains pays, ces tendances n'ont pas été alimentées que par les hausses de revenus. Des politiques publiques ont été mises en place dans les années 1960 dans la période postcoloniale pour lutter contre la pauvreté et la malnutrition. C'est le cas dans les pays du Maghreb et notamment en

Tunisie. Ces politiques de subvention aux aliments caloriquement denses tels que les céréales, le sucre, les matières grasses et le lait, ont favorisé une augmentation rapide de leur consommation dont l'approvisionnement a été assuré par une croissance concomitante des importations. En Tunisie, cette politique de subvention a été très efficace pour réduire les problèmes de sous-nutrition et en 30 ans, le pourcentage de personnes souffrant d'insuffisance pondérale a été divisé par cinq mais dans le même temps celui des personnes en surpoids a été multiplié par deux (Figure 8). Cette transition a été accompagnée d'une augmentation des maladies non transmissibles telles que les maladies cardio-vasculaires.

Figure 8 : Prévalence de l'insuffisance pondérale (IMC < 18) et de l'obésité (IMC > 30) dans la population adulte en pourcentage (Tunisie 1975-2015)



Source : données de l'OMS, IMC (BMI) = Indice de Masse Corporelle

Aujourd'hui les politiques publiques encouragent la diffusion et l'adoption de recommandations nutritionnelles pour lutter contre la pandémie d'obésité et les maladies non transmissibles qui lui sont associées. Mais ces recommandations n'ont que rarement été évaluées en termes d'impact sur les origines des approvisionnements qu'elles pourraient engendrer. Mes travaux en programmation mathématique s'inscrivent dans une démarche d'analyse d'impact des recommandations nutritionnelles telles que celles proposées par l'Organisation mondiale de la santé (OMS). A partir des bilans alimentaires de la FAO[7] et des élasticités de substitution du Global Trade Analysis Project (Hertel, 1997), nous avons calculé l'impact de l'adoption de recommandations nutritionnelles en Tunisie sur la

[7] Les bilans alimentaires de la FAO (Food Balance Sheet) donnent pour plus d'une centaine de pays un bilan de type comptable des disponibilités alimentaires pour plus d'une soixantaine de produits agricoles et agroalimentaires. C'est-à-dire la production, les importations, les usages domestiques (consommation humaine, animale, gaspillage, usages industriels etc.), les exportations et les variations de stocks.

demande domestique et la demande d'importations (**Drogue et al., 2020 [105]**). L'objectif de ce travail était d'évaluer si l'amélioration de la diète pouvait permettre de réduire la dépendance aux importations. Les principaux résultats montrent une diminution drastique des importations de sucre et de céréales mais que cette diminution n'est pas de nature à réduire la dépendance envers les marchés extérieurs car elle serait compensée par une hausse concomitante de viande, produits laitiers, fruits et légumes (*Figure 9* et *Figure 10*).

Figure 9 : Variation de la demande domestique en 1000 t (D0 : demande observée, D1 : demande après optimisation)

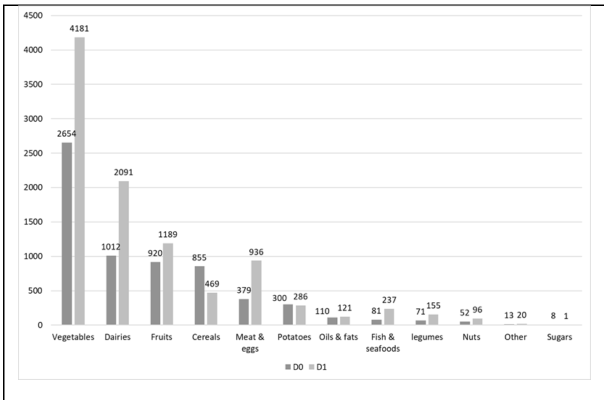
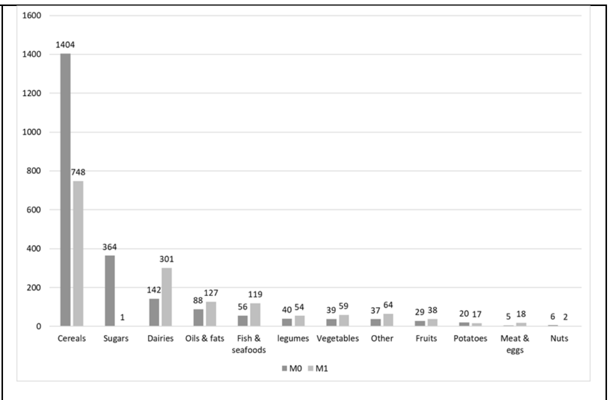


Figure 10 : Variation des importations en 1000 t (M0 : demande observée, M1 : demande après optimisation)



Source : **Drogue et al., 2020 [105]**

L'originalité de ces travaux résident dans le fait que la qualité de l'alimentation ne tient pas seulement aux choix individuels mais également à des choix plus collectifs de politiques publiques nationales ou locales qui déterminent également les possibilités d'accès à une nourriture nutritionnellement adéquate. Cette approche peut aider à la reformulation des politiques publiques agricoles et alimentaires pour une meilleure sécurité alimentaire et nutritionnelle. Les politiques tunisiennes de soutien ont été très efficace pour lutter contre l'insécurité alimentaire et la sous-nutrition mais ce pays est aujourd'hui confronté à la triple charge : coexistence de sous-nutrition toujours présente, de carences nutritionnelles et d'obésité. De plus, elles ont accru la dépendance de la Tunisie aux importations de sucre et de céréales et la rend vulnérable aux fluctuations des prix. Nos travaux montrent qu'encourager les ménages à améliorer la qualité nutritionnelle de leur régime alimentaire peut avoir aussi des impacts au niveau national. Il peut être intéressant pour la Tunisie comme d'autres pays méditerranéens d'encourager la consommation de légumineuses qui ont un intérêt non seulement d'un point de vue nutritionnel mais aussi agronomique. En effet, combinées aux céréales c'est une bonne source de protéines abordables (Xipsiti, Marzara et Calles, 2017) et d'un point de vue agronomique les légumineuses permettent de fixer l'azote dans les sols où elles sont cultivées (Vertes et al., 2015).

b. Cas particulier : les économies insulaires

Les territoires insulaires sont des cas d'étude intéressants dans la mesure où ce sont des économies contraintes qui reposent en grande partie sur les importations pour assurer l'approvisionnement en nourriture de leur population. De plus, ce sont des territoires qui souffrent d'une forte prévalence d'obésité, de maladies cardiovasculaires et de diabète de type 2 (**Colombet et al., 2019 [102]**). Dans ce contexte, les objectifs de mes récents travaux de recherche dans le cadre d'un projet financé par l'ANR : (le projet Nutwind) sont, tout d'abord d'étudier la dynamique des importations de produits alimentaires en termes de prix, de quantités, de qualité nutritionnelle, de types d'aliments, sur deux décennies. Nous utilisons les données douanières et nutritionnelles françaises pour caractériser l'évolution de la structure des importations non pas en termes de produits mais en termes de flux de nutriments. Le défi consiste d'abord à traduire la nomenclature des marchandises en une nomenclature des éléments nutritifs. La nomenclature combinée européenne à 8 chiffres (NC8), qui détermine le taux de droit de douane applicable, a été mis en correspondance avec la nomenclature des éléments nutritifs du tableau de composition des aliments publié en France (**Drogue et al. 2019 [15]**).

Ensuite, nous avons étudié l'impact d'une série de facteurs sur la qualité nutritionnelle des importations. La méthodologie utilisée pour caractériser les importations est basée sur une régression économétrique de la demande d'importation sur un ensemble de facteurs tels que ceux décrits dans (Oberlander, Disdier et Etilé, 2017). Nous explorons ici le lien entre l'évolution « nutritionnelle »[8] de la demande d'importation au cours des 20 dernières années et le revenu, la structure de la distribution alimentaire (présence de supermarchés), la participation des femmes sur le marché du travail ou l'urbanisation sur l'évolution des importations alimentaires aux Antilles françaises (**Lamani et al., 2019 [76]**). Les résultats montrent que la plupart de ces variables (excepté la variable participation des femmes sur le marché du travail pour laquelle l'impact n'est pas robuste) ont des effets positifs sur tous les composants nutritionnels qu'ils soient favorables ou préjudiciables à la santé. Cette apparente dualité s'explique notamment par le fait que les supermarchés (plus présents en zone urbaine) ont permis de par leurs capacités technologiques (de stockage et de distribution) de proposer une offre beaucoup plus diversifiée à la fois sur les produits des deux catégories. Ces résultats sont encore à creuser mais ils permettent déjà de proposer des pistes d'actions auprès des acteurs de la grande distribution afin de promouvoir les aliments favorables à la santé auprès de leur clientèle.

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[8] Les composants nutritionnels pris en compte dans l'analyse sont : les graisses saturées, les fibres, les protéines animales et le sucre.

2.4. La relocalisation des approvisionnements en question

De par leur définition, les systèmes alimentaires ont des impacts environnementaux importants et les changements alimentaires font partie des stratégies recommandées pour les atténuer (Ridoutt, Hendrie et Noakes, 2017). Toutefois, l'accent est mis aujourd'hui sur le fait que les SA doivent être repensés sous les 3 dimensions de la durabilité (Willett et al., 2019) : environnementale (réduction des gaz à effet de serre, préservation de la ressource en eau, moindre consommation de produits phytosanitaires, etc.), économique (maitrise du budget par les consommateurs et juste rémunération pour les producteurs) et sociale (impact favorable sur l'emploi local et la ruralité). Mais ces SA doivent aussi permettre de fournir aux consommateurs une alimentation saine et en quantité suffisante, ce qui ajoute une dimension santé, basée sur une densité nutritionnelle plus importante de l'offre et une moindre exposition aux résidus de pesticides. Pour améliorer la durabilité des SA, les décideurs publics ont souhaité privilégier le recours à un approvisionnement local particulièrement pour les produits frais. Si cette volonté peut plus aisément s'inscrire dans un environnement rural, il représente un défi pour les zones urbaines (Corsi et al., 2015).

Dans la littérature, ces questions sont le plus souvent abordées à l'échelle du système alimentaire global ou à l'autre extrémité, à l'échelle locale pour des réseaux alternatifs (bio, circuits courts). Rétablir le lien entre agriculture, environnement et alimentation est un enjeu important à l'échelle du territoire (Lamine, Magda et Amiot, 2019). L'approvisionnement alimentaire d'un territoire, fait appel à des produits de diverses provenances : locales (qui passent par différents circuits depuis les circuits courts jusqu'à la grande distribution), d'autres régions ou du commerce international. Or, on considère souvent que les circuits courts ont un bilan environnemental plus positif que les circuits longs, bien que ce ne soit pas toujours le cas (Schmitt et al., 2017). De plus, dans ces différentes analyses, la question de l'intégration des objectifs nutritionnels et de l'impact économique n'est souvent pas prise en compte. Ainsi, il y a peu de littérature en sciences économiques qui permettent, par exemple, d'évaluer l'impact de recommandations nutritionnelles sur la durabilité des SA. De même la question reste posée de savoir s'il y a un gain pour les producteurs locaux comme pour la communauté (Sexton, 2009).

Comprendre comment l'environnement agricole local peut subvenir aux besoins alimentaires et nutritionnels d'un territoire, et participer à la durabilité du SA est une question qui commence à être abordée dans la littérature scientifique récente (Sonnino, 2016). Toutefois, peu d'études se sont intéressées à l'impact de la relocalisation de l'approvisionnement alimentaire de manière globale afin de connaître les impacts à la fois du côté de l'offre que du côté de la demande. C'est ce que je souhaite développer dans mon projet de recherche grâce à une approche qui utilise la programmation mathématique (PM).

Du côté de l'offre, depuis (Norton et Hazell, 1986), la PM est un outil standard de modélisation et d'analyse pour l'agriculture au niveau de l'exploitation (**Komarek et al., 2017 [94]**) comme au niveau sectoriel.
Du côté de la demande, initiée par des économistes (Smith, 1959 ; Stigler, 1945) qui l'utilisent pour minimiser le coût des régimes, cette méthodologie a été largement reprise par les chercheurs en nutrition. Actuellement leurs travaux permettent d'identifier le coût minimum de régimes qui respectent les recommandations en matière de nutriments et les habitudes alimentaires (Darmon, Ferguson et Briend, 2006). La littérature en économie déployant ce type de méthode est plus rare. Dans la revue de littérature de (Gazan et al., 2018) sur l'optimisation mathématique des régimes alimentaires, sur 67 articles publiés, seuls 2 ont été publiés dans des revues économiques. Outre les travaux fondateurs de Stigler et Smith, nous pouvons citer les travaux de (Henson, 1991 ; Irz et al., 2015 ; Shankar, Srinivasan et Irz, 2008 ; Srinivasan, 2007 ; Srinivasan, Irz et Shankar, 2006). Cette littérature économique a, dans sa majorité, évalué l'impact de l'optimisation du régime alimentaire essentiellement sur la consommation sans tenir compte du « côté offre du régime ».
Un autre volet de la littérature récente sur l'optimisation du régime alimentaire s'est penché sur les impacts agricoles et environnementaux des changements alimentaires. (Arnoult et al., 2010) ont traduit des recommandations alimentaires en matière de production agricole et d'utilisation des terres. (Macdiarmid et al., 2012) ont évalué les émissions de gaz à effet de serre des régimes alimentaires optimisés (pour un examen complet sur le sujet, voir Hallström et al., 2015). Plus récemment, nous avons estimé les impacts de la satisfaction des apports en nutriments en Tunisie sur l'utilisation de l'eau et des terres (**Perignon et al. (2019) [101**]).
La PM a également permis d'explorer des situations d'équilibre dans les SA locaux dans les pays développés. (Monaco et al., 2016 ; Sali et al., 2016) ont réalisé des scénarios sur la métropole milanaise. (Dundar, Costello et McGarvey, 2017) l'utilisent pour évaluer la possibilité d'avoir recours à la production alimentaire locale dans le Missouri. (Khan et al., 2019) appliquent un modèle de PM au système alimentaire local de Hawaii.
La plupart de ces analyses répondent à la question de savoir si l'amélioration de la diète est bénéfique pour l'environnement ou si une relocalisation de l'agriculture est possible pour répondre aux besoins de la population locale. Mais elles ne permettent pas de calculer les pertes ou les gains de bien-être pour les agents économiques (Doro et Réquillart, 2020). Seule celle de (Khan et al., 2019) propose des résultats sur les bénéfices économiques qui peuvent être générés. Enfin, **jusqu'à présent aucune tentative n'a été faite d'intégrer à la fois des modèles de nutrition et des modèles agricoles pour analyser l'impact d'une relocalisation de l'offre alimentaire.**
L'usage de la programmation mathématique permet de proposer des approches holistiques pour représenter et étudier les liens entre tous les piliers de la durabilité dans les systèmes alimentaires

(économique, social, environnemental et de santé). Je souhaite à partir de cette littérature récente développer des modèles qui intègrent à la fois des données de production, d'environnement et de nutrition afin de proposer des évaluations *ex-ante* de mesures visant à la relocalisation de l'agriculture et son impact sur les trois piliers de la durabilité et la santé.

Pour développer ce projet de recherche j'ai obtenu récemment un double financement pour un contrat doctoral en provenance du département EcoSocio d'INRAE et de la Région Occitanie. Ce sujet de cette thèse est : « Optimiser l'approvisionnement local en fruits et légumes de la métropole de Montpellier dans une optique de durabilité ».

J'ai également déposé une demande de financement auprès de la Fondation de France pour le projet CALALOU : « **C**omment l'**A**griculture **L**ocale peut répondre à des enjeux d'amélioration de la qualité nutritionnelle de l'**AL**imentati**O**n et de réd**U**ction de l'impact environnemental dans les Antilles Françaises ? »

3. Conclusion

Les analyses pluridisciplinaires qui prennent en compte tous les piliers du développement durable dans une logique plus utilitariste que paretienne sont des outils qui doivent permettre aux pouvoirs publics de prendre des décisions en vue d'améliorer la sécurité alimentaire et nutritionnelle des populations notamment des plus vulnérables. Les recherches sur l'alimentation et la nutrition s'intéressent souvent au côté demande à un niveau individuel. Les études du côté offre à une échelle plus agrégée voire nationale ou globale sont plus récentes. Elles montrent que les marges de manœuvre pour améliorer la qualité de l'alimentation et l'état nutritionnel des individus et des populations sont aussi à chercher du côté de l'offre. La question de l'accès à une alimentation saine et en quantité suffisante est aussi essentielle que la question du choix (Etilé et Oberlander, 2019).

Pendant longtemps l'alimentation des populations vulnérables a été envisagée d'un point de vue quantitatif. Les politiques ont privilégié des produits peu onéreux et caloriquement denses qui permettaient de « nourrir le monde ». Ces politiques ont souvent été efficaces au-delà des attentes de leurs concepteurs puisqu'elles l'ont « sur-nourri » induisant des problèmes d'obésité et de maladies cardiovasculaires. Elles ont amplifié dans certains cas les phénomènes de transition et pesé sur la dépendance de certains pays vis-à-vis des importations. Mettre en place des interventions ou des incitations pour orienter le choix des consommateurs vers une alimentation adéquate trouvera rapidement ses limites si ces consommateurs n'ont pas accès à une offre adéquate dans son paysage alimentaire. C'est tout l'enjeu de mes travaux futurs dans l'équipe pluridiciplinaire SAND (vers une sécurité alimentaire et nutritionnelle durable) qui intègre des chercheurs en économie et des chercheurs en nutrition avec des approches très diverses mais complémentaires (approches quantitatives : statistiques, programmation mathématiques mais aussi qualitatives). Les recherches que je souhaite développer ont l'ambition de contribuer à savoir si un système d'approvisionnement local sain, durable, qui réponde aux besoins nutritionnels des populations ainsi qu'à leurs préférences alimentaires, qui permette aux consommateurs de maitriser leur budget et plus rémunérateur pour les agriculteurs est faisable et à quelles conditions.

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ORIGINAL ARTICLE

Does a better diet reduce dependence on imports? The case of Tunisia

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Abstract
In the last 40 years, Tunisia has experienced—as many other developing and emerging countries—a dietary transition, which led to an increase in the consumption of sugar, fats, and animal products. This transition was accompanied by an increase in noncommunicable diseases, particularly cardiovascular diseases. Using mathematical programming, we optimized the Tunisian diet using the French dietary recommendations as constraints. Then, we used the Global Trade Analysis Project's constant elasticities of substitution in order to simulate the impact of fulfilling the nutrient recommendations on international trade and domestic supply. Using this approach, we showed that the Tunisian diet is rich in carbohydrates and sugar but lacks fibers, some minerals, and vitamins. The adherence to all recommendations would induce an imperative shift to less sugar and cereal-based products by reducing the import dependence on these products, but would result a dramatic increase in the domestic supply of products from animal origin, fruits, vegetables, and legumes.

KEYWORDS
Armington function, food trade, mathematical programming, nutrition, Tunisia

JEL CLASSIFICATION
C61, I18, Q17

1 | INTRODUCTION

Until the 1970s, Tunisia faced a high poverty level and undernutrition problems. To tackle these issues, the Tunisian government implemented social policies over the past decades. Tunisian policies had three objectives to improve (i) food security, (ii) health, and (iii) education. Policy on food security was based on direct and indirect food subventions. In direct system, families received cash transfers under conditions such as number of children in the family. The indirect part of the subvention system is a price subsidy on staple food products (wheat, milk, oil seeds, sugar, and tomato paste) and education aids. Moreover, public policies implemented in these decades were focused on the improvement in access to the health system (Dhehibi & Gil, 2003).

These policies have been very effective in increasing the food calories availabilities, which increased steadily and reached an average of 3,329 calories per capita and per day in 2010, according to the apparent consumption of Food and Agriculture Organization (FAO) (see Figure 1). The food subvention system was supposed to be progressive, but inequality persists among poor population as there are fewer benefits from subventions in reality than in theory. Poverty is still present and estimated at 15.5% of the Tunisian population in 2010 (Banque Africaine de Développement, 2013a; Ben Said et al., 2011). Consequently, a gap remains between rich and poor's caloric intake, i.e., 2,594 and 1,903 kcal/capita/day, respectively (Banque Africaine de Développement, 2013b).

However, this dietary trend has benefited more to energy-dense than nutrient-dense products. Even if food transition in Tunisia (as in many developing countries) seemed unavoidable (Rayner, Hawkes, Lang, & Bello, 2006), the food subsidy system has certainly significantly amplified the dietary transition (Lobstein, 2002; Popkin & Ng, 2007) by

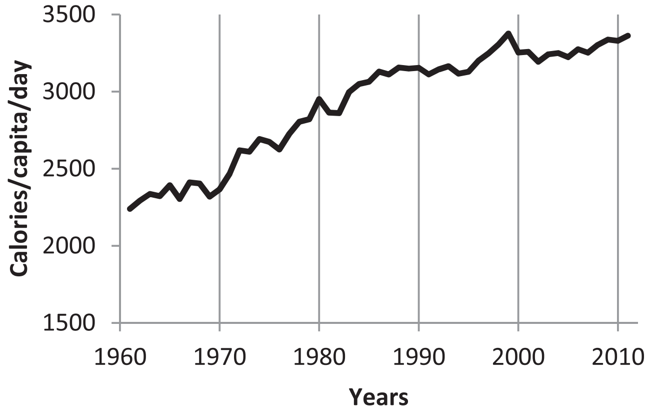

FIGURE 1 Apparent consumption in calories, evolution in Tunisia from 1960 to 2010
Source: Data from FAOSTAT.

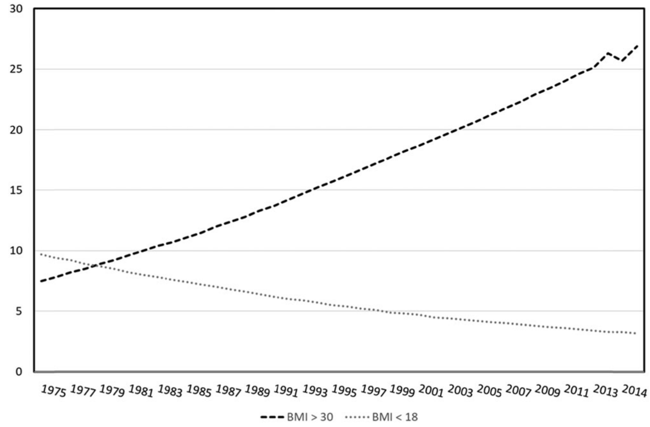

FIGURE 2 Prevalence of underweight (BMI < 18) and obesity (BMI > 30) in adult population in percentage (Tunisia, 1975–2015)
Source: Data from the World Health Organization, BMI = Body Mass Index.

encouraging the consumption of affordable products largely imported from abroad: wheat flour, vegetable oils other than olive oil, and sugar. This situation is all the more worrying that Tunisia has become net importer of cereals, meat, sugar, milk and vegetable oils (others than olive oil), i.e., the products which are the main markers of nutritional transition (Online Appendix, Table A5; Le Mouël & Schmitt, 2018). Observed transitions were accompanied with changes in both food consumption and trade. As a main example, the traditional olive oil consumption has been replaced by imported vegetable oils as maize, palm, and soybean oils. Nowadays, almost all the olive oil produced in Tunisia is sold abroad mainly in the European Union markets (Anania & Pupo d'Andrea, 2007). Tunisia is also a net importer of cereals to be processed for human consumption or animal feed. Finally, sugar displayed the most important evolution as imports of sugar (in raw sugar equivalent) multiplied by more than fourfolds in 40 years (FAOSTAT Food Balance Sheets, hereafter FBS).

These changes toward more westernized diets are understandable as Tunisian authorities aimed at supporting the consumption of cheap energy-dense food and ingredients to fight against undernourishment. The percentage of underweight people has been divided by 5 in 30 years and represents 5% of the population since 1999. The situation evolves in such a way that the prevalence of undernourishment in total population was equal to 5% in 2015–2017 according to the FAO report on nutrition and food security situation (FAO, 2018). But concomitantly, overweight population increased from 10% in 1975 to nearly 30% in 2016. As shown in Figure 2, the two curves expressed in percentage of underweight and obese population crossed in the early 1980s. In addition, the prevalence of overweight children aged less than 5 was 14% in 2012 (FAO, 2018). The problem of overweight and obesity in Tunisia is associated with the rise of unbalanced diets (Gartner et al., 2014). Nutritional transition toward more fat and sugar rather than traditional Mediterranean diet that is recognized as a way to prevent noncommunicable diseases (NCD) (D'Innocenzo, Biagi, & Lanari, 2019) may explain why, in 2016 in Tunisia, NCDs accounted for 86% of all deaths, including cardiovascular diseases (44%) and diabetes (5%) (WHO, 2018).

In this context, the objective of the study was to explore the impact of a better food pattern—bringing caloric intake to recommendations and respecting a large set of nutritional guidelines—that may have on trade. To build a scenario achieving nutritional needs of Tunisian population, we used mathematical programming, which is commonly used in the scientific literature to reach optimal diets in terms of nutrition, cost, consumer preferences, or environmental impacts. Initiated by economists (Smith, 1959; Stigler, 1945), this methodology was taken up essentially by researchers in nutrition to minimize the cost of diets while fulfilling the nutrients recommendations and respecting food habits (Darmon, Ferguson, & Briend, 2006). Nowadays, the literature on agricultural, food or health economics, and policies deploying this type of method is inadequate. It was observed in Gazan et al. (2018), a literature review on mathematical optimization of diets, out of 67 articles published, only two were published in economics journals. Apart from the seminal works of Stigler and Smith, we can quote the works of Henson (1991), Irz, Leroy, Réquillart, and Soler (2015), Shankar, Srinivasan, and Irz (2008), Srinivasan (2007), Srinivasan, Irz, and Shankar (2006). This economic literature in its majority assessed the impact of optimizing the diet essentially on consumption without considering the "supply side of the diet." A recent strand of the literature on diet optimization has focused on the agricultural and environmental impacts of the dietary changes. Arnoult et al. (2010) translated dietary guidelines in agricultural production and land use. Macdiarmid et al. (2012) assessed the greenhouse gas emission of optimized diets (for a comprehensive review on the topic, see Hallström, Carlsson-Kanyama, and

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Börjesson (2015). More recently, Perignon et al. (2019) estimated the impacts of fulfilling nutrient intakes in Tunisia on water and land uses. But to our knowledge, no study addressed the link between nutritionally adequate diets and food supplies, especially on trade. Willett et al. (2019) in the EAT-Lancet Commission recalled that trade may have a positive role on food security by enhancing food availability and diversity but also negative impacts as it can help promoting the distribution of unhealthy foods. Macdiarmid, Clark, Whybrow, de Ruiter, and McNeill (2018) assessed the link between food supply and nutrition security in UK using the FAO FBS and stressed the importance of trade in achieving nutrition security. Our approach complemented these works by exploring the impact fulfilling nutrient recommendations may have on international trade and thus on import dependency.

Using a nonlinear optimization model, our method was to optimize the Tunisian observed diet under a set of nutritional constraints based on the nutritional recommendations of the French agency for Food, Environmental and Occupational Health and Safety (ANSES, 2016, p. 94). Then, we used the Constant Elasticity of Substitution (CES) parameters from the Global Trade Analysis Project (GTAP) database (Dimaranan, McDougall, & Hertel, 2006) to evaluate the impact, fulfilling the nutrients recommendations, may have on the Tunisian domestic and foreign supply of food.

The paper is organized as follows: Section 2 presents the sources and the matching of data, Section 3 describes the model, results are presented in Section 4 and discussion and conclusion are provided in Sections 5 and 6.

2 | THE DATA

In order to perform this analysis, we had to reconcile three sources of data. The food balance sheets from the FAO, which give data estimates of production, utilization and trade for 111[1] food items (FAO, 2001) and two French databases on food contents in macro- and micronutrients: Ciqual (2012) and Nutrinet-Santé (2013). They are composed of respectively 1,343 and 2,609 food products and 60 macro- and micronutrients and other food compounds.

The FBS do not provide the exact food consumption in Tunisia but the apparent consumption (defined as domestic production + imports – exports ± stocks variations). They are expressed in tons per year; we converted them in grams per day per capita (using total population in 2010). Table A1 in the Online Appendix shows the observed food apparent consumption by food items in 2010 in Tunisia. Del Gobbo et al. (2015) have shown that these "guestimates" from the FAO are largely over or underestimated; the estimation error can attain (according to country) +270% for whole grain and −50% for beans and legumes. In Tunisia, the food apparent consumption (FAC) is equivalent to 3,731 kcal per inhabitant and per day, but the mean observed adult[2] intake based on individual dietary survey is 2,702 kcal (Perignon et al., 2019). Therefore, we performed a proportional reduction to end with an observed daily intake of 2,702 kcal (Online Appendix, Table A2). This reduction to 2,702 kcal is not undertaken via the model but is a simple beforehand proportional computation and will be called henceforth the observed diet.

In order to reconcile the FBS and the nutrition datasets, a matching was necessary between the definitions of the products in the three databases. In priority, the Ciqual product description was considered. When a product was not available in Ciqual, the Nutrinet database was considered. When a food item was not available in both nutritional databases, we used average foods, which categorize family of products or the closest product we could associate based on the comparison of nutrients compounds. For instance, the nutrient composition of pulses was elaborated by the weighting of products from this food category according to the Tunisian consumption of these products.

Table 1 shows the observed quantity of nutrients apparent intake in Tunisia in 2010 and the ANSES nutrient recommendations. It indicates that the mean Tunisian diet was rich in carbohydrates and free sugars, while several beneficial nutrients were under the ANSES dietary recommendations: fiber, vitamins (B1, B2, B12, C, and D), calcium, magnesium, zinc, and iodine.

3 | THE MODEL

We proceeded in two steps: In the first step, using a nonlinear programming approach, we optimized the Tunisian observed diet to find out in what proportion the quantity of food items should vary to ensure the adequacy with the nutritional recommendations. The optimizations are made using the GAMS software. The model is composed of 58 food items detailed in the Online Appendix, Table A2, which represent the Tunisian diet observed in 2010 for 2,702 kcal.

To identify the dietary changes needed to fulfil the nutrient recommendations, we used the quadratic modelling. We minimized the objective function (Z), which is the weighted sum of the square of the relative deviations between the observed quantity X_i and the optimized quantity X_i' for each item i in the diet times a coefficient α_i which is the share of each

[1] We analyze only 58 items after selection of influent products on Tunisian trade.

[2] People between 15 and 64 years old represent 69% of the Tunisian population.

TABLE 1 Nutritional constraints in the model (ANSES daily nutritional recommendations)[a]

Nutrients	Constraints	Content in the observed diet
Protein (% total energy)	10–20	14.2
Total fats (% total energy)	35–40	**30.8**
Carbohydrates (% total energy)	40–55	**68.8**
Linoleic acid (% total energy)	≥4	6.92
Linolenic acid (% total energy)	≥1	1.68
EPA+DHA (mg)	≥500	**305**
Saturated fatty acids (% total energy)	<12	6
Free sugar (% total energy)	<10	**11.1**
Fibers (g)	≥30	**18.9**
Vitamin A (μg/d)	700–3000	945
Vitamin B1 (mg/kcal)	≥0.00058	**0.00043**
Vitamin B2 (mg/kcal)	≥0.00071	**0.0005**
Vitamin B3 (mg eq. niacin/kcal)	0.0067–47	**0.00104**
Vitamin B6 (mg)	[1.65–25]	1.65
Vitamin B9 (μg eq. folate)	≥330	346.5
Vitamin B12 (μg)	≥4	**3.72**
Vitamin C (mg)	≥110	**100.1**
Vitamin E (mg)	<300	–
Vitamin D (μg)	[3–50]	**2.01**
Calcium (mg)	≥900	**504**
Phosphorus (mg)	≥700	1071
Potassium (mg)	≥2633.5	3107.53
Iron (mg)	≥11	12.54
Magnesium (mg)	≥390	**300.3**
Zinc (mg)	[12.5–25]	**8.38**
Copper (mg)	[1.125–5]	1.36
Iodine (μg)	[150–600]	**96**
Selenium (μg)	[70–300]	**78.4**
Total energy (kcal/d)	=2467.5	2702

[a]Bold values indicate when a nutrient does not fulfil the constraint.
Source: ANSES (2016).

item i in the total observed diet. This approach allows to take into account consumers preferences reflected in observed food choices as it prevents the model from proposing too large variations from the observed diet or for foods that are consumed in relatively small quantities:

$$Z = \sum_i \alpha_i \left(\frac{X_i' - X_i}{X_i} \right)^2 \quad (1)$$

$$\alpha_i = \frac{X_i}{\sum_i X_i}$$

Z was minimized under a set of constraints on nutrients, which corresponds to the ANSES nutritional recommendations for 34 macro- and micronutrients (the list of nutritional constraints is summarized in Table 1).

For each beneficial nutrient (e.g., vitamins, minerals, fibers, and essential fatty acids), the mean between the intake recommended for men and women was used as a minimal constraint, to ensure nutritional adequacy of the optimized diet. Upper limits have also been set, for macronutrients and some vitamins and minerals have safety limits. Some additional constraints were taken into account to impede the model to increase or decrease the quantity of particular products like tea, coffee, spices which have been fixed arbitrarily at maximum 1.5 times the observed level.

The model output, i.e., the food content of the optimized diet, allowed us to identify the needed variations in grams per day to insure a nutritional adequate diet. These variations are equal to $\delta_i = (X_i' - X_i)/X_i$. We then deduced the "optimal" food apparent consumption $FAC'_i = (1 + \delta_i) FAC_i$.

In the second step, we used the GTAP constant elasticity of substitution (CES) parameter in order to simulate the impact of fulfilling the nutrient recommendations on international trade and domestic supply. According to Armington (1969), we assumed the imperfect substitutability of products from domestic or foreign origins. This assumption considers that consumer demand (here, the *FAC*) in an open economy can be represented by a CES function, aggregating demand for product *i* over domestic and imported origins (Annabi, Cockburn, & Decaluwe, 2006), which forms:

$$FAC_i = A_i\left(\beta_i * Imports_i^{-\rho_i} + \left(1-\beta_i\right) * Domestic_i^{-\rho_i}\right)^{\frac{1}{\rho_i}} \tag{2}$$

where $Imports_i$ *are* imports of products *i* and $Domestic_i$ represents the domestic demand of *i* addressed to domestic producers, A_i, β_i and ρ_i are the CES parameters.

We then, computed d_i the ratios of imports ($Imports_i$) to domestic demand ($Domestic_i$) for the good *i*:

$$d_i = \frac{Imports_i}{Domestic_i} = \left[\frac{PD_i}{PM_i}\frac{\beta_i}{1-\beta_i}\right]^{\varepsilon_i} \tag{3}$$

with $\beta_i = \frac{Imports_i^{(1+\rho_i)}}{Imports_i^{(1+\rho_i)} + Domestic_i^{(1+\rho_i)}}$ and $\rho_i = \frac{1}{\varepsilon_i} - 1$

Where ε_i is the elasticity of substitution of good *i*, PD_i, and PM_i are, respectively, the prices of domestically produced and imported goods *i* in the Tunisian market. In the GTAP database, prices are the same so their ratio is equal to 1; ε_i is retrieved from GTAP (Online Appendix, Table A4). Finally, d_i allowed disentangling the share of local and foreign origin in the optimized food apparent consumption.

$$Domestic_i' = \frac{FAC_i'}{1+d_i} \tag{4}$$

$$Imported_i' = FAC_i' \frac{d_i}{1+d_i} \tag{5}$$

4 | RESULTS

Results of the diet optimization are displayed in Figures 3 and 4 for aggregated items. Detailed results are provided in the Online Appendix, Table A3.

We used the results of the optimization to compute the impact in terms of macro data and particularly in terms of domestic versus foreign origin of food. We thus computed the new domestic supply and trade after the reallocation of food items to ensure an optimized diet at the national level (see Figures 5 and 6 and the Online Appendix, Table A5).

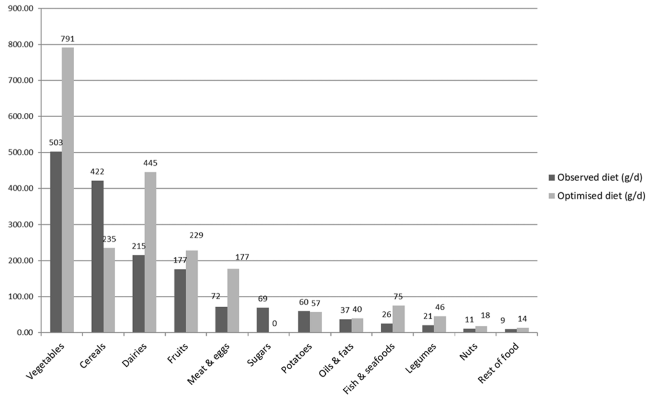

FIGURE 3 Consumption in grams per day and per person at baseline and after optimization (all products)

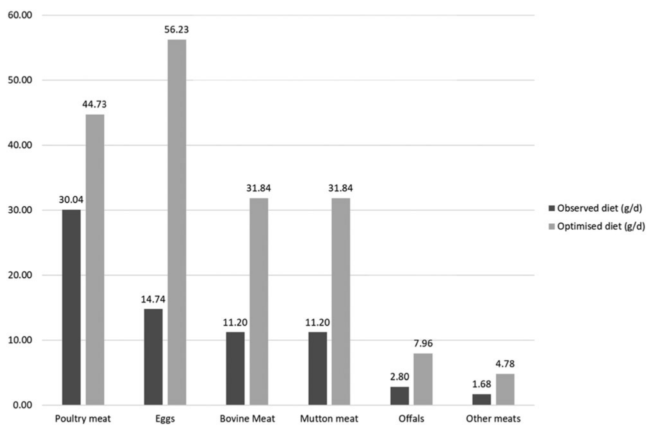

FIGURE 4 Consumption in grams per day and per person at baseline and after optimization (products from animal origin)

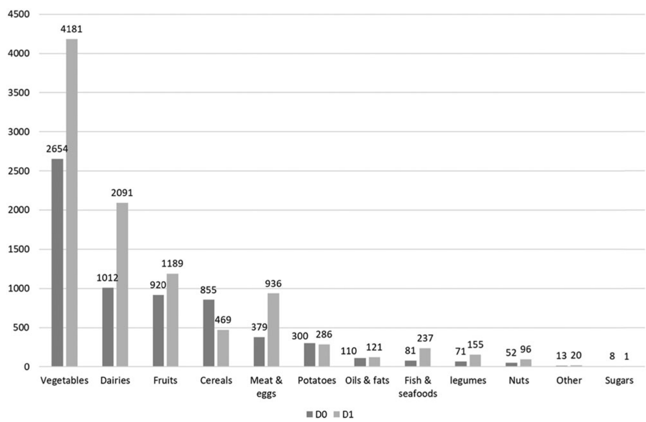

FIGURE 5 Variations of domestic demand in 1000 tons (D0 observed demand, D1 demand after optimization)

Reaching nutritional adequacy induced a strong reduction of sugar products including honey and sweeteners (almost 100%). The consumption of carbohydrates should be 40–55% of the total energy according to the recommendation and free sugars should be limited to 10% of total energy. The

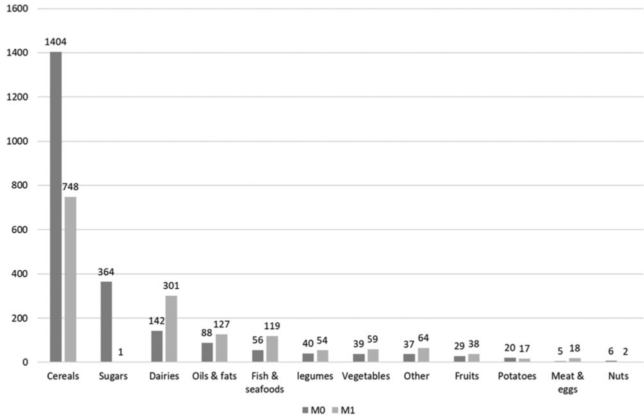

FIGURE 6 Variations of imports in 1000 tons (M0 observed imports, M1 imports after optimization)

Note: The constraint on vitamin D was too strict and made the model infeasible, we thus kept a previous lower limit of 3 μg.

observed diet in 2010 displayed figures above these recommendations. Concerning cereals, their participation to the diet should be decreased by 44%, particularly wheat, which is the main cereal consumed in Tunisia. These reductions are essentially met by decreasing imports by 600,000 tons of cereals and 350,000 tons of sugar (in raw sugar equivalent).

The optimized diet showed a strong increase in products from animal origin: fish and seafood (+194%), meat and eggs (+148%, particularly eggs and red meats), and dairies (+107%). These shifts would result in spectacular increase in domestic supply by 1,000,000 tons of milk, 222,000 tons of eggs, 100,000 tons of bovine meat, and 142,000 tons of fish and seafood. Imports would also increase but in a lesser proportion (essentially milk, +159,000 tons), but also fish and seafood (+63,000 tons) and meats and eggs (+13,000 tons).

Concomitantly to the reduction in cereals, other plant products increased in the optimized diet: legumes (+124%), fruits (+29%) and vegetables (+57%). They would also impact domestic production by +1,405,000 tons of various vegetables and +84,000 tons of legumes. It implies import increases of vegetables (+20,000 tons), legumes (+14,000 tons) and fruits (+9,000 tons). In terms of growth rate, this would represent, according to our calculations, an increase in domestic production of around 1 to 2.5% per year over 20 years, much less than the 2 to 4.5% increase recorded between 2010 and 2017 for these products in Tunisia according to the FAO.

Finally, we made a rough estimate with the GTAP database of the impact of diet optimization on the value of demand. Our results show that the total value of Tunisia demand (imports + domestic production) for agrifood products would increase by $6,616.3 million of which $2,945.3 million for household's demand.

5 | DISCUSSION

Nutritional transition in Tunisia as in other Mediterranean countries of the South side was often largely influenced by the food subsidy system. Food security was insured by Tunisian social policies based on direct allowances to families and prices subsidies for essential food products (wheat, milk, seed oils, sugar, and tomato paste). As stressed by Lobstein (2002), food policies often fail in delivering healthy diets. Our work proposed insights for redesigning public agricultural and food policies.

The first step of our analysis showed that the Tunisian diet was almost adequate but rich in free sugars and insufficient in fiber, vitamins (A, B1, B2, B12, C, and D) and minerals (calcium, magnesium, zinc, and iodine) according to the ANSES set of nutritional recommendations.

The results of the optimization indicate that the consumption of sugar and wheat must be strongly reduced, whereas all other food categories must be increased to achieve the nutritional recommendations.

The reduction of cereals and sugars would induce a decrease of imports by 600,000 tons of cereals and 350,000 tons of raw sugar equivalent. But, in order to maintain an adequate level of calcium, iron, and proteins, our modelling recommend an increase in the consumption of animal-derived products, particularly dairy products. Tunisian consumption of proteins from animal origin is not very high at baseline and could thus be increased. Finally, Tunisians should increase their intake of legumes, fruits, and vegetables, even if the consumption of fruits and vegetables was already adequate at baseline. Such increases are probably necessary to achieve adequate recommendations for fiber, in replacement of cereal.

In Tunisia, sugar and wheat are supported by the food subsidy system and largely imported from abroad. As a consequence, the adherence to nutritional recommendations would translate into impacts at macro level to ensure food security. By adhering to the nutritional recommendations, Tunisia would decrease its foreign dependence on sugar and cereals but would increase its dependence on all other goods.

These changes in food patterns would weigh also on domestic agricultural production but can be achieved in 20 years considering the current agricultural growth rates.

These shifts to an adequate diet have also consequences on the total value of the household demand which would increase by \$0.76/person/day (about 1.1TDN[3]). This increase in the food bill is the consequence of an increase in more expensive products in the optimized diet, particularly products from animal origin.

Our approach is useful to reorientate the current public policies. Tunisian public policies for food security have been

[3] Based on the 2010 exchange rate.

very efficient in cutting down undernourishment. However, Tunisia is nowadays confronted with the triple burden linked to the coexistence of undernourishment (reduced to 5% but still managing; FAO, 2018), nutrient deficiencies and obesity. These policies have also had the effect of increasing import dependency, which affects Tunisia's vulnerability to price instability, which may jeopardize food security.

Our work suggested that encouraging people to improve their diet may have impact at a macro level. Governments should rethink their food policies in a comprehensive way to improve food accessibility, quality, and sustainability.

In our scenario, the strong increase in the consumption of some products like animal products, fruits, vegetables, and legumes is supposed to be met by an increase of the domestic supply. This suggests a profound reorganization of the agri-food systems to restore the competitiveness of domestic production on the internal market. The food value chain must be better organized and coordinated with an integrated approach (Ben Said et al., 2011). At the production level, yields should be improved and a more effective mobilization of production factors should be implemented (Le Mouël & Schmitt, 2018). The factors (land, labor) released by the abandonment of the production of cereals would be available for other agricultural productions. This movement must be accompanied by agricultural policies favoring the adoption of nutritional-sensitive agriculture and technical innovations, improving agronomic and zootechnical practices, especially in the future to face climate change. At the food value chain level, policies should address the reduction of waste and losses by promoting measures to improve pest control, quality standards, traceability, and food processing.

However, a strategy to reduce dependence on imports, mainly in cereals and oilseeds, should also be considered. As the population continues to increase, this demographic change is accompanied by the growth of the young and higher income population suggesting changes in the food diet further increasing dependence on cereals, oilseeds, sugars, and processed products (Le Mouël & Schmitt, 2018). Thus, promoting the health benefits of the traditional Mediterranean-type diet (D'Innocenzo et al., 2019), particularly targeting young people should be encouraged along with reorienting social policies and aids toward food products that are more beneficial to health and less costly for consumers, as for example encouraging the consumption of legumes. Legumes combined with cereals are good sources of proteins with a complementary amino acid profile and cheaper substitutes to animal products (Xipsiti, Marzara, & Calles, 2017).

The present study has several limits. FBS provides aggregated data at country level on food availabilities and do not reflect the exact consumption of the population as dietary survey could do. For this reason, the analysis did not take into account gender and age or socioeconomic distribution in the computation. Yet, the nutritional needs will differ significantly according to the age or gender. Thus, individual dietary survey is still needed to determine the target populations for dietary adjustment. The model of trade used was static and did not include prices or budget constraint, nor did it include an analysis of production capacity. Thus, the ability of Tunisians to switch from one diet to another has to be analyzed in the future.

6 | CONCLUSIONS

In our analysis, we used a quadratic programming model to represent and simulate changes in the Tunisian average dietary pattern. We optimized the diet to respect the adequacy with the French recommendations on macro- and micronutrients. We recalculated the needs for each food item and the impact fulfilling these diet recommendations may have in terms of their foreign and domestic origin (detailed results are provided in the Online Appendix, Table A5).

Ensuring food security in Tunisia has been a major challenge for the public authorities for the past 40 years. Public policies implemented to meet the challenge, coupled with demographic changes, have increased dependence on import markets for energy-rich products. Paradoxically, this dependence endangers food security in Mediterranean countries because they are more prone to price instability.

Favoring a better adherence to nutritional recommendations would help Tunisia to decrease its dependence on international markets for sugar and cereals but it should find levers to cover the needs in products from animal origin, fruits, vegetables, and legumes. This would require both sector initiatives aimed at restructuring the agrifood system to improve its competitiveness and agricultural and nutritional policy actions aimed at jointly promoting public health goals of NCD prevention and limiting the risks associated with high levels of food dependence (Ben Said et al., 2011; Le Mouël & Schmitt, 2018). In conclusion, the combination of a better adherence to a healthy diet, and improvement of agriculture practices and the avoidance of losses at all levels of the agrifood chain could reduce the rise of agricultural import dependence. Thus, there is a need to redirect public subsidies to improve the sustainable productivity of agriculture and to ensure food and nutritional security in Mediterranean countries.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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How to meet nutritional recommendations and reduce diet environmental impact in the Mediterranean region? An optimization study to identify more sustainable diets in Tunisia

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ABSTRACT

Tunisia is a typical country of the Mediterranean region where high prevalence of overweight, obesity and non-communicable diseases co-exist with some micronutrient deficiencies, and diet-related environmental issues must be addressed. Individual food choices may influence both health and environment. The aim of this study was to identify diets that are nutritionally adequate, culturally acceptable, and with low environmental impact for Tunisian adults.

Individual dietary data from a national Tunisian survey on food consumption (n = 7209, 35–70 years) and the national food composition table were used to estimate the food and nutritional content of the mean observed (OBS) diet. The diet environmental impact was assessed through seven metrics: water deprivation, land-use, land-use potential impacts on biodiversity loss, erosion resistance, mechanical filtration, groundwater replenishment, and biotic production. Quadratic optimization models were implemented to obtain diets that met the nutritional recommendations, and concomitantly respected increasingly stringent environmental constraints and minimized the departure from the OBS diet.

Without environmental constraints, the nutritional recommendations were met by increasing the amount of dairy, starch and vegetables, and decreasing foods high in fat/salt/sugar (HFSS) and added fat. Compared with the OBS diet, the environmental impact of this diet increased: +32% for water deprivation and +46–48% for land use and its impacts.

When a moderate environmental impact reduction (≤30%) was added to the nutritional constraints, the

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dietary changes at the food group level were similar to those required to reach nutritional adequacy, except for a progressive decrease in meat/fish/egg quantities. Animal-based product contributions to the total energy and protein content were close or slightly lower than in OBS diet, but a redistribution of sources was required: less meat in favor of dairy, egg and fish products. Stronger reductions (≥40%) required substantial changes that might compromise the optimized diet acceptability.

Targeting a nutritionally adequate diet without considering its environmental impact might increase water deprivation, land use and its impacts on biodiversity and soil quality. In Tunisia, moving towards healthy diets with lower environmental impact relied more on redistributing the sources of animal-based products rather than on reducing their total contribution, together with a decrease of HFSS and added fats, and an increase of vegetables. Actions to favor the adoption of such dietary changes by consumers should be explored to promote more sustainable diets in the Mediterranean region.

1. Introduction

During the last decades, several countries in the Mediterranean region underwent an epidemiological and nutritional transition that has resulted in a major increase of the prevalence of overweight, obesity and non-communicable diseases (NCD), while some micronutrient deficiencies persist (Gartner et al., 2014; NCD Risk Factor Collaboration (NCD-RisC), 2016a, 2016b). Besides these public health challenges, the Mediterranean area is also facing climate and environmental issues, especially water deprivation and biodiversity loss, particularly in the Near East and North Africa (CIHEAM/FAO, 2015). The current food system has a major environmental impact by contributing between 19 and 29% of global greenhouse gas emissions (GHGE) (Vermeulen et al., 2012) and by representing ~70% of global freshwater use (Whitmee et al., 2015). Therefore, changes in food consumption and production patterns are needed to ensure more sustainable food systems and achieve food and nutrition security in the Mediterranean region. As individual food choices can influence public health and also the environment, there is an urgent need to promote sustainable diets, defined by the Food and Agriculture Organization (FAO) as nutritionally adequate, safe and healthy, culturally acceptable, financially affordable, and with low environmental impacts (Food and Agriculture Organization, 2010).

Previous studies have explored the potential of dietary shifts towards more sustainability by assessing the environmental impact of the existing diets (Perignon et al., 2017) or of dietary scenarios, such as the Mediterranean-type diet, New Nordic diet, and diets with reduced levels of animal products, compared with the national average diet (Berners-Lee et al., 2012; Risku-Norja et al., 2009; Sáez-Almendros et al., 2013; Saxe et al., 2013; Temme et al., 2013; van Dooren et al., 2014). However, these approaches do not allow identifying diets that improve simultaneously all dimensions of diet sustainability. Indeed, high nutritional quality is not necessarily associated with affordability or lower environmental impact (Biesbroek et al., 2017; Perignon et al., 2017; Vieux et al., 2013). Moreover, some dietary scenarios may be too different from the dietary habits in the studied countries, which limits their acceptability. Mathematical diet optimization (herein referred as "diet optimization") can be used to find the optimal combination of foods to fulfil a set of constraints, and is a unique and powerful tool for studying simultaneously the multiple dimensions of diet sustainability (Gazan et al., 2018). For instance, when applied to study sustainability issues, diet optimization can be used to meet nutrient recommendations and reduce environmental impacts, while maximizing the similarity with the current diets.

Moreover, previous studies essentially assessed the environmental impact in terms of GHGE (Payne et al., 2016; Perignon et al., 2017). However, it is well known that GHGE are not a proxy for the full range of environmental impacts associated with a diet. Indeed, among the 169 targets of the Sustainable Development Goals, water deprivation, land degradation, and biodiversity loss have been identified as environmental areas of concerns that need to be addressed (IPBES, 2019; Ridoutt et al., 2017; United Nations General Assembly, 2015). Yet, a recent review reported that very few studies investigated dietary changes to reduce these impacts by using metrics that can be applied in a life cycle context (Ridoutt et al., 2017). The authors concluded that the available evidence on dietary patterns and water deprivation, land degradation and biodiversity loss is very limited, and did not identify generalizable findings. In addition, the few existing studies were all conducted in Europe, and only one explored the effect of shifting to a healthier diet on water deprivation (Hess et al., 2015). Therefore, more analyses of the compatibility between nutritional and environmental goals using appropriate metrics are needed, especially in the Mediterranean region where water deprivation is critical.

Tunisia is a typical country of the Mediterranean region that is undergoing a nutrition transition and where high prevalence of overweight, obesity and NCD co-exist with some micronutrient deficiencies (Atek et al., 2013; Traissac et al., 2016). Tunisia has a marked climatic north-south gradient, from a Mediterranean region in the north to a semi-arid and then desert area in the south. This puts the country especially at risk to climate change effects on land, coastal zones, water, and agriculture (Thiébault et al., 2016; Verner and World Bank. Middle East and North Africa Region. Sustainable Development., 2013).

The objective of the present study was to identify, using diet optimization models, the dietary changes that allow fulfilling the World Health Organization (WHO) nutritional recommendations, reducing the diet environmental impact, and respecting the Tunisian population's dietary habits.

2. Methods

2.1. Dietary and food composition data

Dietary data were derived from a nationally representative cross-sectional survey performed among 35-70-year-old adults of both sexes in Tunisia in 2005, as part of the Transition and Health Impact in North Africa (TAHINA) project (Atek et al., 2013). This survey collected retrospective data on food consumption during one month using a validated semi-quantitative food frequency questionnaire (El Ati et al., 2004). For the purpose of our study, the 138 food items declared to be consumed by the participants were classified in 8 food groups [fruits & vegetables, starch, meat/fish/eggs (MFE), dairy, foods high in fat/salt/sugar (HFSS), mixed dishes, added fat & seasoning, drinks], and 23 food sub-groups (Supplemental Table 1). A specific Tunisian food composition database (El Ati et al., 2007), completed by the USDA table (US Department of Agriculture, 2008), additional laboratory analyses and the Food Processor software, version 8.3 (ESHA-Research-Inc, 2003) were used to estimate the energy and nutritional content (macro- and micronutrients) of the identified food items and diets.

The 138 food items were also classified as animal- or plant-based products to estimate the animal-based product contributions to the diet total energy and protein content.

Energy intake under-reporters were identified using Black's equations (Black, 2000). As the prevalence of overweight and obesity was high in the studied population (71% and 37% among women) (Atek et al., 2013), the basal metabolic rates used to calculate Black's cutoffs were estimated using Mifflin equation (Mifflin et al., 1990). The mean observed (OBS) diet was estimated using data from a final sample that included 6279 adults, aged 49.2 ± 9.5 years, among whom 52.9% were women.

2.2. Environmental impact of diets

The environmental impact of food items was estimated using seven metrics: water deprivation, land use, land use potential impacts on erosion resistance, mechanical filtration, groundwater replenishment, biotic production, and biodiversity. Impacts were computed with a life cycle vision using a hybrid method that combined trade statistics and production data, in order to estimate the impact in the countries of production (Tunisia and/or other countries, if imported) of the food items consumed in Tunisia. The methodology used to estimate the seven metrics (expressed by kg of food) for each of the 138 foods declared to be consumed by the Tunisian population in the nationally representative cross-sectional study has been described elsewhere (Sinfort et al., 2017, 2019). Briefly, national dietary survey data were matched with the UNComtrade and the FAOstat databases to obtain the quantity of food produced per production country, for each food item consumed in Tunisia. Yield per crop and per country were used to compute the occupied surfaces, and blue water consumption was extracted from the Water Footprint Network datasets. The potential impacts were then obtained by multiplying the amounts of consumed water and land use surface with characterization factors. The characterization factor used to estimate water deprivation impacts was the Water Stress Indicator provided by Pfister et al. for each country (Pfister et al., 2009). Land use impacts were computed from the occupied surface (including land occupied by animal feed crops), from land use types, and from the main biome of the production country. Then LANCA characterization factors (Beck et al., 2011; Bos et al. n.d.) were used to compute land use potential impacts. The land use impacts on biodiversity were calculated using country-specific global characterization factors estimated by Chaudhary et al. with the countryside species−area relationships (SAR) model and average approach (Chaudhary et al., 2015). The developed methodology assessed the impact at a global scale, which is necessary when studying complete diets that include food items from many countries.

The environmental impact of the OBS and optimized diets was then estimated for each metric by summing the impact of all food items weighed by their quantity in the diet. For each metric, a positive value indicates a detrimental impact, and a negative value a beneficial impact.

2.3. Diet optimization

Quadratic optimization models were used to obtain nutritionally adequate diets that departed the least from the food content of the OBS diet, and with increasingly stringent environmental constraints. The model variables were the 138 food items consumed by the population. For each model, the objective function to be minimized was the quadratic deviation from the mean observed intake for each food item and food group, in order to promote minimal variations on all foods and penalize large variations in the diet composition. The objective function was expressed as follows:

$$Minimize\ f = \frac{1}{138}\sum_{i=1}^{138}\left(\frac{Q_i^{opt} - Q_i^{obs}}{Q_i^{obs}}\right)^2 + \frac{1}{8}\sum_{j=1}^{8}\left(\frac{Q_j^{opt} - Q_j^{obs}}{Q_j^{obs}}\right)^2$$

where i represents the 138 food items and j the eight food groups

Table 1
Nutritional constraints implemented in the diet optimization models, and nutrient content in the mean observed diet.

Nutrient	Constraint applied in the modeled diets[a]	Content in the mean observed diet[b]
Proteins (g*kg of body weight[c]/d)	> 0.83 (WHO/FAO/UNU, 2007)	83.7
Carbohydrates (%E)	[50–75] (FAO/WHO, 2007)	50.7
Total fat (%E)	[15–35] (FAO, 2010)	**35.6**
Saturated fatty acids (%E)	< 10 (FAO, 2010)	7.4
Total PUFA[d] (%E)	[6-11] (FAO, 2010)	9.4
n-6 PUFA (%E)	[2.5–9] (FAO, 2010)	8.0
n-3 PUFA (%E)	[0.5–2] (FAO, 2010)	1.1
Cholesterol (mg/d)	< 300 (WHO-FAO, 2003)	237.5
Fibers (g/d)	> 25 (WHO-FAO, 2003)	31.8
Free sugars (%E)	< 10 (WHO-FAO, 2003)	6.7
Vitamin A (µg RE/d)	[550–3000] (WHO-FAO, 2004)	751.6
Vitamin B1 (mg/d)	> 1.15 (WHO-FAO, 2004)	2.4
Vitamin B2 (mg/d)	> 1.2 (WHO-FAO, 2004)	2.2
Vitamin B3 (mg/d)	[15–35] (WHO-FAO, 2004)	27.7
Vitamin B5 (mg/d)	> 5 (WHO-FAO, 2004)	5.0
Vitamin B6 (mg/d)	[1.3–100] (WHO-FAO, 2004)	1.9
Folates (µg DFE/d)	[400–1000] (WHO-FAO, 2004)	706.3
Vitamin B12 (µg/d)	> 2.4 (WHO-FAO, 2004)	5.0
Vitamin E (mg α-tocopherol/d)	> 15 (WHO-FAO, 2004)	**10.5**
Vitamin C (mg/d)	[45–1000] (WHO-FAO, 2004)	168.3
Vitamin D (µg/d)	[5-50] (WHO-FAO, 2004)	**3.1**
Calcium (mg/d)	[1000–3000] (WHO-FAO, 2004)	**723.6**
Magnesium (mg/d)	[242–350] (WHO-FAO, 2004)	**206.9**
Zinc (mg/d)	[5.95–45] (WHO-FAO, 2004)	9.7
Selenium (µg/d)	[30–400] (WHO-FAO, 2004)	122.5
Iron (mg/d)	[21.5–45] (WHO-FAO, 2004)	**18.2**
Sodium (g/d)	< 2 (WHO, 2012)	**4.7**
Copper (mg/d)	[1.25–11] (WHO, 1996)	**1.0**
Potassium (mg/d)	> 3510 (WHO, 2011)	**3146.8**
Phosphorus (mg/d)	[700–4000] (Institute of Medicine, 1997)	1147.4
Total energy (kcal/d)	Equal to the total energy of the mean observed diet	2702

[a] Mean of the recommended dietary allowances for men and women.
[b] Bold values indicate when a nutrient content does not fulfill the constraint.
[c] Mean body weight was estimated using national Tunisian dietary survey data.
[d] Polyunsaturated fatty acids.

(starch, vegetables, fruits, MFE, dairy, mixed dishes, added fat & seasoning, and drinks), Q^{obs} is the mean observed quantity, and Q^{opt} the optimized quantity. The minimization function was applied at the food item level to deviate as little as possible from the OBS diet, but also at the food group level to respect the meal structure habits and favor substitutions by foods from the same meal component.

The total energy intake of the OBS diet was imposed in all models, as well as nutritional constraints in order to meet the WHO recommendations for 30 nutrients (list of nutritional constraints in Table 1). In addition, the fish subgroup was constrained to a maximum intake of two portions per week, to avoid high exposure to contaminants (ANSES, 2010).

Models with increasingly stringent environmental constraints were defined: a model without constraints on the environmental metrics (Nut-Env_{free} model), a model with constraints that limited the environmental metrics to the observed level (Nut-Env_{obs}), and models with constraints to decrease the environmental indicators by 10% at each step (Nut-Env_{-10}, Nut-Env_{-20}, etc … until mathematical infeasibility).

Finally, realism constraints were included in all models to avoid implausible changes relative to the diet consumed by the general Tunisian adult population. Specifically, the total diet weight could vary only by ± 20% relative to the mean observed intake. Moreover, the quantities of food items, groups and subgroups could range between the 5th and 95th percentiles of the observed intakes (percentiles were calculated for consumers in the case of food items, and for the whole population in the case of food groups and subgroups). All models were run using the GAMS software package (version 23.8.2).

3. Results

The food group and subgroup quantities in the OBS diet and in the optimized diets are detailed in Supplemental Table 2.

3.1. Food composition, nutritional content, and environmental impact of the mean observed diet

The food group composition and nutritional content of the OBS diet are presented in Fig. 1 and Table 1, respectively. The OBS diet did not meet the nutritional constraints for calcium, copper, iron, magnesium, potassium, vitamin D, and vitamin E (all below the WHO recommendations), as well as sodium and total fat (both above the WHO recommendations). Animal products represented 15.4% of the total energy, and 42% of the total proteins.

The environmental impacts (per person and per day) of the OBS diet were 0.32 m^3 eq of water deprivation (Fig. 2A), 262 m^2 of land use (Fig. 2B), 16,538 m^3 of water infiltration loss from land occupation (Fig. 2C), 2.6 m^3 of groundwater regeneration loss from land occupation (Fig. 2D), and $2.2.10^{-13}$ species lost due to land use (Fig. 2E). The impact was beneficial for two metrics: −274.3 kg of soil loss due to erosion from land occupation and −139.5 kg of biotic production loss from land occupation (data not shown). Therefore, the subsequent

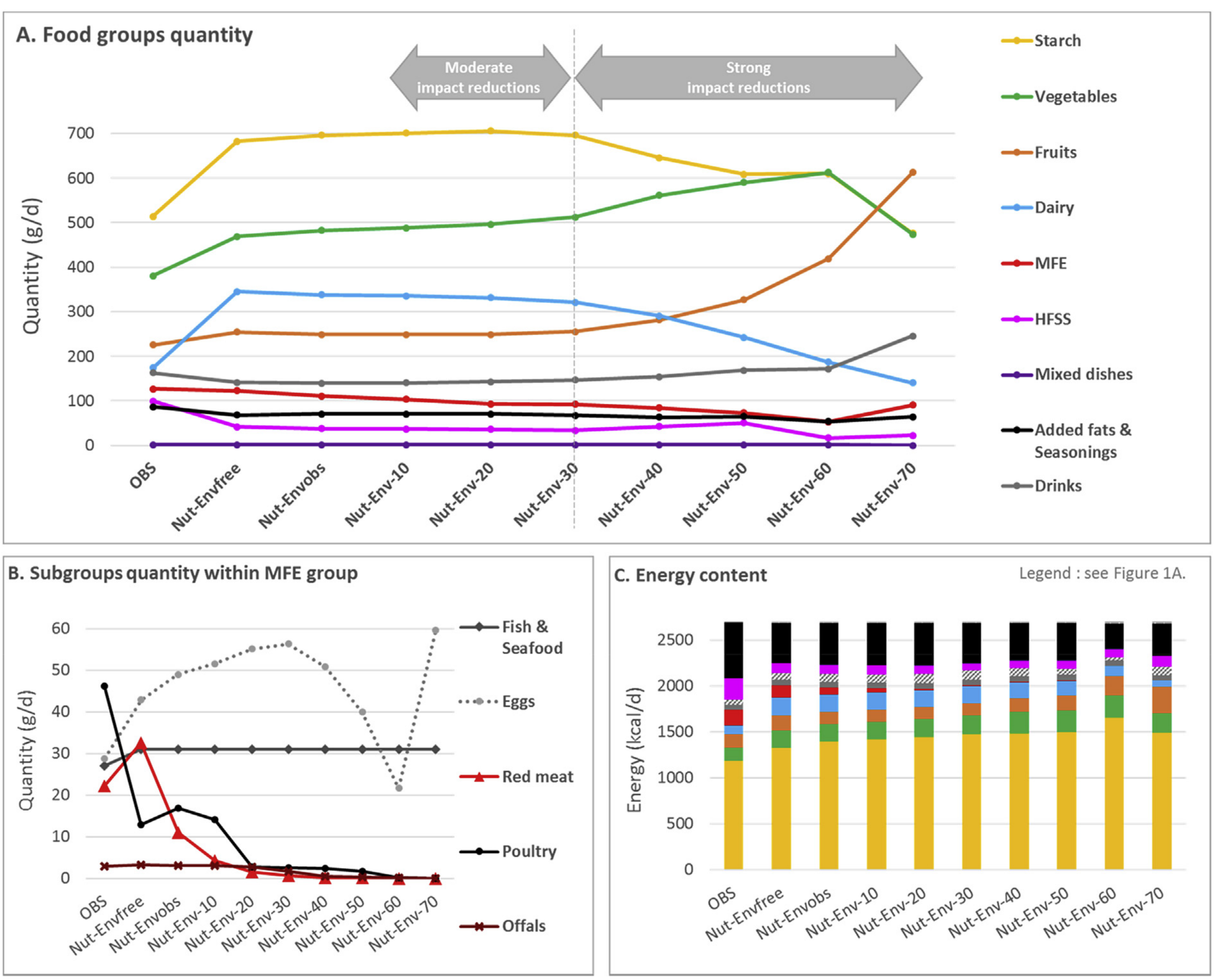

Fig. 1. Food groups quantity (A), Subgroup quantity within the Meat/Fish/Egg group (B), and Energy content (C) in the observed and optimized diets. MFE: Meat/Fish/Egg; OBS: observed diet; Nut-Env_{free}: model without environmental constraints; Nut-Env_{obs}: model with constraints limiting the environmental metrics to the observed level; Nut-Env_{-10}, Nut-Env_{-20}, …etc: models with constraints imposing a 10% decrease of the environmental indicators at each step.

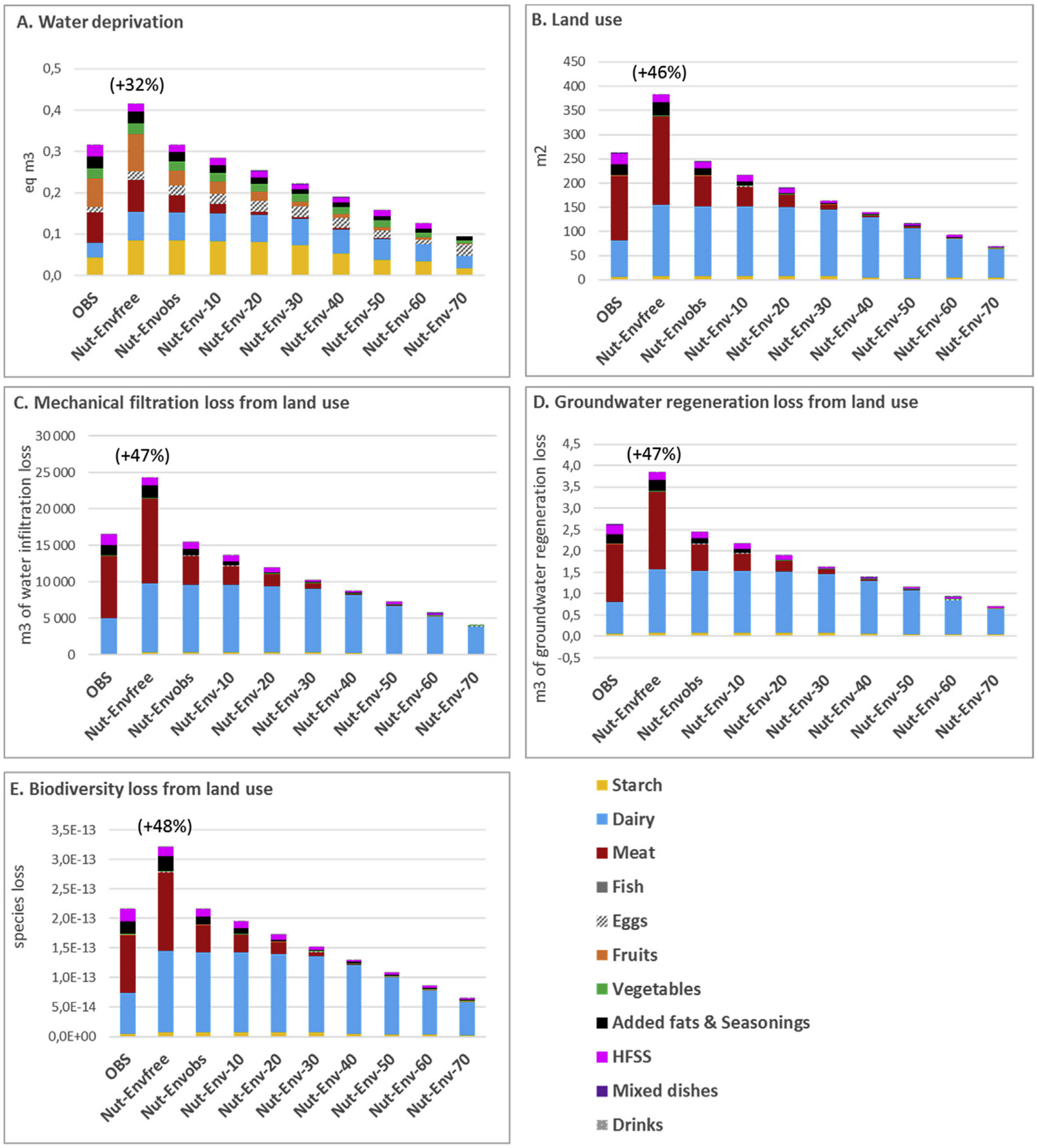

Fig. 2. Food group contributions to water deprivation (A), land use (B), land use impacts on mechanical filtration (C), groundwater regeneration (D), and biodiversity (E) in the observed and optimized diets [1].

[1] Percentages between brackets show the increase of the Nut-Env$_{free}$ diet impact (vs. impact of the observed diet). HFSS: foods high in fat/salt/sugar; OBS: observed diet; Nut-Env$_{free}$: model without environmental constraints; Nut-Env$_{obs}$: model with constraints limiting the environmental metrics to the observed level; Nut-Env$_{-10}$, Nut-Env$_{-20}$, …etc: models with constraints imposing a 10% decrease of the environmental indicators at each step.

analyses focused on the five environmental metrics that showed a detrimental impact of the diet on the environment.

3.2. Dietary changes needed to reach nutritional adequacy and consequences on the diet environmental impact (Nut-Env$_{free}$ vs. OBS diets)

Compared with the OBS diet, dairy (+98%), fruit (+13%), vegetables (+23%), and starch (+33%) quantities were increased, and HFSS (−58%), and added fat & seasoning (−21%) were reduced in the Nut-Env$_{free}$ diet (Fig. 1A). The total MFE quantity did not change between OBS and Nut-Env$_{free}$ diets, but intra-group substitutions occurred (Fig. 1B): the quantity of eggs (+49%), red meat (+47%), fish/seafood (+15%) and offal (+13%) increased, while poultry decreased (−72%).

All five environmental metrics that showed a detrimental impact increased in the Nut-Env$_{free}$ diet compared with the OBS diet (Fig. 2): water deprivation (+32%), land use (+46%), biodiversity loss (+48%), groundwater regeneration loss (+47%), and mechanical filtration (+47%).

3.3. Dietary changes needed to reduce the diet environmental impact and reach nutritional adequacy (Nut-Env$_{free}$ vs Nut-Env$_{-10}$, …diets)

At the food group level, reducing by up to 30% each of the environmental metrics (Nut-Env$_{-10}$, Nut-Env$_{-20}$, and Nut-Env$_{-30}$ models) did not require any additional change in food group quantities than those present in the Nut-Env$_{free}$ diet, except for a progressive decrease in MFE quantities (Fig. 1A, "moderate impact reductions" section). Conversely, for reducing the environmental impact by more than 40% (Nut-Env$_{-40}$ to Nut-Env$_{-70}$ models), major changes in food group quantities were needed (Fig. 1A, "strong impact reductions" section): higher vegetable and fruit quantities, and progressive reduction of the amount of starch and dairy. Thereafter, "moderate impact reductions" and "strong impact reductions" will be used to define environmental impact reductions up to 30% and equal/higher than 40%, respectively.

At the food subgroup level, the changes within the MFE group were different from those induced by the Nut-Env$_{free}$ model when the environmental impact constraints were imposed (Fig. 1B). Specifically, red meat quantity was increased in the Nut-Env$_{free}$ diet (+47% vs. OBS diet), whereas it was reduced by 50% in the Nut-Env$_{obs}$ diet (vs. OBS diet) and even more for moderate impact reductions. For stronger impact reductions, red meat was nearly (impact reductions of 40%) or totally suppressed (impact reductions ≥50%). Egg quantity increased for moderate impact reductions (≤30%), whereas it progressively decreased for stronger reductions (≥40%).

In terms of dietary energy content (Fig. 1C), moderate impact reductions (≤30%) required a decrease of meat contribution to the total energy that was compensated by a progressive increase of the egg and starch contributions. For strong impact reductions (≥40%), the energy contributions of dairy products and egg decreased, and were balanced by higher contributions of fruits and starch.

The greatest achievable environmental impact reduction while respecting all nutritional recommendations was 70%. For 80% reduction, there was no feasible solution (i.e., no combination of foods) to fulfill the whole set of nutritional and realism constraints. The constraints on vitamin D and calcium made not feasible the diet optimization associated with 80% reduction of the environmental impact. Although mathematically possible, reaching nutritional adequacy while reducing by 70% the environmental impact required an extreme shift from the OBS diet (Fig. 1), particularly very high intakes of fruits and vegetables (almost 1.1 kg/day). Considering that vitamin D can primarily be obtained from sun exposure, sensitivity analyses were performed with the constraint that vitamin D level should not be reduced relative to the level in the OBS diet (~3 µg/day), instead of imposing to fulfill the recommendation of 5 µg/day (data not shown). With this new constraint, changes in food group quantities were very similar, except for the model with the highest environmental impact reduction (Nut-Env$_{-70}$). In the Nut-Env$_{-70}$ diet with the new constraint on vitamin D, the quantity of eggs (an important contributor to vitamin D content) did not increase, unlike in the Nut-Env$_{-70}$ model with the vitamin D > 5 µg/d constraint (Fig. 1B), while that of vegetables increased to compensate for the egg contribution to vitamin A.

3.4. Changes in animal-based product contributions

Reaching nutritional adequacy (Nut-Env$_{free}$) induced an increase of the animal-based product contribution to the total energy (from 15.4% in the OBS diet to 18.5% in the Nut-Env$_{free}$ diet) (Fig. 3A). The share of proteins from animal origin was 42% in the OBS diet and 40% in the Nut-Env$_{free}$ diet (Fig. 3B).

When moderate environmental impact reductions (≤30%) were added to the nutritional constraints, the total contribution of animal products to the dietary energy (approximately 1/6 of the total energy) remained similar, but the fraction of animal proteins was lower (approximately one third of the total protein content), compared with the OBS diet. For stronger environmental impact reductions (> 40%), the total contribution of animal products to dietary energy and protein content progressively decreased.

Beyond the total contribution, the contribution of each animal-based product changed. For moderate environmental impact reductions (≤30%), the contribution of the dairy and egg subgroups to the total energy and protein content increased, while that of red meat and poultry decreased compared with the OBS diet. For stronger reductions (> 40%), the meat contribution was < 0.5% and the dairy group contribution progressively decreased.

4. Discussion

Based on individual dietary data from a national survey, the present study i) estimated the environmental impact (water deprivation, land use, land use potential impacts on biodiversity, erosion resistance, mechanical filtration, groundwater replenishment, and biotic production) of the average diet consumed by the adult Tunisian population, and ii) identified the main dietary shifts required to meet the nutritional recommendations, and concomitantly reduce the environmental impact and minimize the departure from the observed average diet for respecting eating habits and cultural acceptability.

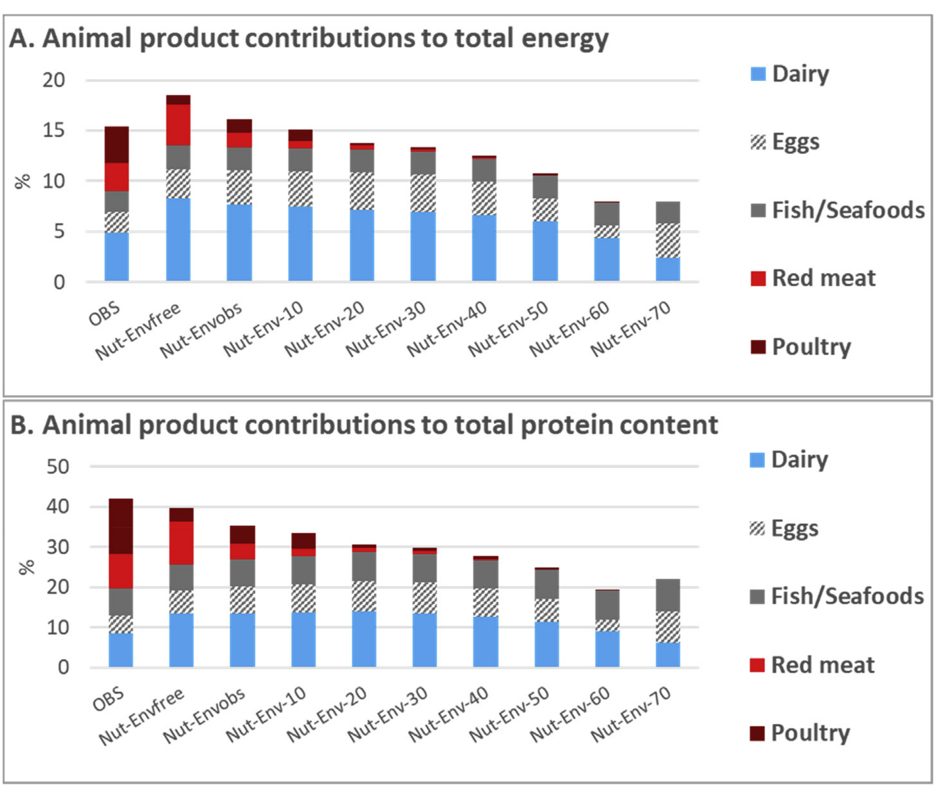

Fig. 3. Animal-based product contributions to total energy (A), and total protein content (B) in the observed and optimized diets.
OBS: observed diet; Nut-Env$_{free}$: model without environmental constraints; Nut-Env$_{obs}$: model with constraints limiting the environmental metrics to the observed level; Nut-Env$_{-10}$, Nut-Env$_{-20}$, …etc: models with constraints imposing a 10% decrease of the environmental indicators at each step.

We estimated the water deprivation impact of the average Tunisian diet to 316 L eq/person per day. This value is twice higher than the 160 L/person per day estimated for the current UK food consumption (Hess et al., 2015). We did not find any literature data to compare the biodiversity impact due to land use. Our study revealed that the soil impact related to land occupation was beneficial, for two of the four indicators. This highlights the complexity of land use impact on the environment, especially in semi-arid regions, such as the south of Tunisia. Indeed, land-saving measures are needed to reduce biodiversity loss and protect ecosystem services (Foley et al., 2011). On the other hand, developing farming in semi-arid areas could be beneficial in terms of biomass production and resistance to erosion, if livestock management is adequate. However, the land use impact estimations should be interpreted with caution because they are computed from annual and country-level averages that do not take into account local specificities.

We showed that fulfilling the WHO nutritional recommendations induced an increase of the diet environmental impact: by approximately 30% for water deprivation and by nearly 50% for indicators of land use impact, particularly biodiversity loss. A previous study reported that the dietary scenario designed to conform with the "Eatwell plate" guidelines led to a modest change in the water-scarcity footprint of UK food consumption (−3%), with a large impact variability depending on the production countries (from −18% for the impact in Belgium to +30% for the impact in Pakistan) (Hess et al., 2015). Our results are consistent with the study by Tom et al. (2015) who found that the blue water footprint increased by 16% when shifting from the current US diet to a healthier diet. The increased environmental impacts found in our study were primarily driven by the increase in dairy products (for water footprint and land use) and starch and fruits (for water footprint). This diet change was probably driven by the low intake of calcium, vitamin D and magnesium in the mean observed diet. Our results highlight the challenge of developing more sustainable diets, with trade-offs between health and environmental goals. Similarly, previous studies observed that healthier diets were associated with higher GHGE (Biesbroek et al., 2017; Perignon et al., 2016; Vieux et al., 2018). However, our diet optimization study also showed that some dietary shifts (increasing the amount of vegetables, dairy and starch products, decreasing HFSS and fats, and reducing meat in favor of fish and eggs) could reconcile nutritional adequacy and a lower environmental impact, while minimizing the departure from the average Tunisian diet. For a 30% reduction of the environmental impact, the magnitude of dietary changes was similar to that required to reach nutritional adequacy alone. However, for higher environmental impact reductions (≥40%), more substantial dietary shifts are required that might compromise the cultural acceptability of such optimized diets.

Reaching nutritional adequacy induced an increase of animal-based products (from approximately 1/6 of the total energy in the observed diet to 1/5 in the optimized diets). When environmental impact reductions were imposed in addition to the nutritional adequacy goal, their energy contribution was decreased to similar levels as in the mean observed diet, but a redistribution within animal-based products occurred with a reduction of meat contribution in favor of dairy products, fish and eggs. Therefore, although reducing the consumption of animal products is often suggested as a key strategy to lessen the environmental impact of diet (Ridoutt et al., 2017), recommendations targeting total animal products may not be appropriate in some Mediterranean countries where the current intake of animal-based products can be, in some contexts, already low. Our optimization study showed that in Tunisia, moving towards a more sustainable diet relied more on redistributing the sources of animal-based products (increase in dairy, fish and eggs vs. reduction of meat products) rather than on reducing their total contribution. Our results underline the importance of context-specific recommendations and confirm that the regional realities need to be carefully considered when examining the role of animal-source foods in achieving more sustainable diets (Willett et al., 2019).

The first strength of our study is the assessment of the diet environmental impact based on several water and land use indicators, and estimated using a life cycle approach that considers the impacts in the food-producing countries. By taking into account international trade and weighing water use with Water Stress Index factors and land use with country-specific characterization factors, the present study assessed sustainability concerns on a global scale. Moreover, our study is based on dietary data from a national survey using a specific and validated food frequency questionnaire, and a Tunisian food composition table. Moreover, our study took into account simultaneously several dimensions of diet sustainability (nutrition, environment, and cultural acceptability) using diet optimization. Accordingly, our study identified not only the dietary shifts required to reach a healthy diet that fulfils a whole set of nutritional recommendations, but also the shifts needed to move towards a healthy diet with a lower environmental impact. Furthermore, by minimizing the changes from the observed diet, the optimized diets were more realistic and potentially culturally acceptable (Gazan et al., 2018).

The present study has some limitations. It could be improved by taking into account the bioavailability of key nutrients, such as iron and zinc, that is influenced by the presence of absorption enhancers and inhibitors in the diet (Barré et al., 2018). Moreover, fish consumption has important effects on biodiversity that are not taken into account in this study due to the lack of data. The studied population (35–70 years) did not include younger adults and this can also be seen as a limitation. In addition, using an individual diet optimization approach (rather than optimizing the population diet as done in the present study) would better integrate individual food preferences and eating habits (Gazan et al., 2018). Moreover, although several sustainability dimensions were taken into account, this study could be improved by integrating the diet cost in the models. Finally, although minimizing the departure from the observed diet and introducing realism constraints allowed avoiding extremely theoretical diets, such method cannot guarantee that the resulting dietary shifts would be acceptable to the consumer.

5. Conclusion

This diet optimization study showed that designing a nutritionally adequate diet without considering its environmental impact might increase diet-related land use, water deprivation, and land use impacts on biodiversity and soil quality. However, nutritional adequacy and moderate reductions of the environmental impacts (−30%) might be achieved through dietary shifts different in type but of similar magnitude than those required to meet the nutritional recommendations alone. In Tunisia, moving towards healthy diets with lower environmental impact relied more on redistributing the sources of animal-based products rather than on reducing their total contribution (less meat in favor of dairy, egg and fish products), together with an increase of vegetables and a decrease of fat and sweet products. The dietary changes identified in this study can be translated into action proposals to target food consumption and production in order to promote more sustainable diets in the Mediterranean region. The implementation of actions to favor the adoption of the identified dietary changes by consumers should be investigated.

Declarations of interest

None.

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Appendix A. Supplementary data

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Similarity and Competition in the Agri-Food Trade among European Mediterranean Countries

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ABSTRACT
Using Eurostat and OECD data on agri-food exports, this article provides a picture of the evolution in the similarity between Italian and other European Mediterranean countries' exports, before and after the recent financial crisis. Considering different indexes, the similarity is somewhat moderate and does not vary noticeably among the indexes when considering the EU-25 market. By contrast, a strong qualitative dissimilarity is recorded in the North American market. Overall, France and Spain appear more similar to Italy and likely to compete in the same agri-food market segments. The crisis seems associated to a slight modification of the exports structure.

KEYWORDS
Agri-food sector; export structure similarity; international competitiveness

I. Introduction

As specified by the European Commission, competitiveness is important in the European agri-food market. In the last decades, the Central and Eastern European countries' (CEECs) accession to the EU and the global economic crisis of 2008 have affected the competitiveness of the agriculture and food industry in several EU member states. The enlargement of the EU has modified trade and product demand (Bojnec and Fertő 2015; Qineti, Rajcaniova, and Matejkova 2009; Torok and Jambor 2013; Zaghini 2005). Furthermore, the global economic crisis of 2008 has shaped trends in the agriculture and food industry (European Commission 2009).

Besides, other factors such as globalization, changes in consumer preferences for health, and environmental concerns are affecting the level of the EU competitiveness (Harling 2008; Wubben and Isakhanyan 2013).

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In the Mediterranean area, the agriculture and food sector plays a key role, and the importance of France, Italy, and Spain is significant in the agri-food trade. The share of world agri-food trade of these economies is important; the weight of Spain was 4.4% in 2016, Italy accounted for 3.0%, and France 3.4%, while the other EU members play a minor role.

Countries exporting "similar" products towards the same market may be considered as competitors (De Benedictis and Tajoli 2007a, 2007b). Trade similarity indicators are commonly employed as analytical instruments for assessing the competitiveness of groups of exporters towards a specific market. In general, the analysis of similarities aims at evaluating changes in trade similarity between countries as a result of exogenous shocks, such as the entry of new competitors into a market or political and financial upheavals (Antimiani et al. 2012; Antimiani and Henke 2007; Pomfret 1981).

The main purpose of this article is to provide a picture of the evolution in the similarity of Italian exports compared to other European Mediterranean countries' exports (France, Greece, Spain, and Portugal) before and after the most recent financial crisis towards two reference markets (EU-25 and North America). We focus on Italy because it is one of the biggest food producers and exporters in the EU. With a turnover of around 190 billion euros, the agri-food sector represents the second largest production sector in Italy (ISTAT (Istituto Nazionale di Statistica) 2014). The most exported agri-food products are wines, cheeses, oil, pasta, confectionery products, and cured meats, which represent the "core" of the "made in Italy" and "Italian Sounding."

Furthermore, we are interested in the North American market as this topic is becoming relevant with the new wave of EU trade agreements.

The EU countries under scrutiny are similar in terms of natural factors (land and climate), agri-food productions, and production technologies. Furthermore, they share a common currency and trade policy. Thus, any dissimilarity in exports between Italy and its major competitors may be ascribed to factors such as product quality or greater weight of the production process into the global value chain. Three indexes are computed: the export structure similarity index (ES), the product similarity index (PSI), and the quality similarity index (QSI), which take into account different aspects of the similarity of the agri-food export structure. Such indices have been calculated both on "gross" exports and on exports in terms of value-added. The latter ones allow a more meaningful picture of the competitiveness and export capacity of an economy and its integration into the global value chain. Indeed, traditional trade statistics, recording gross flows of goods and services every time they cross a border, get into the so-called problem of "double counting or multiple counting" (Johnson 2014).

To emphasize the importance of the production process – which could increase the diversification of products and, therefore, strongly affect competitiveness in international trade – the present article takes into account the similarity as well as the quality of exports considering export flows in value added.

Moreover, focusing on the main products exported by Italy to North America (USA and Canada) and the EU market, we verify whether the quality factor may ensure the competitiveness of agri-food exports, since apparently similar but qualitatively different products could belong to heterogeneous market segments.

Evaluating the exports performance over the periods of 2005/2006, 2008/2009, and 2011/2012, the analysis considers the years straddling the most recent global economic crisis. The agri-food sector has not received sufficient consideration from the economic literature dealing with the effects of the crisis, whereas the mobilization and comparison of the similarity index in export structure, product and quality based on trade flows data, and value added may provide some insight on the impact of the financial crises on agri-food trade. Therefore, we try to answer the following question: Did the competitiveness of Italian agri-food exports to the EU and North America change after the crisis?

According to our main findings, the similarity between Italian agri-food exports and the group of Euro-Mediterranean countries varies depending on the targeted market and the agro-food sub-sector. However, considering the European market, the level of similarity is quite moderate and the values of the three indexes are not dramatically different, with France and Spain presenting the higher values. Moreover, these countries, in the North American market, confirm their greater similarity with Italy with extremely high index values. This high similarity is not confirmed, yet, from a qualitative point of view, as the QSI values tend to zero overall. Finally, as expected, considering exports in value added, France and Spain are still the countries more similar to Italy.

Yet, results show that the economic crisis is associated with a slight modification of the exports structure and the country's competitiveness in the last period we consider. The degree of similarity in terms of product between Italy and the European Mediterranean countries increased in the first two periods of our analysis 2005/2006 and 2008/2009, but fell in several cases thereafter. However, an increase in the PSI does not always correspond to a decrease in the quality indicator. At the sectoral level, differences are more marked. The structure of the exports is slightly modified: the similarity in terms of product decreases but rises in goods whose features can be qualitatively equal in the EU market; the opposite is recorded in the North American market. This result is interesting if we consider that Italy has the highest number of agri-food products certified by the EU. On the 31 January 2015, the Italian RDOs and GIs products registered were 278 out of a total of 1,311 (21.1% of the total); thus, the quality factor may play a key role in determining competition among countries.

The article is organized as follows: Section 2 presents a review of the literature. Section 3 describes the structure of agri-food exports of the Euro Mediterranean countries. Trade similarity indicators are described in Section 4. Section 5 reports data. Section 6 illustrates the evidence based on the indexes computation. Finally, Section 7 concludes.

II. Literature review

The application of similarity indicators

The application of similarity indicators is manifold. In general, the analysis of similarities aims at evaluating changes in trade similarity between countries as a result of exogenous shocks, such as the entry of new competitors into a market or political and financial upheavals. Giving an economic assessment of such events is also relevant for designing appropriate economic policies. Indeed, finding potential competing countries on a specific market may recommend policies to prevent negative economic consequences such as a reduction of export flows and, consequently, the loss of market share. Adopting the ES index, the seminal contribution of Finger and Kreinin (1979) analyzes the exports similarity between the USA, Japan, EEC (European Economic Community at six countries), and some countries of Eastern Europe in different reference markets. Their data concern manufactured goods for the years from 1960 to the mid-1970s. Their results showed an increase of the similarity between EEC and USA and EEC and Japan in the years analyzed.

Analogously, using OECD data on agri-food trade, Pomfret (1981) applies the ES index to assess the similarity between Spain, Greece, and Portugal and several countries from North Africa and East Asia. According to the results obtained, Greece and Spain showed high similarity indices, particularly in commercial structures related to primary products.

A fundamental limitation of both works is the failure to account for differences in the quality of products, which is a crucial element in the competition between countries. To face this limitation, the PSI and QSI have been included in this type of analysis, for instance, De Nardis and Traù (1999) investigate the similarity of Italian exports in the manufacturing sector relative to a large group of countries (such as G7 countries, Brazil, and some Asian countries). Looking at the results, Italy appears closer to developed countries than to developing countries in terms of exported products. Moreover, considering the quality attribute of exports, the similarity was even lower.

Antimiani and Henke (2007) analyze the similarity of the EU-15 members' exports with those of some emerging partners: the EU New Member States (NMS), Turkey and China, onto the EU-15 market. Using Eurostat data on agri-food products at the 8-digit level of the combined nomenclature, they compute three indicators (ES, PSI, QSI) for two distinct periods (1996/1997 and 2003/2004). The results show that Italian exports are more similar to those of the countries of Eastern Europe than those of Turkey and China; however, the QSI confirms that the Italian products differ greatly from a qualitative perspective. Analogously, they investigate the opportunities and risks implied by the integration of China in the world food markets. According to their results, the similarity between European countries and China is low and decreases considerably when considering the QSI (Antimiani and Henke 2006). In this regard, Zheng and Qi (2007) empirically analyze the structure of agricultural trade between China and the United States. Their findings show that trade between them was more complementary than competitive.

Furthermore, Antimiani et al. (2012) explore the impact of the EU enlargement process on the agro-food market, with a focus on product quality over two specific periods, 1996/1997 and 2006/2007. The values of the QSI show that the qualitative factors were explaining a third of the similarities of both commercial structures in the 2006/2007 period, but only 25% in 1996/1997.

Further analysis on the degree of competition in the agricultural sector between the EU-15 countries and the eight CEECs new entrants in 2004, over the period 1995 to 2005, is carried out by Duboz and Le Gallo (2011). Computing the ES index from 1999, a growing similarity emerges; more specifically, the countries that appear potentially more affected by the integration of the CEECs are Germany and Austria – likely for the geographical proximity – and France – possibly because of climatic similarity.

The role of quality: quality and unit value in empirical models

The discussion about the role of quality in the agri-food sector is very present in the international trade literature, which provides new approaches to evaluate and estimate quality from trade data. The works of Fontagné, Gaulier, and Zignago (2008), Crespo and Simoes (2012), and Harding and Javorcik (2009) assess the quality of exports using the unit value as a proxy. Kaitila (2010) evaluates the EU-27 countries' export structures defining a quality-adjusted similarity indicator based on unit value. Moreira, Simoes, and Crespo (2017) represent trade competition as a function of the degree of both structural similarity and total exports overlap. Structural similarity is disentangled in three dimensions: sectoral shares similarity, inter-sectoral similarity, and intra-sectoral similarity defined as the proximity in terms of quality varieties exported using unit values. Furthermore, Di Comite et al. (2011) study the relative quality of Chinese versus European products exported in the clothing sector after the end of the Multi-Fiber Arrangement, finding that European varieties exported to the US are typically sold at a higher price than identical Chinese varieties exported to the US, but this price gap is limited.

Since quality is unobservable, the previous literature is based on the idea of considering higher unit values – nominal values divided by physical volumes – as a proxy of higher quality. This approach is based on strong assumptions as differences in unit values between products might be ascribed to dissimilarities on manufacturing costs and factor prices (Khandelwal 2010).

In this regard, to estimate the quality of the products exported to the US, Khandelwal (2010) relaxes these assumptions by taking advantage of price and quantity information.[1] The idea is that the higher quality of a product is attributed to those with a higher market share, conditional on price.[2] The quality measures are derived from a nested logit demand system (Berry 1994) including preferences in both horizontal and vertical terms. The vertical component of the model is the quality that indicates how consumers evaluate, on average, the imported products. In particular, it captures three aspects: the time-invariant valuation that the consumer attaches to a certain imported variety, the secular time trends common across all varieties, and a variety-time specific deviation. Hence, the quality of an imported product is defined as the sum of these estimated parameters.[3]

Consistent with Schott (2004), who uses unit values as a proxy for quality, he shows that developed countries export higher quality products relative to developing countries.

Similarly, Hallak and Schott (2011), using information contained in trade balances, develop a way for decomposing countries' observed export prices into quality versus quality-adjusted components.

Basically, they assume that consumers, in choosing amid products, pay attention to price: consequently, two countries with the same export prices, but unlikely to have the same global trade balances, must have products with dissimilarities in terms of quality. Likewise, among countries with equal export prices, the country with the higher trade balance has a higher product quality. The measure of a country's product quality with respect to another country is determined by looking at data on their observed export price and including details about the demand for their products; the latter are incorporated in the trade balance with the rest of the world. However, the main issue in defining the consumer demand is that the most stable time-series data on countries' trade balances are documented according to comparatively coarse industries rather than disaggregated products.

To circumnavigate this problem, Hallak and Schott (2011) derive an "Impure Price Index" (IPI) based on prices that are implicitly related to quality. This index aggregates countries' observed product-level export prices up to the industry level. In addition, it is separable into quality versus quality-adjusted-

[1]The author uses US product-level import data from 1989 to 2001 (Feenstra, Romalis, and Schott 2002).

[2]The procedure requires no special data over those available in standard disaggregate trade data. The implementation consists in estimating separate demand curves for hundreds of manufacturing industries.

[3]See Khandelwal (2010) for a detailed review of this approach.

price components, albeit the assumption that countries' quality is constant across products within industries is required. This methodology produces estimates of quality that vary by country, industry, and year.

Hummels and Klenow (2005) use import prices and quantities to infer the cross-sectional elasticity of quality with respect to country income and size. Notwithstanding, it does not allow explicit estimation of product quality by country, sector, and year.

Furthermore, Khandelwal, Schott, and Wei (2013) define the "quality adjusted price" based on the idea that a product variety with a higher quantity is linked with higher quality, conditional on price. Quality is assumed as any attribute that increases consumer demand more than prices, and it is possible to estimate it indirectly through observed prices and demands specified with an explicit functional form. They assume that quality is incorporated in the consumer preferences, and the "effective quality" of an exported product *h* shipped to destination country *c* by firm *f* in year *t* is derived by dividing the residual of the estimated demand equation for a given firm *f*'s export of a product *h* in a destination country *c* in year *t* by the country-industry specific elasticity of substitution minus one. Then, the quality adjusted prices are obtained by subtracting the estimated effective quality from the observed prices.[4]

Curzi, Raimondi, and Olper (2014) evaluate the extent to which the reduction of import tariffs as a measure of import competition affects the quality upgrading of the food products exported to the European Union. Product quality is measured using the approach of Khandelwal (2010); furthermore, robustness checks on the main finding has been computed inferring the quality via the methodology of Khandelwal, Schott, and Wei (2013) and the classical approach of unit value. These checks confirm the main results even if with the latter method magnitudes effects are smaller in absolute terms than the baseline specification. Feenstra and Romalis (2014), in estimating quality and quality-adjusted price indexes, show, on the export side, that much of the variation in unit values is explained by quality; hence, quality adjusted prices vary much less than the raw unit values or than the quality-adjusted estimates of Hallak and Schott (2011) and Khandelwal (2010).

III. The structure of agri-food trade of Italy and the other Mediterranean countries

As can be seen from Figures 1 and 2, the amount of agri-food exports of Italy and the other Mediterranean countries are remarkably different, but it is possible to identify a certain homogeneity between countries regarding the main products exported (Tables A1 and A2 in the Appendix).[5]

[4]See Khandelwal, Schott, and Wei (2013) for detailed review of this approach.

[5]The appendix can be found online at www.tandfonline.com/uitj.

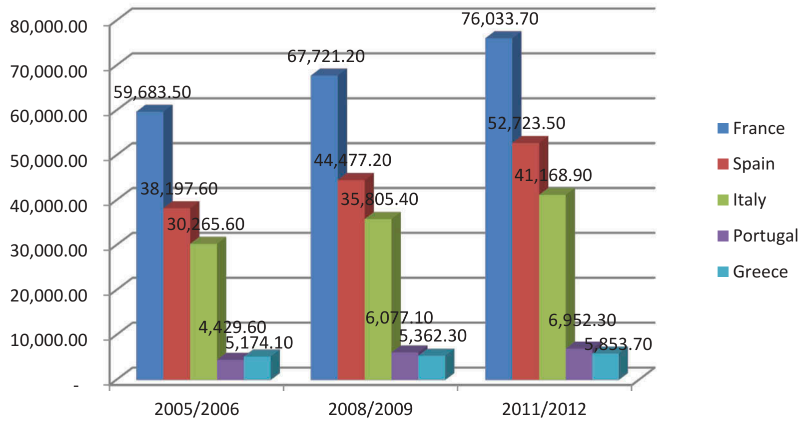

Figure 1. Agri-food exports to EU-25 (million euros). Own elaboration on EUROSTAT COMEXT data.

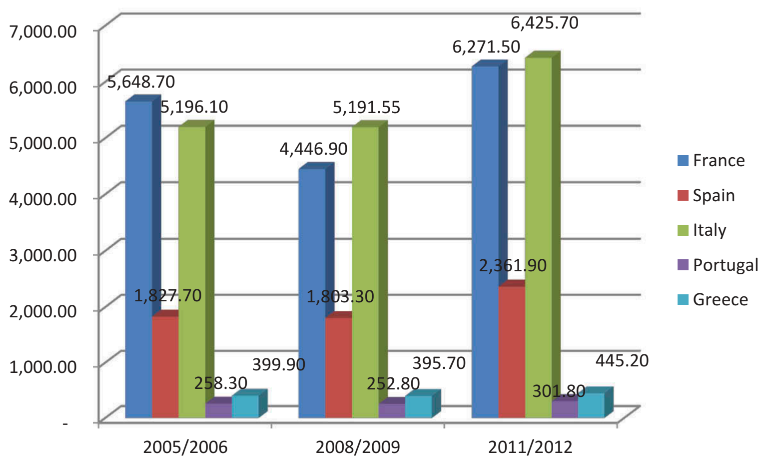

Figure 2. Agri-food exports to North America (million euros). Own elaboration on EUROSTAT COMEXT data.

EU-25 market

The European market is the major destination market for the agri-food exports of the five countries under scrutiny. As Figure 1 shows, France is the largest exporter, followed by Spain and Italy. In general, during the period analyzed, exports toward the EU-25 market have steadily grown. In particular, Italy registers a 36% increase of its intra-EU trade.

Table A1 in the Appendix reports the composition of the exports. We can observe a broad similarity between the countries of our sample. The main products exported from Italy to Europe are *beverages* (22-HS),[6] which represent

[6]HS (Harmonized System) is an abbreviated expression for the Harmonized Commodity Description and Coding System developed and managed by the World Customs Organization (WCO), used by 141 countries as a basis for the determination of tariffs and for the collection of statistics on international trade in commodities. EU members use the 'Combined Nomenclature', which extends the HS up to 10,000 clusters goods, classified with 8-digit

around 16% of total agri-food exports; followed by *fruits and nuts* (08-HS); *preparation of cereals* (19-HS); *preparation of fruits and vegetables* (20-HS); *meat* (02-HS); and *dairy products* (04-HS). The exports share of these products account on average for 64% of total Italian food exports towards EU-25, confirming the leadership of the Italian agro-food. The export trends remain rather stable over time, except for fruits and nuts characterized by a constant decrease during the years under consideration.

Considering France, the main products exported to Europe are *beverages*, representing around 17% of total agri-food exports; followed by *dairy products* and *cereals*, which show a constant increase during these years; and finally, with lower weights *meats, preparation of cereals, sugar*, and *sugar confectionaries*. All these products make on average about 57% of total French agri-food exports; moreover, the exports trend appears stable over the years considered.

The Spanish exports composition instead is more concentrated; the first two products exported are *fruits and nuts* and *edible vegetables* accounting for, respectively, 21% and 16% of its total exports to Europe. The other main products are *meats* with a steady rising trend; *beverages, animal or vegetable fats and oils*, and *fish*. These six products represent on average about 70% of Spanish agri-food exports to EU-25.

The Greece situation is more unsteady. Indeed, *animal or vegetable fats and oils* and *fruits and nuts* decreased from 17.4% in 2005/2006 to 9.80% in 2011/2012 and from 15.75% to 12.8%, respectively. Conversely, *preparation of fruits and vegetables, fish*, and *tobacco* record an important increase during the same period.

Finally, the main products exported by Portugal are *beverages* showing, a noteworthy fall from 20.7% in 2005/2006 to 15% in 2011/2012. The other important products are *fish*, which account for 13% of total agri-food exports; *tobacco; dairy products*; and lastly, with lower weights, *fruits and nuts* and *preparation of fruits and vegetables*. Although exports show a decreasing trend in the analyzed period, the percentage of total agri-food exports remain important, about 70% on average.

North American market

As shown in Figure 2, agri-food exports towards North America are smaller than the corresponding exports towards EU-25.

codes (CN8). The 24 chapters of the agri-food trade are: (01) live animals, (02) meat, (03) fish, (04) dairy products, (05) products of animal origin, (06) trees and other plants, (07) edible vegetables, (08) fruits and nuts, (09) coffee and tea, (10) cereals, (11) products of the milling industry, (12) oil seeds/grains/plants/straw, (13) lac/gums/resins, (14) vegetable plaiting materials, (15) animal or vegetable fats and oils, (16) preparation of meat and fish, (17) sugar and sugar confectionaries, (18) cocoa and cocoa preparation, (19) preparation of cereals, (20) preparation of fruits and vegetables, (21) miscellaneous edible preparations, (22) beverages, (23) residues from food industries, and (24) tobacco.

Over the years, the five countries show an export reduction in 2008/2009 and a significant recovery in the next period. France and Italy are the leading exporters, followed by Spain, Greece, and Portugal, which display relatively lower amounts of agri-food exports. Table A2 in the Appendix shows that the exports composition of these countries is very similar, being concentrated on certain products.

The main products exported by Italy to North America are *beverages*, which represent on average about half of total agri-food exports; followed by *animal or vegetable fats and oils*, which show a negative trend; *preparation of cereals; dairy products; preparation of fruits and vegetables;* and *miscellaneous edible preparations*. These products account on average for 90% of all Italian agri-food exports.

Beverages represent the main products exported by France, accounting on average for 80% of its total exports. The other main exported products are: *dairy products; miscellaneous edible preparations, cocoa and cocoa preparation; lac/gum/resins*; and *preparation of cereals*; the latter accounting for a small share of total exports. Overall, they represent on average 93% of French agri-food exports.

The Spanish exports composition is less concentrated if compared to the other counties. The main exported products are *preparation of fruits and vegetables* and *beverages*, which represent on average 50% of total Spanish agri-food exports. *Animal or vegetable fats and oils* account on average for around 15%. Furthermore, *fruits and nuts, lac/gum/resins,* and *dairy products* represent a small share of agri-food exports.

Preparation of fruits and vegetables are the main products exported from Greece to North America with an increase of exports' share from 40% in 2005/2006 to 50% in 2011/2012. Other products are: *animal or vegetable fats and oils, beverages*, and *fish*, which show a drastic rise in exports' share over the years. By contrast, *tobacco* and *dairy products* present a negative trend.

Portuguese exports are composed mainly of *beverages*, which represent around 60% of total agri-food exports; other main products exported are *animal or vegetables fats and oils, products of animal origin* that show a fall in the export size; conversely, *preparation of fruits and vegetables, fish*, and *preparation of fish and meat* display a positive trend.

Exports in value added

Looking at the agri-food exports in terms of value added (Table 1), analogously to the pattern depicted in Figures 1 and 2, we can observe a general increasing trend, the absolute values of flows remaining quite different across the sample countries.

Considering the export flows in value added to the EU-25 market, France is still the leader, followed by Spain, Italy, Greece, and Portugal. Moreover, in

Table 1. Exports in value added to EU-25 and North America (million dollars).

	EU-25			North America		
	2005	2008	2011	2005	2008	2011
Italy	10,884.55	15,163.53	16,412.92	2,098.46	2,693.18	2,634.06
France	20,477.94	28,590.14	26,688.10	2,228.60	2,912.10	2,540.50
Greece	2,675.05	2,966.00	3,027.53	310.97	311.97	267.76
Portugal	1,840.10	3,108.67	3,108.18	130.1	176.56	175.03
Spain	15,511.80	21,064.96	22,281.96	904.86	1,079.58	1,033.13

Note: Elaborations on TiVA data (OECD.org).

2011, the value added exports towards EU-25 account for 37% of total agri-food exports for Greece, 32% for Portugal, 30% for Spain, 28% for Italy, and 25% for France.

On the other hand, the agri-food exports in terms of value added to North America appear significantly lower in comparison with those to the European market. The main exporting countries towards North America are Italy and France, followed by Spain, Portugal, and Greece. All countries record an increase in exports in 2008 and a subsequent decrease in the following period. In 2011, the exports in value added account for 43% of total agri-food exports for Greece, and 41% for Portugal; whereas lower values are recorded for Spain (31%), France, and Italy (both around 29%).

In what follows, we present a deeper analysis of agri-food exports from the five Euro-Mediterranean countries in terms of similarity by using three indexes: the export similarity index (ES), the product similarity index (PSI), and the quality similarity index (QSI).

IV. Trade similarity indicators

The Finger-Kreinin index (ES)

The Finger-Kreinin index is used to measure the export similarity between countries (or group of countries) considering a third destination market. In other words, it compares the relative size of the export flows of both countries toward a specific target market allowing an evaluation of the competition between agri-food exports towards a specific market. The higher the similarity, the stronger the competition between countries in terms of exported goods. In the literature, this indicator is also defined as an export similarity index (ES). An advantage of this indicator, over other measures of similarity, is that it only requires international trade data, and these are available in a standardized way for all countries (Finger and Kreinin 1979).

The ES index is defined as follows:

$$ES_{ij,h} = \left\{ \sum_k \min\left(x^k_{i,h}, x^k_{j,h}\right) \right\} \cdot 100 \qquad (1)$$

where $x^k_{i,h}, x^k_{j,h}$ are, respectively, the shares of commodity (k) exported from country i to country h and from country j to country h.[7]

This index measures the difference in the export structure between two countries i and j, considering the country or market of destination h. If the commodity distribution of i's and j's exports are equivalent ($x^k_{i,h} = x^k_{j,h}$ for each k), the index will take a value of 100. If i's and j's export flows are completely dissimilar (for each $x^k_{(i,h)} > 0$, $x^k_{j,h} = 0$, and vice versa), the ES index will take a value of zero. Therefore, the index may range from a minimum of zero, indicating the absence of any overlap between exports of i and j to h, to 100, indicating, in this case, a perfect identity of the export flows composition between i and j in market h. However, there is no possibility of determining a threshold above which the export structures between the two countries could be defined as "similar"; typically, in the literature as a rule of thumb, a threshold value of 50 has been used.

Other criticisms toward this index concern the choice of the more appropriate level of aggregation to use. It has been demonstrated that an increase in the level of commodity disaggregation generates a trend towards reduction of the index value (Pomfret 1981). Furthermore, the ES index provides a measure of similarity in the export structures between two countries in a specific market considering the share of exports, but it does not give information on the absolute dimension of the export flows. Indeed, two countries, while having a similar export structure from a product prospective, may export remarkably different amounts in absolute value, such as not to determine an actual competition. To deal with this limitation, the analysis should be complemented with another indicator, the PSI which is used to refine the analysis in relation to the absolute values of export flows (Antimiani et al. 2012).

Product similarity index (PSI)

The PSI can be used to assess the real competitive pressure between countries (De Nardis and Traù 1999). This indicator measures the similarity, in a particular sector, between the absolute export dimensions of two economies (exports overlap) accounting also for the commodity flows structures. The PSI is defined by the formula:

$$PSI = \left\{ 1 - \left[\frac{\sum_k \left| X^k_{i,h} - X^k_{j,h} \right|}{\sum_k \left(X^k_{i,h} + X^k_{j,h} \right)} \right] \right\} \cdot 100 \tag{2}$$

[7]The shares have been computed considering as denominator the total value of exports from country *i* to *h* and from country *j* to *h*, respectively.

where $X_{(}i,h)^{k}$ and $X_{j,h}^{k}$ are, respectively, the export flows of commodity k for countries i and j *to* country h. The index varies between zero and 100; in the former case, the similarity of the products is null; in the latter case, the flows between the two countries are identical.

The limitation of such an index is that it might be inadequate to estimate the similarity of products; actually, goods *apparently* similar could be qualitatively different to the point that they do not belong to the same segment of the world demand. As a result, similar commodities may be directed to satisfy consumer groups with different types of preferences or tastes (Antimiani and Henke 2007; Bojnec and Fertő 2010; De Nardis and Traù 1999). Consequently, two apparently competing countries for a given market segment might not be competitors at all. For this reason, it is useful to define the QSI.

Quality similarity index (QSI)

In this work, we hinge on the empirical literature on intra-industry trade to select a methodology identifying qualitatively similar products; this involves splitting up the Grubel-Lloyd index into two components: the horizontal and vertical trade, based on average unit values of the goods concerned (Greenaway and Milner 1983; Grubel and Lloyd 1971).[8] This literature assumes two basic hypotheses: i) differences in prices for a given product internationally traded reflect qualitative differences; and ii) at a sufficient disaggregation level, average unit values indices are acceptable proxies of foreign trade prices.

According to the first hypothesis, the price of an item sold on the *world market* is a reliable indicator of quality, as higher prices should reflect products qualitatively more valuable and price is the main information on product qualities available to consumers. The second hypothesis establishes that average unit value differences do not constitute a distorted measure of differences in international prices. Considering that average unit values (ratio between value and quantity) are often distorted due to inappropriate aggregation by product segment, the difference in the unit value of the same product that the *world* buys from two different countries may reflect a difference in the composition of primary products within the aggregate or the geographical diversity of the markets' sources (De Nardis and Traù 1999). An appropriate price index calculation allows isolating the differences due to real prices from those due to the mix of products and partner

[8]Horizontal trade represents the exchange of differentiated products, while vertical trade is the exchange of shares of similar products but with different processing degrees. From an analytical point of view, the two kinds of trade are divided based on product average unit values. Namely, the products of the same SITC code, presenting the average unit values within a specific range, are considered qualitatively similar and are assigned to the horizontal trade; those which average unit values diverge of an amount greater than the selected amount are considered qualitatively different and, consequently, belong to the vertical trade (Abd-el-Rahman 1991).

countries; however, this can only be done correctly if the primary product, whose average unit value is used to derive subsequent aggregations of index numbers, does not contain additional effects of composition (Aw and Roberts 1988). However, most of the empirical work, aiming at distinguishing vertical from horizontal trade, analyzes trade data at a high level of disaggregation without removing the distortion in the computation of the average values for isolating "the price effect" properly from the composition effect so far described. Thus, the average unit values available are considered as proxies of prices.

Analytically, to build the QSI, the share of qualitatively similar goods is extrapolated within the PSI. In the QSI calculation, a first step is the choice of similar goods to be analyzed; the *k* commodities for which the average unit values (AUV) satisfy the following condition are regarded as similar, namely the *condition of similarity in average unit values*:

$$(1-a) < \left(\frac{AUV_k X_i}{AUV_k X_j}\right) < (1-a) \tag{3}$$

where $AUV_k X_i$ and $AUV_k X_j$ are the average unit values of the *k* product exported by country *i* and the competing country *j; a* is the dissipation factor of the average unit value in the product *k* on the international market; such a parameter can take values ranging from 0.15 to 0.25. The choice of a large range of dispersion reflects the need to minimize the risk of excluding from the QSI calculation goods that are qualitatively similar, but whose average unit values diverge for possible anomalies or composition effect residues. In detail, the indicator is defined as follows (Antimiani and Henke 2007):

$$QSI = \left\{1 - \left[\frac{\sum_k \left|X_{i,h}^{k,q} - X_{j,h}^{k,q}\right|}{\sum_k \left(X_{i,h}^{k,q} + X_{j,h}^{k,q}\right)}\right]\right\} \cdot \left[\frac{\sum_k \left(X_{i,h}^{k,q} + X_{i,h}^{k,q}\right)}{\sum_k \left(X_{i,h}^{k} + X_{j,h}^{k}\right)}\right] \cdot 100 \tag{4}$$

where $X_{i,h}^{k,q}$ and $X_(i,h)^(k,q)$ represent, respectively, the export of country *i* and country *j* of product *k* towards country *h*, restricted to products which respect the condition of similarity average unit values previously reported; while $X_(i,h)^k$ and $X_(j,h)^k$ are the exports of country *i* and country *j* of product *k* towards country *h*, respectively.[9]

The index varies between 0 and 100. A value of 100 means that the observed similarity index based on the PSI is an effective similarity of the quality of exported products; naturally, the opposite applies when QSI is

[9] In this formula, the second term in the equations represents the quota of qualitative similar products on overall flows of the sector. This weight was added to make the QSI index reflect the part of the PSI index value attributable to them, namely the part of the total index PSI which is effectively composed by qualitatively similar products.

zero.[10] Therefore, higher index values indicate that the qualitative similarity of the products exported increases; i.e., countries tend to export qualitatively similar products, and so they are competing with each other.

V. Data

The ES, PSI, and QSI are computed using data from the Eurostat database and concern agri-food exports (expressed in euros and quintals); they belong to the first 24 chapters of the HS classification. Export flows are considered at an "eight digit" merchandise disaggregation of the combined nomenclature.

The ES, PSI, and QSI are calculated comparing Italy (country *i*) to each other country *j* (France, Greece, Portugal, and Spain) for two reference markets: EU-25 and North America (hereafter, NAM). The time periods considered are 2005/2006, 2008/2009, and 2011/2012, and the analysis evaluates the similarity between each country pair for each class of goods.

The same analysis is carried out considering agri-food export flows in terms of value added, using data from the "Trade in Value Added" (TiVA) database, for the years: 2005, 2008, and 2011.[11] Exports are reported as "*domestic value added embodied in gross exports*" (EXGR_DVA), expressed in millions of US dollars and representing the added value generated by exports during the production processes, as well as any added value coming upstream from domestic suppliers that is embodied in exports.[12] Indeed, exports in today's global economy are based on the values of global production chains, using intermediate products imported from various industries in a number of distinct countries.[13] Goods and services acquired, in general, are composed of inputs from various countries around the world. However, the flows of goods and services within these global production chains are not always evaluated efficiently through the conventional measures of international trade (Koopman et al. 2010; Koopman, Wang, and Wei 2008, 2014). The TiVA approach circumvents the problem of "double counting" by detecting the net flow of trade between countries.

[10]The difference between the PSI and the weighted QSI is as well constituting a qualitative dissimilarity index (QDI) (De Nardis and Traù 1999).

[11]The 2015 edition of the TiVA database includes 61 countries: OECD, EU-28, G-20, most of the economies of Eastern and South-East Asia and a selection of South American countries. The years covered are 1995, 2000, 2005, and 2008 to 2011. It is worth mentioning that the TiVA database does not employ the HS classification. The relevant sectors from this database are C01T05: agriculture, forestry, hunting, and fishing, and C15T16: food products, beverages, and tobacco.

[12]For example, if China exports a microwave oven to the United States, the total export value of the microwave oven is considered as Chinese export and recorded as such in the trade account by national authorities; and from the United States perspective, the microwave oven is recorded as an import from China (and will probably require a tag "Made in China"). However, some of the inputs employed to produce the microwave oven might have been produced in and imported from different countries, for example, Thailand, Malaysia, or even the United States. The value of these intermediates has been recorded as Chinese imports from Malaysia, Thailand, or the United States, but not linked with the exportable final product (Javorsek and Camacho 2015).

[13]Case studies of global value chains in industries such as electronics, apparel, and motor vehicles have provided detailed examples on the discrepancy between gross and value-added trade. According to a commonly cited study, while the Chinese factory gate price of an assembled iPod is $144, only $4 constitutes Chinese value added (Dedrick, Kraemer, and Linden 2010).

VI. Results

The similarity of agri-food trade between Italy and other Mediterranean countries on the EU-25 market.

Looking at Table 2, according to the ES index, the most similar country to Italy is Spain, with an index of 36.09% in 2011/2012, slightly increasing compared to the first year of the sample.

The indicators concerning France and Portugal are somewhat lower, the Italy-France index tends to decrease, whilst the others tend to increase over the years. Finally, the most dissimilar country is Greece with an indicator equal to 25.55% in 2011/2012, slightly increasing over time.

Moving from ES to PSI, as expected, in general values tend to reduce; Spain still remains the most similar country in terms of products similarity with a PSI of 35.41% in the last year. An analogous pattern emerges for France, while the product similarity with Greece and Portugal drops noticeably.

Finally, looking at the QSI, the most similar country is France with an indicator equal to 15.90 in 2011/2012, even if it decreases by eight percentage points over the years. Spain follows with a QSI of 13.5 in 2011/2012, then come Greece and Portugal with much lower values.

Thus far, the analysis has been carried out considering the agri-food sector as a whole. We now compute the same indexes for the Italian products most exported: *beverages, fruits and nuts*, and *preparations of cereals* for the EU market; *beverages, animal and vegetable fats and oils*, and *preparations of cereals* for the North America destination.[14]

First considering the main products exported by Italy to the EU-25 (reported in Table 3), the similarity value decreases when moving from PSI to QSI.

Regarding *beverages* – the Italian products most exported – the most similar country is Spain, followed by France; the PSI in 2011/2012 being around 44% and 30%, respectively. Moreover, from a qualitative point of view, Italy is totally dissimilar to all four countries, indexes tending to zero in

Table 2. Similarity indexes between Italy and Mediterranean countries (EU-25 market, agri-food sector).

	ES			PSI			QSI		
	2005/06	2008/09	2011/12	2005/06	2008/09	2011/12	2005/06	2008/09	2011/12
ITA-FRA	32.57	33.21	31.5	31.93	32.48	30.92	23.76	14.9	15.9
ITA-GRE	24.77	25.38	25.55	16.43	12.84	12.72	10.99	8.15	7.39
ITA-POR	27.36	28.37	29.41	13.8	15.73	15.84	4.61	7.14	5.37
ITA-SPA	35.24	36.25	36.09	34.4	36.00	35.41	15.14	14.46	13.52

Note: When calculating QSI, the parameter *a*, the average unit value of dissipation factor for the product k, is equal to 0.25. Elaborations on NC 8-digit EUROSTAT data.

[14]Tables A3-A10 in the Appendix report the indexes for each agri-food sub-sector (identified by the 24 chapters of the HS classification).

Table 3. Three main subsectors exported by Italy vs EU and NAM (in millions of euros).

	2005/06	%	2008/09	%	2001/12	%
EU-Market						
Beverages	5,104.60	16.87%	5,780.00	16.14%	6,864.30	16.67%
Fruits and nuts	3,955.03	13.07%	4,342.30	12.13%	4,580.10	11.13%
Prep. of cereals	3,508.60	11.59%	4,434.95	12.39%	4,676.70	11.36%
NAM-Market						
Beverages	2,405.10	46.29%	2,474.50	47.66%	3,169.90	49.33%
Anim./Veg. fats and oils	1,102.30	21.21%	879.2	16.94%	971.3	15.12%
Preparation of cereals	527.5	10.15%	540.2	10.41%	657.1	10.23%

Note: Elaborations on EUROSTAT data.

all cases. These results show that, in this area, quality could be a discriminating factor affecting the level of competitiveness among countries. Divergences in the QSI may be ascribed to a different quality signal or different production processes or, again, differences in the characteristics of agri-food products. Consequently, products may be similar in essence, but different in quality. Concerning *fruits and nuts*, the Italy-France PSI is higher (about 50% on average over time); Portugal is the country most dissimilar, even if the PSI increases over the years. From a qualitative perspective, greater similarity as well is recorded with France (QSI is 34.40% in 2011/2012) and with Spain, for which the QSI rises in the last period. Considering the export of *preparation of cereal*, France is once again the most similar country to Italy either considering the PSI or QSI, equal to 39.5% and 30%, respectively, in the last year.

The similarity of agri-food trade between Italy and other Mediterranean countries on the North America market.

In this section, trade similarity is calculated considering North America as the reference market. Table 4 shows the ES indexes which are very high, close to 100%, representing perfect similarity.

The values remain stable during the analyzed period. Moving from ES to PSI, France and Spain maintain a high degree of similarity with Italy, the index values tending to increase over the period. By contrast, the other

Table 4. Similarity indexes between Italy and Mediterranean countries (North American market, agri-food sector).

	ES			PSI			QSI		
	2005/06	2008/09	2011/12	2005/06	2008/09	2011/12	2005/06	2008/09	2011/12
ITA-FRA	98.12	98.24	97.88	85.64	86.32	87.1	0.67	0.06	0.19
ITA-GRE	95.73	95.05	94.41	9.2	9.78	9.72	0.04	0.03	0.06
ITA-POR	97.13	97.47	97.09	24.12	24.29	26.43	0.04	0.1	0.07
ITA-SPA	97.41	97.35	97.28	74.7	77.72	81.08	0.13	0.12	0.23

Note: When calculating the QSI, the parameter a, the average unit value of dissipation factor for the product k, is equal to 0.25. Elaborations on NC8-digit EUROSTAT data.

countries' indexes drop dramatically. In addition, for all countries, the QSI tends to zero.

Put in a nutshell, observing the ES index, there is a significant similarity in exports towards North America between Italy and the considered Mediterranean countries. Yet, considering the absolute flows incorporated in the PSI, France and Spain confirm the high level of similarity. However, looking at the qualitative factor, the countries under study do not seem to compete with Italy, since the exported products are apparently bound to satisfy different market segments given their quality differentiation.

In particular, in what follows, we consider the similarity of the three main categories of agri-food products exported by Italy[15] (see Table 3). According to our computations, similarity in the *beverages* sub-sector is somewhat low; in addition, the QSI tends to zero in all cases. Good degree of similarity, instead, is registered with Spain in *animal and vegetable fats and oils*' exports, the PSI increasing over the years and amounting to 51.1% in 2011/2012. This similarity is confirmed from a qualitative perspective (QSI) until 2008/2009; after that, it drops dramatically. Looking at exports of *preparation of cereals*, the similarity is relatively low; the Italy-France PSI is around 22% in 2011/2012; moreover, considering the qualitative factor, the similarity between the European Mediterranean countries and Italy tends to zero, even though there is a slight increase of qualitative similarity with France and Spain in the last period.

In brief, in the three sub-sectors considered here, the similarity between Italy and France, Greece, and Portugal tends to be negligible. Furthermore, from a qualitative perspective, these countries are strongly dissimilar from Italy, thus the qualitative factor, which should guarantee products differentiation, may be a discriminating variable for increasing competitiveness in the North American market.[16] An exception is Spain, which keeps with Italy a sufficient qualitative similarity for *animal and vegetable fats and oils*'s exports.[17] Besides, in this reference market, we do not record relevant changes over the years in the indexes of interest.

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[15]Figures on all agri-food subsectors are reported in Tables A4, A6, A8, and A10 in the online Appendix.

[16]Furthermore, the exercise might suggest that in isolated cases where the similarity increases in a particular product could cause the reduction in the amount of exports in one of the two countries. A particular case is the evaluation of similarity between Italy and Greece in *tobacco*'s exports; it actually represented in the period 2005/2006 a significant portion of exports of Greece to North America, about 17%, whereas, exports of such goods have been reduced over the years to reach 3% of the total export in 2011/2012. However, the similarity between Italy and Greece, considering these types of goods, significantly increased from 9% to 47% in 2008/2009, with a subsequent slight decline in the third period. Moreover, exports were marked by a significant increase also in the quality factor. This could mean that the increase in similarity and, therefore, competitiveness between the two countries has in fact caused the reductions listed in the amount of *tobacco* exports from Greece to North America.

[17]In the other merchandise categories, excluding the qualitative factor, high level of similarity is found with France and Spain in exports of *meat, fish* and *fruits and nuts;* in this case PSI, Italy-France accounted for around 90% in 2011/2012; however, these results are not confirmed by QSI. In addition, a modest level of similarity is recorded to Spain in *lac/gum/resins* exports; this is partially confirmed by the qualitative similarity index.

Similarity in export flows in added value

In this section, we report results on two indicators (ES and PSI), as the TiVA database does not provide information on the quantities exported, thus excluding the QSI computation. The aforementioned indexes are calculated for the agri-food sector as a whole because data are not available at a more disaggregated level.

As shown in Tables 5 and 6, in both targeted markets, the similarity between Italy and Mediterranean countries is quite high when considering the relative shares of exports through the ES index. Besides, over the period, in the EU-25 market, the Italy-Greece ES and PSI steadily decrease and the Italy-France PSI shows a positive trend. In addition, ES for Spain and Greece in the North American market rises steadily; conversely, the Italy-Greece PSI presents a negative trend.

Considering first exports to the EU-25 (Table 5), focusing on PSI results, Italy displays a great degree of similarity with France and Spain, with a positive trend over the years. Turning to the results in the North American market, we can see a striking similarity between Italy and France (near 100%); a good degree of similarity is also recorded with Spain, about 52% on average.

To summarize, considering exports in value added, there is evidence that during the years analyzed in both reference markets, the most similar countries to Italy are France and Spain, even if the latter shows a greater dissimilarity in the North American market; Portugal and Greece being dissimilar in both markets when considering the PSI.

Table 5. Similarity indicators between Italian and Mediterranean countries in exports in value added to EU-25.

	ES			PSI		
	2005	2008	2011	2005	2008	2011
France	91.24	90.50	89.66	69.41	69.31	76.16
Greece	87.73	83.63	82.08	39.46	32.72	31.15
Portugal	95.38	96.50	94.04	28.92	34.03	31.84
Spain	80.76	80.88	82.64	82.47	83.71	84.83

Note: Elaborations on TiVA data (OECD.org).

Table 6. Similarity indicators between Italian and Mediterranean countries in exports in value added to North America.

	ES			PSI		
	2005	2008	2011	2005	2008	2011
France	95.75	97.39	95.28	94.99	96.09	93.68
Greece	80.18	83.19	84.62	25.81	20.76	18.45
Portugal	96.47	99.84	96.23	11.68	12.31	12.46
Spain	81.26	85.96	87.66	52.20	53.92	52.43

Note: Elaborations on TiVA data (OECD.org).

Finally, comparing the results of this section with the results previously obtained on gross flows of exports, and taking into account the limitations of this comparison, it is clear that in the EU market, the similarity based on value added export data between Italy and Mediterranean countries is somewhat higher in both indexes. This could be due to the fact that excluding inputs imported from foreign markets, these countries could have a very similar productive system with Italy and, consequently, this generates a greater similarity when considering just the value added by countries.

On the other hand, in the North American market, the results diverge from those mentioned earlier on gross export flows only in the case of PSI. Related to this, the similarity based on value added between Italy and France or Italy and Greece seems to be higher than that calculated on gross exports data; contrariwise, it is lower focusing on the country pairs of Italy-Portugal or Italy-Spain.

The similarity of agri-food trade in the crisis period

Thanks to the analysis of the three indexes over time, we may verify whether or not the economic crisis has been associated with a change in the competitiveness of the European Mediterranean countries in the EU and North American markets.

France and Spain, overall, appear to be the main competitors of Italy in the EU-25 market, especially France concerning the qualitative factor, albeit the degree of similarity drops over time. In more detail, the ES indicator shows a slight increase compared to the first year of the analysis implying that countries after the crisis show a more similar structure of exports, except for France. The Italian exports similarity with Spain and Portugal is higher than that with Greece.

Moving from ES to PSI, the value for Spain and Portugal increases while it reduces for Greece and France. The value of PSI is largely different from ES; indeed, the PSI are smaller than the ES; therefore, the magnitudes of the flows matter. The QSI decreases showing that the crisis has probably triggered a quality-based diversification in the products exported. Indeed, a possible explanation could be that only exporters able to diversify have withstood the crisis.

At the sectoral level, the results are heterogeneous. Our findings show for France a declining of the degree of product similarity on *dairy products, cereals, sugar* and *sugar confectionary, flowers, beverages, fruits*, and *preparation of fruit and vegetables*. Sectors with an evident decrease of the similarity are *trees and other plants* and *lac, gums, and resins*. It is also possible to observe a decline in the QSI; thus, compared markets compete on products that are qualitatively different.

Spain presents a slight decrease in similarity on *live animals, fruits and nuts, products of the milling industry, lac/gums/resins, oils and fats*, and *residues from food industries*. As Greece and Portugal present great dissimilarities in most of agri-food sectors, however, the similarity between Italy and Greece seems to be the most affected by the crisis. Italy gains in competitiveness compared to Greece.

In the North American market, the main competitors of Italy seem to be France and Spain, but this pattern is not confirmed by the QSI with values close to zero. Looking at the period of the crisis, the ES index for all countries is quite constant, although slight increases have been recorded in the case of PSI compared to the first period of analysis. Noticeable changes have not been found at the QSI level. Therefore, the crisis seems to have not influenced the similarity between Italy and the EU Mediterranean countries analyzed in North America.

However, at the sectoral level, the results are much more heterogeneous. Our findings show an increase in the level of similarity with Greece and Portugal for several products.[18] Regarding France, a dramatic drop in similarity has been recorded for *trees and other plants* (idem for the QSI) and *products of the milling industry*; instead, the similarity increases for *miscellaneous edible preparations* (idem for the QSI) and *beverages*. The similarity with Spain at the sectoral level presents greater variation. We find a drastic increase in sectors such as *live animals, products of animal origin, oils and fats, beverages, residues from food industries*, and *tobacco*; on the other hand, in *edible vegetables, cereals, products of the milling industry, oilseeds*, and *lac/gums/resins* the similarity decreases remarkably. Nevertheless, in terms of quality, the similarity is fairly constant, except for *oils and fats, preparation of meat and fish*, and *tobacco*, for which it rises drastically, and *sugar* and *sugar confectionaries*, for which it drops considerably.

The economic crisis seems associated with a slight modification of the exports structure. The degree of similarity in terms of product between Italy and the European Mediterranean countries increased in the first two periods of our analysis, 2005/2006 and 2008/2009, but fell in several cases during the biennium of 2011/2012; by contrast, in terms of quality, the similarity drops remarkably in the biennium of 2008/2009; in this regard, a V-shaped trend has been recorded in the North American market in the scrutinized period. These tendencies show that flows that are similar are of different quality. The main result of the analysis is that products are more complementary than similar. In other words, the decreasing QSI for *preparation of fruit and vegetables* or *fruits* implies a dissimilarity in terms of quality of products: France and Italy export products having different quality. It could be that France exports more “Fuji Apple” and Italy more “Golden Apple,” or Spain exports “Virgin Olive Oil” and Italy “Extra Virgin Olive Oil.” Therefore, countries address products in different market segments.

[18]As Greece is concerned, edible vegetables, Cocoa and cocoa prep, Prep. of fruit and vegetables, Misc. edible preparations and Beverages present a decline. This evidence is mainly confirmed also in terms of quality. In Portugal sectors such as Trees and other plants, Edible vegetables, Prod. of the milling industry and Misc. edible preparations register a drop in terms of product similarity.

VII. Conclusions

This study investigates the evolution in the similarity of Italian exports compared to other European Mediterranean countries' exports, in the EU and North American markets, before and after the most recent financial crisis.

Overall, results show that the similarity of the Italian agri-food exports relative to the group of Euro-Mediterranean countries appears heterogeneous depending on the targeted market, the compared country, and the agri-food sub-sector.

When considering "gross" exports and the ES and PSI, the greater degree of similarity with Italy has been recorded for France and Spain, in both the North American and the EU-25 markets. More precisely, in the North American market, the main competitor seems to be France, while in the European market, France and Spain appear to be equivalent.

However, the similarity between Italy and the other European Mediterranean countries is relatively small and drops dramatically considering the QSI. This is particularly true for the North American market, where QSI tends to zero, implying that the products exported are qualitatively dissimilar.

Similarity indexes based on specific agri-food items generally reflect the similarity calculated in the aggregate sector, even though in sporadic cases, the maximum value reached by the QSI is greater than 50%. This suggests that flows, apparently similar, tend to satisfy different market segments; thus, the competition among countries seems to be decreasing when considering the quality factor. Indeed, Italy is an important stakeholder in the world food system having developed a strong reputation for high quality products, such as pasta, cheese, olive oil, wine, and so on.

Observing exports flows in value added, index values tend to be relatively higher compared to gross exports flows. These results may suggest that the domestic production process is somewhat similar between Euro-Mediterranean countries and Italy. Accordingly, a crucial role in order to further diversify products and become more competitive might be played by innovations in the production process.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Full Research Article

Measuring the complexity of complying with phytosanitary standard: the case of French and Chilean fresh apples

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Abstract. Nowadays, complying with technical, sanitary and phytosanitary (SPS) regulations and standards is becoming more and more demanding due to their proliferation and increasing complexity. Consequently, increasing requirements in plant health protection and food safety can lead to a loss of competitiveness in countries that are major exporters of fresh products, causing a redistribution of the market shares in certain sectors. Exporters complying with regulatory standards benefit from better market access and avoid boarder rejection or product downgrading but incur additional costs due to additional procedures and paperwork. This is the case for French apples producers which are losing competitiveness compared to the Chilean ones on foreign markets. This situation can be partially explained by the difficulties of French exporters to comply with international SPS requirements. The aim of this article is first to make a compilation of phytosanitary requirements facing French and Chilean exporters of fresh apples, then to propose a score (hereafter phytosanitary score) which allows to assess the degree of complexity of these SPS requirements. This score is interesting as it synthesizes qualitative information in a metric which can be easily used in quantitative analysis. The results show that even if France and Chile are rather close in terms of SPS requirements, Chilean apples exporters are more capable to comply with foreign SPS requisites than the French ones.

Keywords. Cost of compliance, scoring, apples, sanitary and phytosanitary regulations.

JEL codes. C51, I18, Q18.

1. Introduction

The literature on sanitary and technical regulations has shown that if regulations and standards are market facilitators by decreasing asymmetries, they also hamper trade (Swinnen and Vandemoortele, 2011; Marette and Beghin, 2010). The effects that SPS regu-

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lations have on the economy depend on how they impact consumers, domestic producers and foreign competitors (Swinnen and Vandemoortele, 2009). The cost of production and marketing will increase with the increasing complexity of the regulations abroad. *In the importing country, compliance with a regulation involves a cost to foreign suppliers, which acts like a trade tax, resulting in a deadweight loss as well as transfers from consumers to producers* (Beghin and Bureau, 2002). On a specific market, foreign producers are impacted by the SPS requirements depending on their relative differences in the marginal cost of the regulation, thus on their relative efficiency to comply with importers' standards. This may affect countries that were major exporters, causing a redistribution of the market shares in certain sectors. It is the case for French apples exporters who compete now with newcomers as China which were not even producers 10 years ago.

International trade of apples (and more generally of fruits and vegetables), requires that products intended for marketing come with a Phytosanitary Certificate (PC) which certifies that they are properly inspected, pest-free, and comply with national and international phytosanitary regulations. However, regulatory constraints and requirements in the importing countries may differ substantially from those in the country of departure. This asymmetry directly impacts the phytosanitary risk management and therefore the costs of compliance. Usually, to deliver the PC for fresh apples, countries require either a cold treatment and/or fumigation with methyl bromide (APHIS USDA, 2014 Calvin and Krissof, 1998). The former, even if simple to apply, can become quite complicated because the required temperature for cold treatment may vary from one destination to another. Moreover, if the majority of countries agree on a pre-shipment cold treatment, others require it during transportation or even at the port of arrival complicating the procedure. But the cold treatment is one among many requirements and paperwork an apple exporter faces before selling its products abroad.

Even if a producer is able to comply with all these measures, a possible refusal of the apples still remains if at the port of arrival, a further inspection proves that something went wrong during the transportation or if the regulations have changed meanwhile. Rejections of apples occurred between the US and Japan in 2002, the US and Taiwan, Australia and New Zealand in 2007 (WTO, 2010) also between France and Vietnam in 2012 (France Agrimer, 2015).

These examples illustrate that quantifying costs of compliance is not an easy task due to the proliferation of technical and sanitary regulations and standards and to their increasing complexity. Moreover, whereas models for policy analysis often require quantitative data, these regulations are often not quantitative. *For qualitative standards, like labelling, no numerical values can be directly used. Further, these qualitative policies affect different components of costs of production and marketing and cannot be easily aggregated into a single price equivalent. Evaluating the protectionist component of these numerous qualitative policies into a protectionist score is likely to remain a challenge* (Li and Beghin, 2014). Several authors worked on the issue of introducing qualitative policy instruments in quantitative analysis by producing different synthetic indicators. Among others we can quote works on technological positions (Jaffe, 1986), regulations on Genetically Modified Organisms (Vigani *et al.*, 2011) or varieties of grapes and wines (Anderson, 2010). More recently, Ferro *et al.* (2015), Li and Beghin (2014), Winchester *et al.* (2012) or Drogué and Demaria (2012) also built synthetic metrics to compare bilateral regulations on maximum residual level of food contaminants.

In this article we build a phytosanitary score that allows approximating the relative complexity of phytosanitary requirements in the marketing of fresh apples. We compiled the sanitary and phytosanitary regulations French and Chilean apples exporters must comply with on their main markets of destination. These two countries have been chosen for two main reasons. First, at international level, in comparison with Chile, French producers are losing market share, which could be explained by their difficulties to comply with international phytosanitary regulations. The second reason lies in the characteristics of the countries themselves. France is a traditional provider of apples with a long history of production and consumption, while Chile is a more recent producer export-oriented, and, being located in the Southern Hemisphere; apples in Chile are produced off-season.

The indicator presented henceforth can be seen as a proxy for higher compliance cost born by exporting countries when shipping their apples abroad. This kind of indicator can be used in econometric models to evaluate the impact of non-tariff barriers on trade. At the same time, supply chain operators can also use it as synthetic information on the complexity of phytosanitary requirements in importing countries.

In order to compute our indicator, we first identified all the components of apples phytosanitary requirements Chile and France must comply with by destination (number of inspections, number of treatments and location of treatment, signature of an agreement between countries, etc.). Then, each component is graded with an increasing value according to its degree of complexity; finally we sum them up in a normalized score.

Results show that the scores for France and Chile are rather close, but suggest that overall France suffers from more stringent foreign regulations and Chile is able to reach more easily any destination markets thanks to a better geographical position and phytosanitary situation.

The originality of this work is a deeper understanding on sanitary and phytosanitary requirements that French and Chilean apples producers necessarily face if they decide to gain foreign markets' share, and more particularly the design of a tool that allows to grade and to translate regulatory data into a single score useful for quantitative analysis.

The paper is organized as follows: section 2 is an overview of the international market of apples and the recent redistribution of market shares between countries in this sector. Section 3 is devoted to the presentation of the data on phytosanitary requirements. Section 4 presents the building of the score. Section 5 is devoted to the sample and the numerical results. Section 6 concludes.

2. The international market of apples

Compared with other markets of agricultural commodities, such as sugar, coffee or bananas, the apple world market can be broadly considered as residual: in 1961, only 9.5% of the world fresh production was traded on international markets and reached 11% fifty years later (2012). The main reason is that, historically, traditional producing countries (essentially Western countries) were also the main consumers. From the 90s, an evolution took place in the global geography of production and consumption, leading to evolving trade flows. The description of these changes is therefore important to understand the main opportunities and obstacles encountered by the major exporting countries (like France or Chile).

Figure 1. World apple market: production (with and without China).

Source: Faostat.

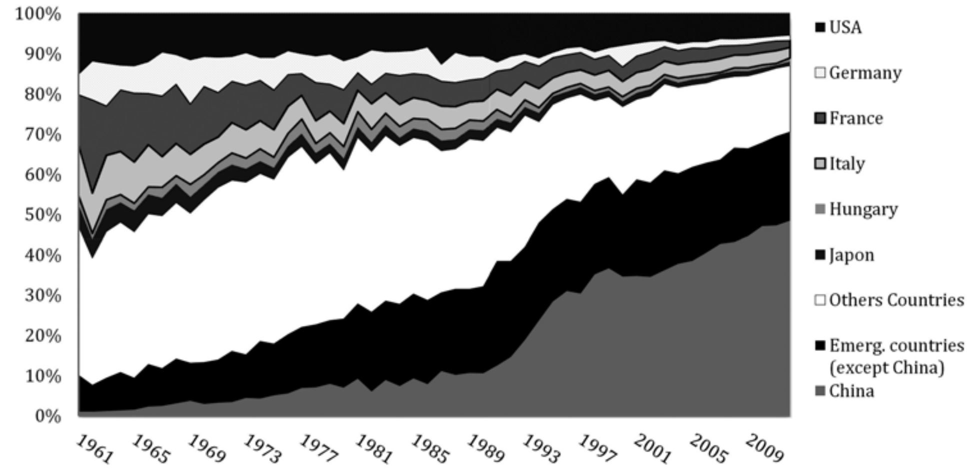
According to the FAOSTAT database, apples are nowadays the second most produced and consumed fruit in the world after bananas and before oranges and grapes. Its production evolved greatly during the last 50 years, from 17 million tons in 1961 to more than 76 million tons in 2012 (+300%). This apparently linear development, hides some recent and deep changes in the geography of production. First and foremost, there is the spectacular increase, from the beginning of the 90s, of the Chinese production (Figure 1). From just 1% of the world production in 1961, it represents today half the global output in the world (48% in 2012)[1]. In general, during this same period there is a globalisation of apple production and traditional producers (as France or Italy) have lost market shares in relative and absolute value, to the benefit of China and emerging countries (Figure 2).

On the demand side, we observe the same evolution: in countries of traditional consumption, with high incomes, saturated food demand, and with stronger health and environmental concerns, apples suffer the competition of other fruits, including exotic ones (Figure 3). In contrast, population growth recorded in emerging economies, combined with higher average incomes and the dissemination of national and international education policies promoting fruit consumption[2] explain the increase of their respective demand for fruits, especially apple, one of the easiest to store (Figure 3).

Finally, if the geographical area of apple production and consumption has greatly expanded in the last 20 years, the new consumer countries are not necessarily the producing ones. Therefore, and except for China, which is largely able to meet its own domestic

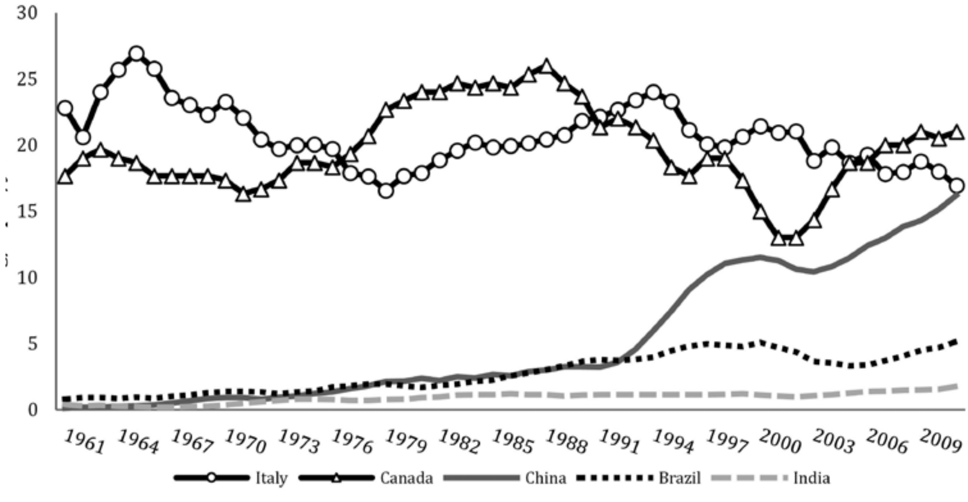
[1] What explains this phenomenon is the liberalization process of the Chinese market implemented by Deng Xiaoping (Murphy *et al*., 1992). His reforms have allowed the Chinese farmers to sell their excess production on the free market, leaving the market price system drive the allocation of productive investments.
[2] WHO: http://www.who.int/mediacentre/news/releases/2003/pr1/en/.

Figure 2. World apple market: production shares - selected countries.



Source: Faostat.

Figure 3. World apple market: per-capita apple consumption – selected countries.



Source: Faostat.

demand, the increasing consumption of apples in developing countries (like India, Indonesia or Brazil for example) represents a new opportunity for all exporters.

Among the major producing and exporting countries in 2012, Table 1 differentiates those for which the domestic market remains a priority (such as China) from those for which external demand represents a major challenge. In the latter category, Chile, France

Table 1. World apple market: production and export shares – selected countries.

Country	National production on world production (%)	National net exports on world exports (%)	National net exports on national production (%)
Italy	3.2	11.3	38.9
Chile	2.1	9.6	50.4
China	47.3	9.1	2.1
USA	5.6	8.2	16.0
France	2.4	7.1	31.7
Iran	2.4	1.3	5.7
Turkey	3.5	1.0	3.0
India	3.8	-1.8	-7.0

Source: Faostat, 2012.

and Italy[3], represent about 30% of apple's worldwide exports.

If in the following study, we limit the comparative analysis to France and Chile, thus excluding Italy, several reasons justify our choice. First, to avoid duplication effect: France and Italy have similar characteristics in terms of seasonality, produced varieties, production conditions and supplied export markets. Second, the lack of data, especially regulatory data (bilateral phytosanitary agreements), for Italy, does not allow us to add this country to the comparative analysis.

Therefore, we focus on the comparison between France and Chile. These two countries differ not only in terms of geographical location, seasonality, climate characteristics or supplied markets[4]. They also face contrasting trends in exports. French apples exports are falling in the last 20 years, while they are increasing in Chile (Figure 4). These trends can partly be explained by the differences in importers' SPS requirements.

3. Data description of phytosanitary requirements in the apple sector

Diseases and pest invasions vary greatly with place and time affecting the risk management and the protection of trees. The main pests damaging apples and apples orchards are: insects (codling moth, fire blight, sawfly insects, tortricid, aphids, and fruit tree spider mites), fungal diseases (apple scab - *Venturia inaequalis* and powdery mildew - *Podosphaera leucotricha*) and viral diseases.

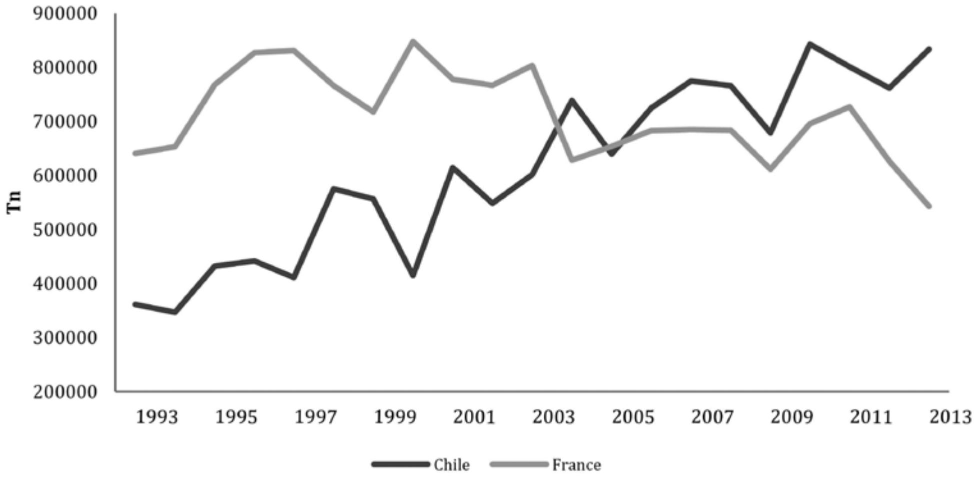
Viral diseases have been less damaging since plants carried a certificate which guarantees against the presence of the Mycoplasma-like Organism (MLO) disease, the apple mosaic or the bitter pit disease (affecting the fruit).

In order to mitigate the phytosanitary risk, regulators impose that crop products intended for marketing are accompanied by a Phytosanitary Certificate, defined above.

[3] We could add to this short list, New Zealand, a strongly export-oriented country. However, it does not represent a sufficient volume of exportations to be mentioned among the major players of the apple world market.

[4] According to the detailed trade matrices published by Faostat, France exports about 75% to EU countries and 11% to Asian countries (in particular middle east). Contrariwise, Chilean exports are more diversified: half of its exports concern the Americas (especially Canada and USA), 23% come to Asia and 23% to Europe.

Figure 4. France and Chile apple exports (1993-2013).



Source: Faostat.

These regulatory constraints and associated additional treatment operations impact the SPS risk management and increase, the costs of production and marketing. However, even if a producer is able to comply with all these measures, some possible rejection/refusal of products may still happen if at the port of arrival further inspection prove the presence of a pest. Rejections of apples occurred between the USA and Japan in 2002, the USA and Taiwan, Australia and New Zealand in 2007 (WTO, 2010) and in 2012 Vietnam stopped apples coming from France and re-negotiated a bilateral SPS agreement (France Agrimer, 2015). To illustrate the complex nature of pest risk management in the framework of international apple trade, let's take the example of cold treatment. Cold treatment is a common practice to fight main apple pests (especially *Ceratitis capitata*), which in some cases, must be associated to fumigation (APHIS USDA, 2014). The cold treatment requires that fruits must be stored at a constant temperature between 0° and 4° for a period of 14 to 21 days to prevent contamination of products by harmful organisms. Even if simple to implement, the cold treatment may become quite complicated because in case of a random interruption, the procedure must start again from the very beginning. An interruption is more likely to occur during shipment because temperature sensors cannot be verified easily and the common practice is that of cold treatment in transit[5].

Moreover, doubts about the presence of pests or harmful organism in a given area may rise the alert level with consequent tightening of controls. This happened, with Vietnam, which denied market access to its trading partners between 2013 and 2015 in order to modify the phytosanitary regulations.

In this context analysing SPS regulations imposes a case by case analysis. Therefore, for the countries under scrutiny (France and Chile) we retrieved information from vari-

[5] Source: EPPO, URL: https://www.eppo.int/QUARANTINE/data_sheets/insects/CERTCA_ds.pdf

ous sources. The first and main sources of information are the websites of the national food safety authorities managed by the respective Ministries of Agriculture (Exp@don for France and the Servicio Agricola y Ganadero (SAG) / Department of agriculture and livestock for Chile). However, in some cases information was missing, thus we also consulted the World Integrated Trade Solution (WITS) maintained by the World Bank, the World Trade Organisation (WTO) dataset and finally the International Plant Protection Convention (IPPC). All this information was crossed-checked with experts from the SRAL (Service Regional de l'Alimentation / French Food Regional Service). The analysis of all the information at our disposal allowed us to identify an exhaustive list of the many requirements apples exporters face[6]. These requirements are of two types: (i) operational as the cold treatment or fumigation: in this case the requirements from the Animal and Plant Health Inspection Service of the United States Department of Agriculture (APHIS/USDA) are the leading reference in many countries; (ii) administrative, taking the form of inspections or of declarations and can vary a lot according to bilateral agreements between the countries of origin and destination. We identify 9 requirements, called "dimensions" and described in the Box A2 in appendix.

To each dimension of the phytosanitary regulation we assigned a grade increasing with the complexity of implementation. The lowest grade is 0 (no constraints). Then, 1 when the regulation requires a form of monitoring easy to apply; a value equal to 2 or 3 when fulfilling the requirements is complex and finally the maximum value in case of a ban. For instance, the grade for the cold treatment ranges between 0 and 3. It takes a value equal to 0 if any cold treatment is required; a value equal to 1 if the cold treatment is applied in transit, a value of 2 when the regulation requires a cold treatment at the port of arrival and a value of 3 for ban. We assume that any kind of activity is more difficult or more expensive to implement in the country of destination than during the shipment or pre-shipment. Indeed (i) the absence of national operators in the foreign countries, (ii) the difficulties related to the use of different languages or different standards or (iii) the potential higher cost of the cold treatment activities in the foreign countries makes the procedure more difficult.

The ban is not difficult to implement but it prevents all imports from the banned country; this is the reason why we consider the ban equivalent to assigning the highest grade to each dimension. Table 2 displays the grades by dimension. As we can see from table 2, the number and the values of each restriction vary from country to country depending on the underlying domestic regulation. Each phytosanitary requirement is controlled and certified by the representative safety authority: the SRAL in France, the SAG in Chile. They perform the required inspections and deliver the phytosanitary certificates.

Once this evaluation has been made, in the next section we synthesize all the components into one metric which gives the relative "phytosanitary distance" between the exporter (*i.e.* France or Chile) and their importers.

4. Building a Phytosanitary Score

In order to assess the complexity of the overall SPS regulations imposed to French and Chilean apple exporters we built a Phytosanitary Score (hereafter *PS*). Follow-

[6] The analysis was carried out between 2014 and 2016. During this period, no major changes took place in trade relations, except for the negotiation of a new bilateral protocol between France and Vietnam.

Table 2. Dimensions and grades of the Phytosanitary Requirements and underlying regulations.

Dimension	Values	Underlying Regulations
Territorial Restriction / QO Restriction	0 (No restriction) 1 (Yes restriction) 2 (Ban)	**Bilateral agreements:** - between France and China, Indonesia, Sri Lanka, Taiwan, Thailand, Vietnam, USA - between Chile and China, India, Taiwan, Thailand, USA, Mexico. **In the other cases**, the information comes from: - Exp@don database (for France) - SAG database (for Chile) - Wits database (by World Bank) - Food Safety Authority of importing countries (Website)
Agreement	0 (No agreement needed) 1 (Agreement on pre-listing) 2 (Agreement on yearly check) 3 (Ban)	
Import Permission	0 (No IP needed) 1 (The IP has been negotiated) 2 (The IP has not been negotiated) 3 (Ban)	
Phytosanitary Certificate	0 (No PC) 1 (The PC has been negotiated) 2 (The PC is under negotiation) 3 (The PC is non official) 4 (Ban)	
Pre-inspection	0 (No Pre-inspection) 1 (Pre-inspection is required) 2 (Ban)	
Pre-clearance	0 (No Pre-clearance) 1 (Pre-clearance is required) 2 (Ban)	
Pre-cold treatment/fumigation	0 (No treatment needed) 1 (Treatment needed) 2 (Ban)	
Cold Treatment	0 (No cold treatment) 1 (In transit cold treatment) 2 (At arrival cold treatment) 3 (Ban)	
Inspection at arrival	0 (No inspection at arrival) 1 (Inspection at arrival) 2 (Ban)	
Total Requirements	24 (maximum requirements)	

ing Ferro *et al.* (2015), *PS* is designed as the sum of the grade obtained by each phytosanitary constraint (dimension) imposed by the importing country to the exporting one. We then normalized it in order to obtain a value ranging between 0 and 1 and further imposed convexity as in Li and Beghin (2014). In our analysis we consider that *PS* measures the relative severity of the phytosanitary constraints imposed by the importing country.

$$PS_{ij} = \frac{1}{N}\left[\sum_{t=1}^{N} \exp\left(\frac{Phyto_{ijN} - minPhyto_N}{maxPhyto_N - minPhyto_N}\right)\right]$$

Subscript i denotes the exporting country and j importing country (here i is equal to France or Chile), $Phyto_{ijN}$ is the grade of the requirement imposed by country j to country i in the dimension N; $maxPhyto_N$ is the highest grade in the dimension N; $minPhyto_N$ is the lowest grade in the dimension N. The PS indicator ranges between 1 (in the absence of any specific requirements) and $e \approx 2.72$ which corresponds to the case of a ban, the greater the score the more difficult to comply with all the dimensions of the country of destination's SPS regulation.

The advantage of introducing the convexity in the standard is that it imposes more weight on more demanding requirements suggesting that it is more difficult to reach higher standards and thus that the marginal cost of compliance is increasing. We are particularly interested in verifying the relationships between trade and *PS* that is to say between trade and the phytosanitary requirement (*Phyto*). Our intuition being that the two variables are negatively correlated.

5. Sample and results

Crossing data on French and Chilean apple exports during the period 1986-2013 with the sanitary regulations, we have been able to select a sample of 82 countries (over 146 destinations in 2013) for France, and a sample of 51 countries (over more than 100 destinations in 2013) for Chile (see the complete list of countries in table A1 in appendix). For the selected countries there is a positive flow of apples from France and Chile over the period and information on phytosanitary regulations is available. We exclude from our samples, countries with zero trade flows except when those countries imposed a ban on French or Chilean apples. The countries in the sample represent, for both exporters and for the entire period, 99% of their exports of apples on average.

Our sample can be disaggregated in 3 sub-groups. The first one gathers European countries which apply similar phytosanitary regulations (Directive 2000/29 CE, European Commission, 2000). In this common phytosanitary area, French apples move freely without control or particular certificates, while Chilean apples need a simple inspection at arrival. The second sub-group gathers 52 extra-European destinations for which French and Chilean apples must be accompanied by a PC or by a specific phytosanitary document or both. The third group is constituted by countries which banned imports of apples from France or Chile (Indonesia, Japan, South Africa, South Korea and Tunisia).

Table A1 in appendix reports the values of the scores for all countries importing French or/and Chilean apples. It shows in the first column the selected countries importing apples from France; in the second column the values of *PS*; and in the third column the average trade in volume. Columns 4 to 7 display the same information for Chile.

This score is able to capture the degree of complexity of the regulation. In order to test the relationship between trade and the score we proceed by simple correlation analysis.

In Figure 5 and 6, we can appreciate the position of both exporting countries in comparison to their own trading partners. It is interesting to note that the distribution of the phytosanitary score (*PS*) seem comparable in the two graphs: the group of European countries is always on the left of the distribution, while the group essentially composed by Asian countries is, in both cases, on the right. This illustrates that European countries apply relatively looser regulatory restrictions compared to Asian countries, regardless

Figure 5. *PS* Country Mapping (France).

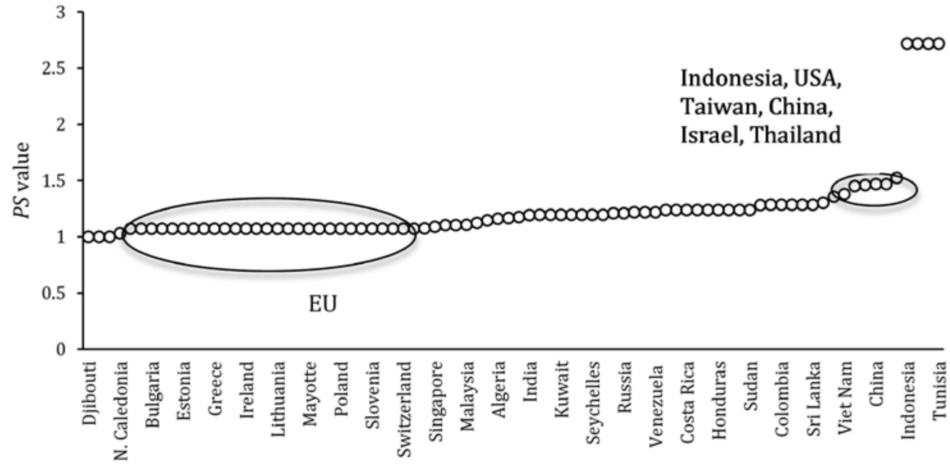
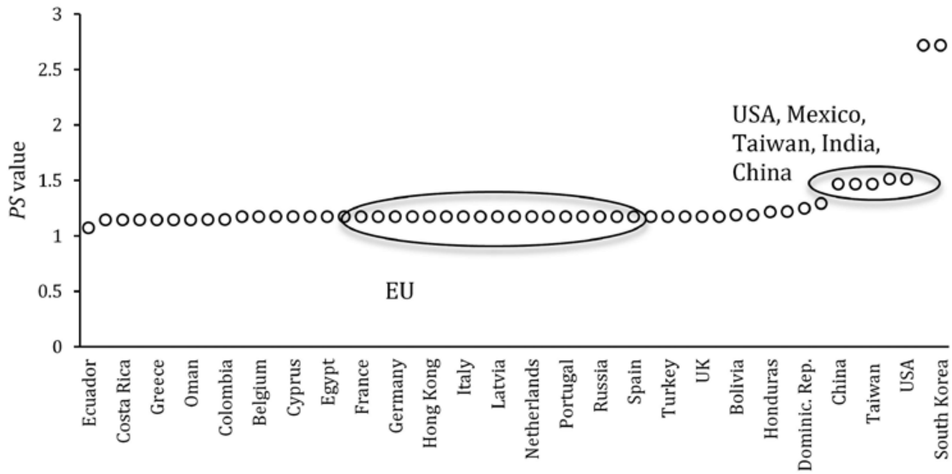


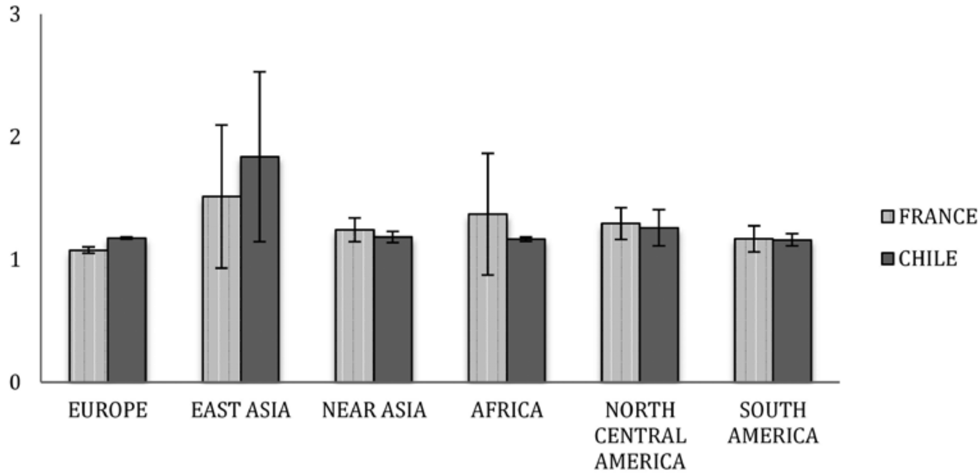
Figure 6. *PS* Country Mapping (Chile).



of the source of exports. However, while it is obvious that France belongs to the group of European countries (as importer, Figure 6), it is also important to note that Chile as importer, belongs to the group of countries applying more complex regulations (as China, Indonesia, Taiwan, Thailand, or the USA).

The box plot in Figure 7 shows the distribution of *PS* by region. In this figure the higher the boxes the more demanding the phytosanitary requirements between France or Chile and their clients. First, we can observe that both exporters face similar average level of complexity by region. However, France is almost always facing a higher degree of variability accord-

Figure 7. *PS* distribution by region (average and standard deviation).



ing to the destination. This variability is at its maximum within the Asian countries. More generally, the variability increases with the level of complexity. It is also interesting to underline the results obtained for African destinations: while the phytosanitary requirements are strongly homogeneous *vis à vis* Chile, they are very heterogeneous for France.

The next Figures from 8 to 11 present the relationship between the importers' complexity of phytosanitary constraints and exports. In order to reduce the high trade variability, we aggregate trade volumes by countries sharing similar or identical phytosanitary scores. In the case of France, we are able to distinguish 6 ranges. Conversely, for Chile we only have 5 ranges, because of the strong requirements' homogeneity.

Figure 8 suggests that for France, the level of trade is, as expected, inversely related to the level of complexity in the sanitary requirements of its partner, and reaches zero in the case of a ban (maximum restriction). Figure 9 shows that this result is globally confirmed, even when we eliminate extreme values, such as EU (no restriction) and bans (full restriction).

However, results are quite different for Chile. As Figure 6 shows, the phytosanitary constraints imposed to Chile by its trade partners are particularly homogenous (except for a few countries on the right side of the distribution). This strong homogeneity of the score does not allow us to discriminate between several ranges and therefore correctly test the correlation between trade flow and score value. Therefore, although figures 10 and 11 show a negative and clear correlation between trade and the complexity in phytosanitary regulations (as for France), the results seem more difficult to interpret.

In order to support our argument, we try to provide further analytical details about this topic. If we look at the trade between Chile and North-American countries, we can see that, while the volume of apples from Chile to the USA is important (103,000 tons on average between 2008 and 2013), this is not the case for Mexico (8,000 tons on the same period). The reason has to be found in the stronger demand of Mexican regulations. Yet, although the USA and Chile are located in the same continent (and thus closer in distance), Chile exports more with the EU (347,000 tons in average between 2008 and 2013)

Figure 8. *PS* value by range and volume of French apple export (2007-2013).

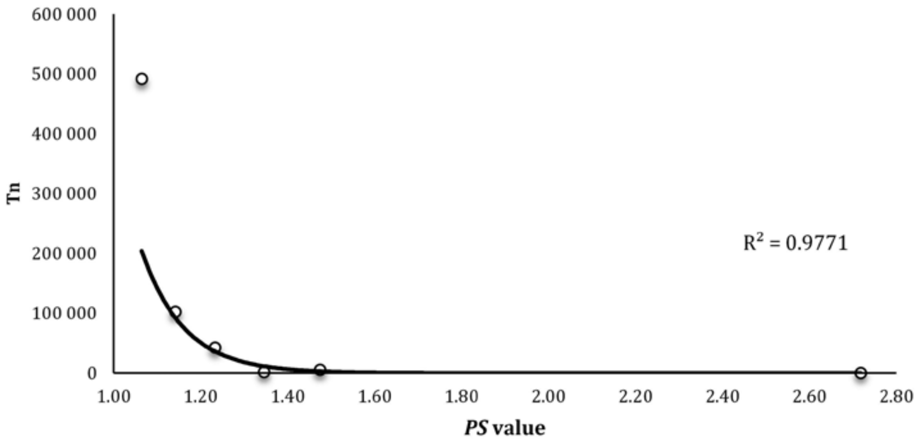
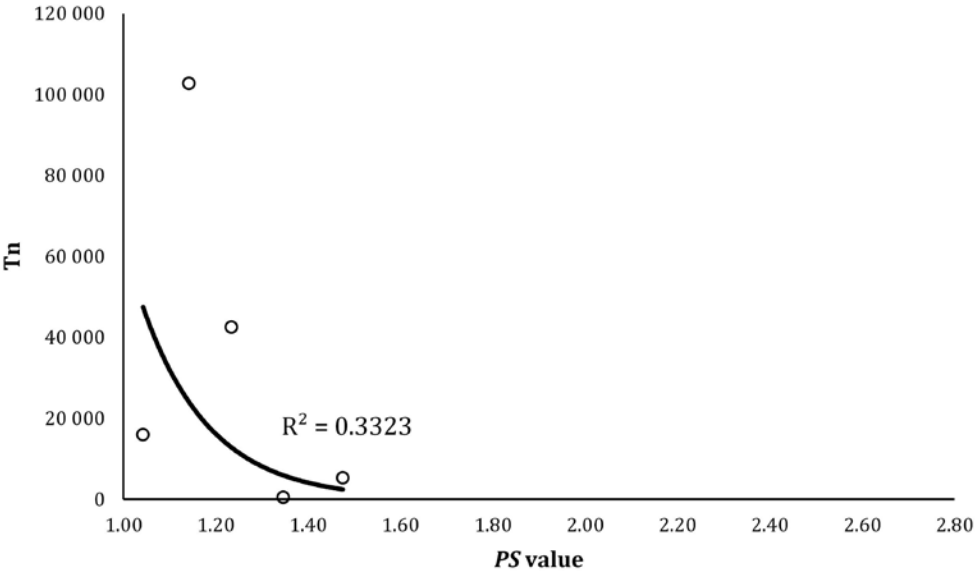


Figure 9. *PS* value by range and volume of French apple export (2007-2013) without EU countries.



than with the USA. We suggest that the cause can also be attributed to the stringency of the US regulations in comparison with those of the EU.

Another explanation could be found in the existence of a trade agreement between the two countries under scrutiny and their trade partners. Table A1 in appendix shows the existence or absence of a trade agreement. The information suggests that for France the geographical proximity and the existence of a trade agreement often overlap and the link

Figure 10. *PS* value by range and average volume of Chile apple export (2007-2013).

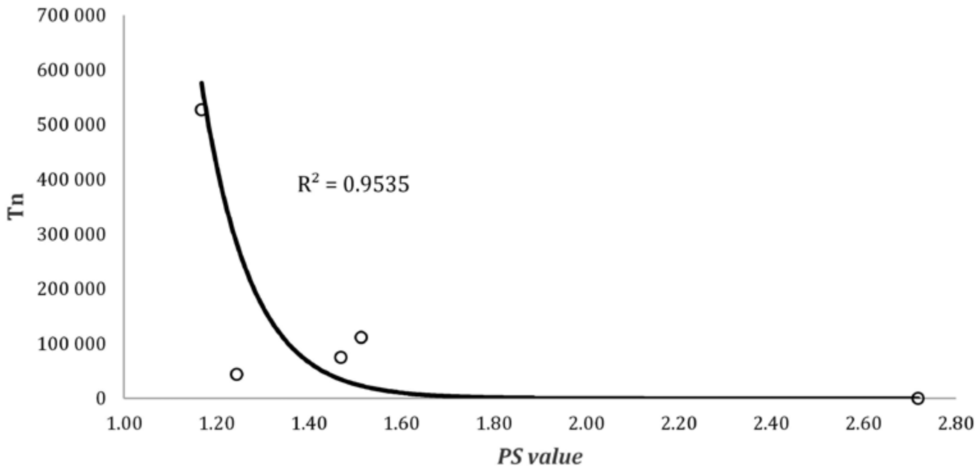
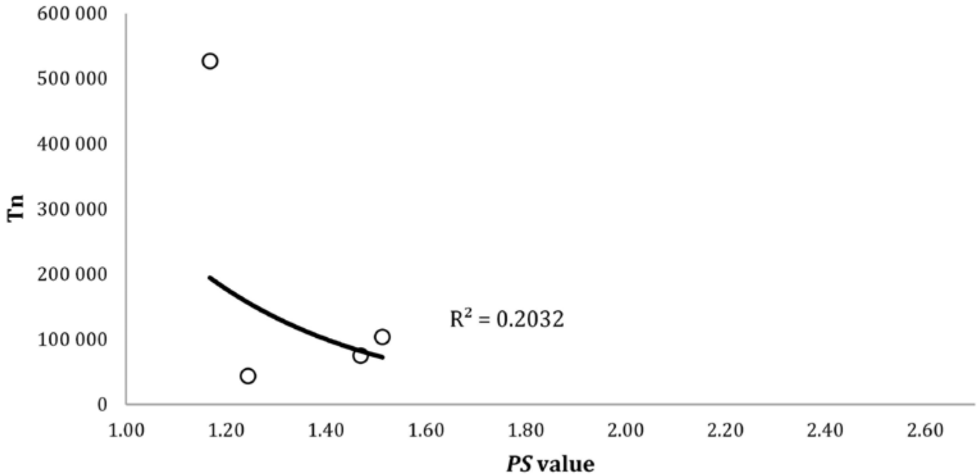


Figure 11. *PS* value by range and average volume of Chile apples export (2007-2013) without USA.



between the existence of the agreement and the level of trade cannot be clearly traced. Moreover, even if the EU (and therefore France) has signed a trade agreement with South Africa, South Korea and Tunisia, French apples are still banned from these countries for phytosanitary reasons.

For Chile, it is slightly different. There is no particular overlapping between the existence of a trade agreement and proximity. But there is also no clear link between the absence of a trade agreement and the absence of trade. Chile exports more apples to Colombia, Ecuador or Peru where no agreement has been signed compared to Brazil with which an agreement has been signed. The same is true when the importer is farer: Chile is able to export high volumes even without the existence of a trade agreement; it is the case with India, Russia, Saudi Arabia, Taiwan or the Arab Emirates (see table A1).

6. Conclusion

For a long time, France has taken the world leadership in the apple international markets. But the French competitiveness is short of breath. French exporters point at the increasing complexity of the phytosanitary rules governing fresh fruits trade, especially in Asia and the USA.

On the other side, Chile, a growing stakeholder in the apple sector has seen its exports increase regardless of the destination. Even if Chile benefit from its off-season supply with respect to its main destinations (USA, Europe, China), it seems generally less sensitive to the phytosanitary restrictions.

Using a synthetic measure, we studied the link between the level of French and Chilean apples exports and the complexity of the phytosanitary requirements imposed by importing countries. Analysing the regulations for more than 130 destinations (84 importing countries for France and 51 for Chile), we were able to draw several conclusions.

First, we observe that no significant difference between phytosanitary restrictions imposed to France and Chile by destinations exists; therefore, the distributions of *PS* in Figures 5 and 6 are rather similar for both exporting countries.

Second, there is no clear link between the existence or absence of a trade agreement between the two countries and their trade partners and their capacity to penetrate a specific market.

Third, we have yet underlined that the French and Chilean positions inside the *PS* distributions is not the same. France belongs to the EU which is less demanding in terms of phytosanitary regulations, while Chile belongs to the group of countries applying more complex phytosanitary regulations (as China, Indonesia, Taiwan, Thailand or the USA). Therefore, this difference in the relative phytosanitary positions of France and Chile with respect to phytosanitary restrictions abroad, allows us to better explain why Chile resists better to more demanding destinations in terms of phytosanitary regulations than France (see Figures 7 to 11).

French exporters suffer higher costs in complying with phytosanitary rules, especially when they are imposed by the most dynamic importing countries (as Asian countries). For instance, French producers must make a greater effort in pest risk management in comparison to the Chilean producers, when they want to export apples free from the Mediterranean fly to China or Taiwan.

As emerging economies increase their consumption of fruits, with the increase in their per capita income, a new demand appears, especially in Asian countries, opening opportunities for apple growers and exporters.

However even if Chile and France face regulations from Asian countries (especially China, Taiwan or India), its geographical location, the off-season nature of its production and its natural phytosanitary conditions (Mediterranean fly free area) give the former an advantage in terms of capacity of compliance. In the Chilean case, as their phytosanitary restrictions are very close to those imposed by Asian countries or USA, it acts as a "common regulatory language". It reduces asymmetries in pest risk management and facilitates trade. Thus, it is possible to understand why Chilean exports to Taiwan or USA coexist with high score value: once the constraints overcome, due to a learning effect or similarities in natural phytosanitary conditions, trade can unlock its potential.

In the French case, phytosanitary restrictions imposed by Asian countries or USA are the translation of really different natural and phytosanitary conditions. Then the regulations imposed to France by third countries act as real barriers with high costs of compliance (and learning).

These results, despite apparently opposed for France and Chile, are both consistent with the economic literature on international trade and non-tariff barriers, and suggest once more that sanitary and technical regulations can facilitate as well as hamper trade causing redistribution in the market shares.

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Appendix

Table A1. PS by country of 20 selected destinations of France and Chile apples.

France				Chile			
Country	PS Value	Trade Average 2007-2013	Existence of a trade agreement	Country	PS VALUE	Trade Average 2007-2013	Existence of a FTA
Algeria	1.16	63,437	Yes	Algeria	1.18	601	No
Angola	1.24	46	No	Bahrain	1.14	1,307	No
Australia	1.22	14	No	Belgium	1.18	5,756	yes
Austria	1.07	614	Yes	Bolivia	1.18	14,974	No
Bahrain	1.24	365	No	Brazil	1.15	13,400	Yes
Bangladesh	1.28	261	No	Canada	1.18	15,548	Yes
Belgium	1.07	37,748	Yes	China	1.47	12,467	Yes
Brazil	1.21	2,049	No	Colombia	1.15	68,894	No
Bulgaria	1.07	16	Yes	Costa Rica	1.14	7,810	Yes
Canada	1.15	422	No	Cyprus	1.18	535	Yes
China	1.47	638	No	Denmark	1.18	1,952	Yes
Colombia	1.28	965	No	Domin. Republic	1.25	1,705	No
Costa Rica	1.24	93	No	Ecuador	1.07	44,748	No
Cote d'Ivoire	1.24	727	No	Egypt	1.18	5,378	No
Czech Republic	1.07	449	No	El Salvador	1.14	4,841	Yes
Denmark	1.07	12,580	Yes	Finland	1.18	1,162	Yes
Djibouti	1.00	24	No	France	1.18	9,452	Yes
Ecuador	1.20	57	No	Georgia	1.18	327	No
Egypt	1.08	1,619	Yes	Germany	1.18	12,456	Yes

France				Chile			
Country	PS Value	Trade Average 2007-2013	Existence of a trade agreement	Country	PS VALUE	Trade Average 2007-2013	Existence of a FTA
Equat. Guinea	1.30	31	No	Greece	1.14	5,028	Yes
Estonia	1.07	318	Yes	Guatemala	1.18	5,403	Yes
Ethiopia	1.24	0.1	No	Honduras	1.22	3,243	No
Finland	1.07	11,745	Yes	Hong Kong	1.18	8,716	No
Germany	1.07	56,902	Yes	India	1.47	20,605	No
Greece	1.07	96	Yes	Ireland	1.18	2,530	Yes
Guinea	1.20	254	No	Italy	1.18	10,135	Yes
Honduras	1.24	0.1	No	Japan	2.72	0	No
Hong Kong	1.00	1,968	No	Jordan	1.30	797	No
Hungary	1.07	54	Yes	Kuwait	1.18	3,740	No
Iceland	1.07	65	Yes	Latvia	1.18	360	Yes
India	1.19	339	No	Libya	1.14	2,568	No
Indonesia	2.72	1,126	No	Malta	1.18	495	Yes
Iran	1.24	1,576	No	Mexico	1.51	8,053	Yes
Ireland	1.07	20,274	Yes	Netherlands	1.18	63,406	Yes
Israel	1.46	1,021	Yes	Norway	1.18	3,990	Yes
Italy	1.07	3,952	Yes	Oman	1.14	1,814	No
Jordan	1.28	213	Yes	Panama	1.19	1991	No
Kazakhstan	1.18	103	Yes	Peru	1.22	38,402	No
Kenya	1.28	199	No	Portugal	1.18	2,978	Yes
Kuwait	1.20	2,226	No	Qatar	1.18	1,193	No
Latvia	1.07	72	Yes	Russia	1.18	38,062	No
Libya	1.20	2,992	No	Saudi Arabia	1.18	49,620	No
Lithuania	1.07	718	Yes	South Korea	2.72	0	Yes
Luxembourg	1.07	1,092	Yes	Spain	1.18	21,593	Yes
Malaysia	1.11	4,885	No	Sweden	1.18	5,573	Yes
Maldives	1.00	276	No	Taiwan	1.47	41,995	No
Malta	1.07	7	Yes	Turkey	1.18	2,266	Yes
Mauritania	1.20	657	No	UAE	1.18	26,322	No
Mayotte	1.07	438	Yes	United Kingdom	1.18	31,919	Yes
Morocco	1.10	914	Yes	USA	1.51	103,697	Yes
N. Caledonia	1.03	163	Yes	Venezuela	1.18	28,416	No
Netherlands	1.07	66,287	Yes				
Nigeria	1.36	3	No				
Norway	1.07	2,279	Yes				
Oman	1.24	2,631	No				
Poland	1.07	644	Yes				
Portugal	1.07	25,520	Yes				
Romania	1.07	78	Yes				
Russia	1.21	26,118	Yes				
Saudi Arabia	1.12	16,631	No				

France			
Country	PS Value	Trade Average 2007-2013	Existence of a trade agreement
Seychelles	1.20	56	No
Singapore	1.09	3,770	No
Slovenia	1.07	36	Yes
South Africa	2.72	40	Yes
South Korea	2.72	0	Yes
Spain	1.07	101,845	Yes
Sri Lanka	1.28	49	No
Sudan	1.24	479	No
Sweden	1.07	9,104	Yes
Switzerland	1.07	643	Yes
Taiwan	1.47	287	No
Thailand	1.45	3,375	No
Togo	1.20	200	No
Tunisia	2.72	18	Yes
Turkey	1.28	204	Yes
United Arab Emirates	1.10	16,033	No
Uganda	1.17	14	No
United Kingdom	1.07	132,141	Yes
Uruguay	1.22	24	No
USA	1.52	25	No
Venezuela	1.22	200	No
VietNam	1.38	120	No

Box A1. SPS requirements description.

1. Ban and Territorial restriction. The ban forbids all exports of a product towards a third country. The ban may be justified either because of the presence of a quarantine organism in the country of origin but in the country of destination, as it is the case in Tunisia or in South Africa for French apples. Furthermore, countries of destination can temporary refuse imports as in the case of the apples from USA in Japan and from France in Vietnam (see above). Territorial restriction/Quarantine organism restriction: the importing country can impose to its providers that goods crossing its borders originate only from specific parts of the country of origin where quarantine organisms are absent or under control. For instance, France has negotiated a protocol with Indonesia which makes sure that only apples from the region «Pays de la Loire» can be exported. China and Taiwan impose similar restrictions to Chile. Area restriction is then an actual trade restriction.
2. Accreditation: is a more advanced form of territorial restriction. For instance, China or Taiwan establishes a precise list of orchards, of storage and packing facilities, of exporters with the domestic sanitary authorities. The list of accredited organisms can be defined in different ways. In the simplest case it is the local authority (in France the SRAL) which compiles the list of producers complying with phytosanitary requisites and the importer only needs to approve or not the list. Or, the importing country may decide to approve the list after the inspection of the producing units by its own inspectors. The frequency of inspections may vary according to what has been agreed upon by both parties.
3. The import permit (IP): this document is required by few countries imposing additional/reinforced inspections of goods. For instance, Israel phytosanitary authorities require that 2% of the total French exports are examined by local authorities (SRAL). Similar requests are addressed to Chile by countries like Honduras or Bolivia. In both cases, it is a more demanding control compared to the one usually performed by national sanitary authorities to deliver the PC. It is for this reason that the results of IP's inspections are quoted in the PC in the box "additional documents".
4. The Phytosanitary Certificate (PC): in the simplest case (as it is the case for France vs. Norway), the PC is obtained after a visual inspection by the SRAL of apples to be exported. Thus, issuing the PC is equivalent to an inspection. In more complex cases, the PC must mention also all the additional inspections required by the importing country and certified by the SRAL (origin of the products, agreement, import permit, cold treatment etc.)
5. Pre-inspection (or internal inspection): is an additional inspection required by a few countries among which USA and Taiwan. It is also qualified as double internal inspection because it must be implemented by the storage/packing employees before and during the packing operations. This double checking must be validated by the national Safety Authority.
6. Pre-clearance is an additional pre-shipment inspection required by the USA. The pre-clearance procedure must be performed by the APHIS/USDA inspectors and APHIS/USDA trained domestic inspectors (from the SRAL). Moreover, the volumes of the sample intended for inspection are defined by the APHIS/USDA regulation and are larger than those usually required by the SRAL (it is the reason why the presence of the SRAL is necessary during the samples' inspection). However, though we have to consider here the pre-clearance as a simple additional inspection, negotiations between USA and Italy or New Zealand show that pre-clearance is a heavier system of export control (2 or 3 inspections) which can coincide in the French case with a mix of pre-inspections and cold treatment.
7. The pre-cooling/fumigation: in case of the presence of the Mediterranean fly in the producing country, some importers require that the exporter prove that before the loading of apples in the refrigerated container, the merchandise has already reached the temperature recommended by the regulation (pre-cold treatment) or has been subjected to fumigation (with Methyl bromide). In this case the exporter requests the national Safety Authority to certify the apples have been subject to fumigation or pre-cooling during the storage and they have reached the temperature needed to start the cold treatment.
8. The cold treatment requires that fruits must be stored at a constant temperature between 0° and 4° for a period of 14 to 21 days to prevent contamination of products by harmful organisms. For all destinations requiring the cold treatment during the transit, the SRAL is requested to inspect and certify all the stages of loading in the refrigerated containers and the position of the sensors. The SRAL certifies the first stage of the process.
9. Inspection at arrival: it is a final and additional (or unique) inspection performed by representatives of the local phytosanitary authority, which sets the volumes of the samples to be inspected.

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Maximum residual levels of pesticides and public health: best friends or faux amis?

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Abstract

The purpose of this article is to analyze the relation between public health and the regulations of Maximum Residue Limit (MRL) of pesticides. Many authors underline the role of trade protectionism in fixing these limits, whereas these regulations should be intended for public health protection. We first establish the link between the MRL for a given chemical in plant products and its level of toxicity. In order to perform this analysis, we cross the FAS USDA MRL database and the classification of the long-term toxicological effects (LTE) for active substances provided by SAgE pesticide. We then compute a synthetic and polyvalent tool, namely, "Health Score," which provides a first overview of the link between LTE and MRL by country. Then this score is regressed in a logit model in order to identify the relationship between the countries' Health Score and the socioeconomic and political characteristics of such areas. Results highlight the importance of public health expenditures in determining the settings of MRL toward stricter levels.

JEL classifications: C51, I18, Q18

Keywords: Food safety; Pesticide residues; Fruits and vegetables; Scoring; Logit model

1. Introduction

According to Henson and Caswell (1999), food safety regulations are *the outcome of a complex trade-off between (. . .) consumers, food manufacturers, food retailers, farmers, (. . .) the government itself and taxpayers*. Concerning regulations on Maximum Residual Level (MRL) of pesticides, it is widely recognized that they have been designed in order to protect the health of consumers and ensure that farmers adopt good practices. But even if an international regulation has been designed by the Codex Alimentarius (hereafter Codex), its application is not compulsory and nations keep their sovereignty in fixing these limits. Some countries appear as very severe while others, and particularly those deferring to the Codex, are considered as much laxer. This regulatory heterogeneity is at the core of a growing literature (Drogué and Demaria, 2012; Li and Beghin, 2014; Winchester et al., 2012; etc.). These authors try to measure the differences in regulations by comparing the limits set by countries' authorities. This literature generally tries to measure the trade impact of setting stricter MRL for a product or a group of products. It draws a picture of the trade-restrictiveness of MRL regulations around the world. National regulations are compared to the international regulation used as the reference point above which national standards may be considered as protectionist.

Recently, a new literature emerges to analyze the "formation" of the MRL. Referring to the model of Grossman and Helpman (1994), Folletti (2012) has opened the debate on *disentangling protectionism from health protection as drivers for MRL regulations* inserting the Acceptable Daily Intake (ADI) in its empirical analysis. Her analysis also includes the impact on human health of the various chemicals referenced in her database. She draws some results on the motivations of countries in setting their MRL which can be either set for health protection or for trade protectionism. More recently, Li et al. (2014) propose a model which *contributes to the understanding of the policy formation of food safety standard*. These authors use a political support function approach to represent the decision of policy makers in setting the MRL and measure econometrically the level of trade protectionism induced by the MRL of pesticides and veterinary drugs. They introduce in their model economic, social, and political variables and measure the weight of each

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other. They find that MRL regulations and tariffs are substitute trade protectionism tools and that, *countries with higher regulatory quality set tougher standards.* For these authors, MRL are the outcome of the complex trade-off described by Henson and Caswell (1999). But claiming that MRL of pesticides are the results of a political compromise denies that they are set independently, based on sound science, and therefore suggest that they do not respond to legitimate social objectives. The World Trade Organisation (WTO), and particularly the Sanitary and Phytosanitary (SPS) committee, declares that *SPS measures should be based on (i) international standards as those of the Codex, (ii) science, including assessment of risk, (iii) a temporary principle of precaution in the absence of international standards or scientific evidence. Countries are free to set their own standards based on science*. As a consequence, each country can establish MRL independently on national conditions and on the basis of agricultural practice. This means that for a given product, countries may regulate various substances. A pesticide authorized in a country may not be regulated or even prohibited in another one.

But how are the MRL actually established? According to the Food and Agriculture Organisation (FAO), the MRL is the maximal concentration of a residue legally permitted or considered acceptable in or on a food product, a farm produce, or a product intended for animal feeding. When a chemical is approved, studies on residues are made in order to determine the residue level which could remain in the product after harvest in the worst case (worst case scenario). For this purpose, the substance studied is applied at the maximum of its recommendation for a given crop. During the field experiment, a theoretical maximum daily intake (TMDI) is computed taking into account all the vegetables and animal products a human being can consume given his diet pattern ($TMDI = \sum_i MRL_i(\text{mg/kg}) * Consumption_i(\text{kg})$), being *i,* the product. This TMDI is then compared to an ADI which is the maximum quantity of a substance someone can consume during its lifetime without adverse effects. The MRL should be fixed such that:

$$TMDI\,(\text{mg}) \leq ADI\,(\text{mg/kg}) * Body\ mass\,(\text{kg}).$$

Each country establishes a list of MRL and sometimes provides a default value for those pesticides that are not explicitly listed (see Table 1).

It seems thus, that MRL are efficient to protect human's health. Despite this, consumers' protection nongovernmental organizations still claim for a reduction in the use of pesticides or even the ban of other ones and declare that the setting of MRL can be called into question.

For instance, regularly the Pesticide Action Network (PAN) tries to alert the public opinion that current MRL would not be protective enough regarding consumers' health (PANE, 2014).

In this article, we try to investigate the strength of the relationship between the setting of MRL and their primary objective that should be the consumer's health protection. We reconcile the link between MRL regulations and public health and investigate, more thoroughly, the social drivers of regulations on limits of pesticides' residues. We restrict our analysis to plant products (i.e., fruits, vegetables, seeds, nuts, spices, tea, etc.). In order to perform this analysis, we compute a synthetic and polyvalent tool, hereafter Health Score (HS). This HS takes into account the level of long-term toxicity of the regulated pesticides on consumer health and ranks their MRL in order to establish if they are consistent with health protection (and have legitimate purpose) or if it is much laxer than the required level of protection it should provide.

We use the database on MRL of pesticide provided by the Federal Agricultural Service of the United State Department of Agriculture (FAS USDA MRL database: http://www.fas.usda.gov/maximum-residue-limits-mrl-database). We cross the MRL with the classification of long-term toxicological risk effects (hereafter Long-Term Effects or LTE) provided by the Quebec Ministries of Agriculture, and Environment and the National Institute of Public Health of Quebec on the SAgE pesticides Web site (http://www.sagepesticides.qc.ca/Default.aspx). The information provided in this Web site was used to compute the Quebec Pesticide Risk Indicator (Samuel et al., 2012). The combination of these two sets of information provides an original database that establishes the link between long-term toxicology and MRL by

Table 1
List of countries in the analysis and MRL regulation rules

Rule	Countries
Countries set their own standards	Argentina, Australia, Brazil, Canada, Chile, China, India, Indonesia, Israel, Japan, Korea, Russia, Singapore, South Africa, Taiwan, Thailand, Turkey, New Zealand, Vietnam, United Arab Emirates, Malaysia, Switzerland
Countries defer to Codex	Algeria, Angola, Barbados, Bermuda, Bahamas, Bangladesh, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Hong Kong, Honduras, Jordan, Kenya, Lebanon, Morocco, Netherlands Antilles, Nicaragua, Pakistan, Panama, Peru, Philippines, Trinidad and Tobago, Tunisia, Venezuela
Countries defer to EU standards	Belgium, Denmark, Finland, French Pacific Islands, France, French West Indies, Germany, Greece, Ireland, Italy, Jamaica, Netherland, Norway, Poland, Portland, Spanish, Sweden, the United Kingdom
Countries defer to Gulf Cooperation Council standards	Bahrain, Kuwait, Saudi Arabia, Oman, Qatar
Countries defer to exporting countries standards	Albania, Antigua and Barbuda, Cayman Island, Haiti, St. Kitts and Nevis, Sri Lanka, St. Lucia
Countries defer to U.S. standards	The United States, Mexico

product and country. Intuitively, these two variables should be negatively correlated, as a low LTE should imply a high MRL and *vice versa*. At first, we cross data on MRL and LTE and compute the HS in order to identify how cautious a country is when it fixes the limits of pesticides residue that plant products should contain in order to be suitable for consumption. We cluster the HS to draw a world picture of consumers' health protection. Then, we model the relation between the HS and certain variables that take into account not only socioeconomic patterns but also political and health characteristics to understand the formation of this specific standard.

We analyze the link between pesticides MRL regulations and public health as this link has been somehow neglected in previous literature which mainly focus on the trade protectionism aspect of the MRL. The literature on political economy on food standards, particularly the works of Swinnen and Vandemoortele (2008, 2009, 2011), provide our analysis for theoretical foundations. Following these authors, a standard should be the result of a social optimum which is determined by comparing the gains and losses of both producers and consumers. The determinants can be summarized from the supply side by the difference between the prices and the costs of compliance and from the demand side by the difference between the price and the "consumption effect" which is the benefit for a consumer to consume pesticide-free goods. But given the existence of conflicting interests, they model the standards as the results of a political optimum by introducing in the analysis the weight of the lobbies and the taxpayers. Our analysis addresses two issues: (i) Are the MRL of pesticides driven by legitimate precautionary motives? (ii) What is the role of these objectives (proxied by public health expenditures) in the setting of the MRL? We deal with the first issue by trying to give a measure of the "precautionary MRL" via the computation of a HS; the second issue is addressed thanks to an econometric modelization of the relation between this score and selected variables to understand the role of certain determinants (and particularly public health) in its formation. The results show that public health expenditures play a stronger role in the setting of stricter MRL for hazardous substances than the level of income.

This article is structured as follows. Section 2 presents the motivation of the analysis performed in this article. Section 3 describes the data and the clustering approach we implemented. The model is specified in Section 4 and results are developed in Section 5. Section 6 is devoted to the discussion of the results and conclusion.

2. Building a HS

At first we draw our analysis using information on MRL and on LTE which include three different dimensions: countries, products, and substances. For more clarity, we will use hereafter the term "product" to designate the plant products and the word "substance" to designate the chemicals. Information on the level of MRL is from the FAS USDA international MRL database which provides the level of pesticides and veterinary drug for 661 plant and animal products commodities, 90 markets (the European Union (EU) constitutes one market), and 352 pesticides. The database does not include processed food products. Our analysis focuses only on plant products (fruits, vegetables, cereals, etc.); meat, fish, and dairies are not considered.

The toxicity of the pesticides is captured through the LTE provided by the SAgE pesticides Web site maintained by the Government of Quebec (Canada). This Web site describes for a list of 441 substances their impacts on health and on environment. The impacts on human health are disaggregated in acute toxicity and long-term toxicity. Long-term toxicity of a substance is graded according to its risk level (extremely high, high, moderate, and low, see Table 2 and Table A.1 in the Online Appendix).

The intuition is that the MRL of a given substance should vary inversely with the level of its toxicity. Here, we are mainly interested in the chronic toxicity (or LTE) which affects the consumer (acute toxicity affects above all the producers). We can summarize this proposition in the following way: a low LTE should be associated with a high MRL for a harmless substance, while a high LTE should be associated with a low MRL for a hazardous substance. Thus, we can grade the substances listed by the SAgE pesticides by level of toxicity. We attribute a grade of 1 if the substance has a low level of risk, to 4 if the risk for human health is extremely high. Then, we match the list of substances contained in the FAS database with the corresponding one in the SAgE pesticides database. This merging led us to keep a list of 252 substances, 116 countries (for the need of the estimation we disaggregated the EU in 27 countries), and 585 plant products.

Combining LTE and MRL allows the performance of a score analysis to classify countries regarding their sensitivity to health concerns. In some way, we measure the level of precaution of countries with respect to human food exposure to pesticides and we can rank countries depending on their precautionary status.

Before computing the HS, we study the distribution of MRL (see Table A.2 in the Online Appendix). The MRL ranges between 0.0005 and 1,500 mg/kg with a kurtosis equal to 535.5. The peak of the distribution is around zero. To get an accurate overview of the sample, we first focus on the values of the MRL ranging between 0 and 500, and then on the values between 0 and 50; and subsequently between 0 and 10 to finally zoom in on the MRL between 0 and 1, which are the most frequent values. As far as the MLR values above 500 are marginal (they represent 0.004% of the observations), the kurtosis is still high; in the second, we lose 1.1% of the observations and the kurtosis is still high; in the third one, we lose 5.14% of observations; and finally in the fourth 21%.

Looking at the distribution of MRL for LTE equal to 3 or 4 (see Figs. A.1–A.3 in the Online Appendix), we define seven classes of scoring for each triplet country (c)/product (p)/substance (s) based on the following rule of decision:

$HS_{cps} = 7$ if LTE $= 1$ or 2 and $0 \leq$ MRL $\leq 1{,}500$

Table 2
Long-term effect of active ingredients

Long-term effect	Severity of the effects					
	Extremely high risk		High risk	Moderate risk		Low risk
	Indicators value					
Carcinogenicity	Human carcinogen	Probable human carcinogen	Possible human carcinogen	Data inadequate for assessment of human carcinogen potential		Not likely to be carcinogen to humans
Genotoxicity		Genotoxic for human	Potential genotoxic for humans		No or inadequate data	No evidence of human genotoxicity
Endocrine disruption		Evidence of endocrine disruption	Potential endocrine disruption		No or inadequate data	No evidence of endocrine disruption
Reproductive effects	Confirmed human effects	Suspected human effects	Confirmed animal effects	Suspected animal effects	No or inadequate data	No effects
Development	Confirmed human effects	Suspected human effects	Confirmed animal effects	Suspected animal effects	No or inadequate data	No effects

Source: Samuel et al. (2012) and Sage Pesticide, http://www.sagepesticides.qc.ca/Infos/SignificationSymbole.aspx#link-TraitementSanteTableau1.

Table 3
Distribution of $HS_{cps} = 7$

HS_{cps}	Freq.	Percent	Cum.
1	210,856	25.85	25.85
2	19,533	2.39	28.24
3	29,695	3.64	31.88
4	7,543	0.92	32.8
5	25,578	3.14	35.94
6	15,805	1.94	37.88
7	506,804	62.12	100
Total	815,814	100	

$HS_{cps} = 6$ if LTE $= 3$ or 4 and $0 \leq$ MRL < 0.02
$HS_{cps} = 5$ if LTE $= 3$ or 4 and $0.02 \leq$ MRL < 0.05
$HS_{cps} = 4$ if LTE $= 3$ or 4 and $0.05 \leq$ MRL < 0.1
$HS_{cps} = 3$ if LTE $= 3$ or 4 and $0.1 \leq$ MRL < 1
$HS_{cps} = 2$ if LTE $= 3$ or 4 and $1 \leq$ MRL < 10
$HS_{cps} = 1$ if LTE $= 3$ or 4 and $10 \leq$ MRL $\leq 1{,}500$.

Table 3 summarizes the distribution of the $HS_{cps} = 7$.

Then, we calculate the score by country as follows:

$$HS_c^7 = \frac{\sum_p \sum_s HS_{cps}}{7 * P.S},$$

where c denotes the countries, p denotes the product, and s the substance; $P.S$ is the number of products and substances pairs. The denominator is multiplied by 7 to take into account the number of classes for each product and substance pair. Due to its formalization, the HS_c is lower and upper bounded between 0 and 1. This score should be interpreted as a precaution level index. The higher the score, the more a country is concerned with human dietary exposure to pesticides in food. A score equal to 1 means that the country has ruled out all pesticides in which the LTE is high or extremely high.

We observe that whatever a given MRL the HS_{cps} is decreasing with LTE for a given pair of product/substance. Reciprocally, the HS_{cps} is decreasing or constant with MRL whatever the level of LTE. This index allows us to rank countries combining the level of the toxicity of a substance and the enforced regulation. Our previous considerations about the monotonicity along the LTE (respectively MRL) are transmitted to the HS_c at the country level. As a matter of fact, the HS_c can be considered as a mean of the HS_{csp} for a specific country. Thus, if almost all the substances regulated by a country displayed a high LTE, it would correspond to an overrepresentation of low HS_{cps}, which sum would tend to remain low (and vice versa). The same argumentation is also true for the MRL.

Finally, the HS_c is invariant to the number of the regulations by averaging the sum of HS_{cps} by the total number of products and substances pairs. In other words, even changing the number of products or substances referenced by a given country, the computation of the HS_c does not change.

This score ranges between 0.43 and 0.74 (see Map 1, Fig. A.4 and Table A.3 in the Online Appendix). For instance, a country with a score equal to 0.74 can be considered as more cautious than another with a score equal to 0.43. Globally, the score is not very high (between 0.4 and 0.7). But when we cluster it some rough observations can be made.

The lowest scores appear for countries referring to the rules of the Gulf Cooperation Council. Then, come two groups of countries where we find China, New Zealand, Mexico, India, Australia, Brazil, and the United States, among the main actors on the world agricultural markets. The fourth group gathers

Map 1. World distribution of the HS_c^7.

the countries which defer to the Codex. Finally, the EU and Russia close the series. It seems that for the chemicals explicitly listed (we do not take into account missing MRL), those with the highest toxicological effects are not those with the more stringent limits.

3. The model

In order to establish the determinants of the HS_c, we complete our analysis with an econometric estimation accounting for legitimate public health objectives. Following Swinnen and Vandemoortele (2008, 2009, 2011), we consider the HS_c as the level of standard s. They consider two levels of standards: $s^{\#}$ corresponds to the social optimum resulting from the maximization of a welfare function and s^{*} is the political optimum, a result of the maximization of the same welfare function taking the lobbies influence into account. $s*$ is driven by a trade-off between social, economic, and political interests, while $s^{\#}$ is driven by legitimate social objectives.

We are interested in econometrically investigating the relationship between certain determinants (and particularly public health) and the variation of the HS. Today, the Codex is considered as the reference by many countries. But we observe in our data that countries which adopt more restrictive standards than the Codex have a HS_c greater than the countries which follow the Codex. Moreover, as underlined by Josling et al. (2004, p. 43): *the SPS agreement has politicized decision making within the Codex more than in other standards organizations*.[1] Thus, we suppose that standards higher than the Codex's HS (hereafter HS_{Codex}) tend to be more influenced by public health considerations than the others.

Countries with a $HS_c > HS_{\text{Codex}}$ may be considered as countries which standards are more driven by precautionary

[1] We thank an anonymous referee for this valuable suggestion.

legitimate motives than countries with a $HS_c \leq HS_{\text{Codex}}$. We thus take the HS_{Codex} as the threshold (denoted $\overline{s^*}$). We define a binary variable $\widetilde{s^*}$ to discriminate against these two classes in order to understand what drives the HS_c beyond the reference level defined by the Codex (HS_{codex}).

For this purpose, we use a logit model by redefining the dependent variable as follows:

$$\begin{cases} \widetilde{s^*} = 0 & \text{if } s^* \leq \overline{s^*} \\ \widetilde{s^*} = 1 & \text{if } s^* > \overline{s^*} \end{cases}.$$

Let y the observed dependent variable and y^* the latent variable satisfying the single index model

$$y_j^* = x_j' \, \beta + \varepsilon_j. \quad (1)$$

Even if y^* is not observed, we do observe

$$y_j = \begin{cases} 1 & \text{if } y_j^* > 0 \\ 0 & \text{if } y_j^* \leq 0 \end{cases}. \quad (2)$$

In their model, Swinnen and Vandemoortele (2009) considered that the level of a food safety standard is driven on the supply side by the producers' cost of compliance, and on the demand side by the consumers' preferences, their perception bias (also called consumption effect), and the externality effect (also called warm glow effect). For the authors, public food safety standards do not induce any warm glow effect (Swinnen and Vandemoortele, 2009, p. 515), and thus we do not include it in our empirical analysis. Increasing the stringency of a food safety standard is a cost for both domestic and foreign producers, and consequently the impact will depend on the relative competitiveness of both industries. Concerning the consumers, increasing the stringency of the standard, the cost for the consumer increases but it increases its utility because it guarantees a safer product particularly if consumers trust in the capacity of the government to enforce the standard. We test some of these indicators on the standard setting. Our empirical model is written as follows:

$$\widetilde{S_c^*} = \beta_0 + \beta_1 Lngdp\_cap_c + \beta_2 Corruption_c + \beta_3 Autoc\_bin_c + \beta_4 Lnpubhexp_c + \beta_5 RCA\_veg_c + \beta_6 MFN\_veg_c + \varepsilon_c.$$

On the demand side $Lngdp\_cap_c$ is the logarithm of the gross domestic product (GDP) per capita of country c. It takes the level of consumption into account. $Corruption_c$ is the World Bank's Control of Corruption indicator. It *captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.* Following Onyango et al. (2007), the trust in institutions, particularly those in charge of food safety, has a positive influence on the consumer's perception of food safety, and thus this variable accounts for the perceived risk probability. Both indicators come from the World Bank Development Indicators (WBDI) database.

On the supply side, the RCA_Veg_c is the revealed comparative advantage of Balassa for vegetable products which accounts for the competitiveness of the domestic industry. MFN_veg_c is the weighted average most-favored-nation tariff rate for agricultural products. Both indicators have been retrieved from the World Bank World Integrated Trade Solution (WITS) database.

We also add two variables which may explain the formation of stringent/loose standards and have an impact on the cost for both consumers and producers. $Lnpubhexp_c$ is the logarithm of public health expenditures in percentage of GDP. Public expenditure consists in the *recurrent and capital spending from (central and local) government budgets, external borrowings and grants and social (or compulsory) health insurance funds*. We suppose that countries with high percentage of public health expenditures will be more inclined to set stringent standards. This indicator comes from the World Health Organization National Health Account database. On the contrary, following Besley and Kudamastsu (2006) whose results suggest that there is a positive link between health and democracy, we suppose that countries with a lower level of democracy are less able to set and enforce stricter standards. In order to test this relation, we add the Autocracy score from the Polity IV Projects (www.systemicpeace.org/polity/polity4.htm) which measures the degree of a government authority. Where "autocracy" defines *the political systems whose common properties are a lack of regularized political competition and concern for political freedoms.* It ranges from 0 (weak autocracy) to 10 (strong autocracy). We transform this variable in a binary variable. $Autoc\_bin_c$ is equal to 0 for a value of the original variable lower than 2, and 1 otherwise. MLR variables are measured for 2010; all other variables are for 2011 (except when they were not available in this case the closest values were substituted).

4. Results

Our model includes economic, social, and political factors that may influence the $\widetilde{S_c^*}$. This section presents the results from the specification of a logit regression[2] (see Table 4).

The model is consistent in the sense that the impacts of most regressors are statistically significantly different from zero but *Lngdp_cap* and *Corruption*. The confusion matrix gives the performance of the model in the classification of the observations. Looking at the confusion matrix (see Table 5), we can tell that this model fits quite well regarding the sample size in terms of its overall and correct classification rates. It also correctly predicts more than 86% of the countries' positioning. The confusion matrix highlights also that the model performs better (88%), the negative predicted values (that is to say, countries with the lower score), than the others (81%). These slightly unbalanced predictive performances can be imputed to the fact that there are more countries which score is lower

[2] The reduced number of observations does not allow performing an ordered logit regression.

Table 4
Estimations results

$\widetilde{S}_c^*$	Coefficients	Odd ratios	Marginal effects
$Lngdp\_cap_c$	0.006 (0.602)	1.006	0.0006 (0.062)
$Lnpubhex_c$	1.688^{*} (0.950)	5.413	0.174^{*} (0.909)
RCA_veg_c	-0.976^{***} (0.409)	0.376	-0.100^{***} (0.037)
$Corruption_c$	0.797 (0.767)	2.219	0.082 (0.077)
$Autoc\_bin_c$	-2.821^{***} (1.027)	0.059	-0.291^{***} (0.086)
MFN_veg_c	-0.080^{*} (0.049)	0.919	-0.008^{*} (0.004)

Note: Standard errors in parentheses; significant at level: $^{*}P < 0.10$, $^{**}P < 0.05$, $^{***}P < 0.01$.

Table 5
Confusion matrix

True			
Classified	D	$\sim D$	Total
+	22	5	27
−	7	53	60
Total	29	58	87

Classified + if predicted $\Pr(D) \geq 0.5$
True D defined as $HS_c \neq 0$

Sensitivity	$\Pr(+ \mid D)$ 75.86%
Specificity	$\Pr(- \mid \sim D)$ 91.38%
Positive predicted value	$\Pr(D \mid +)$ 81.48%
Negative predictive value	$\Pr(\sim D \mid -)$ 88.33%
False + rate for true $\sim D$	$\Pr(+ \mid \sim D)$ 8.62%
False – rate for true D	$\Pr(- \mid D)$ 24.14%
False + rate for classified +	$\Pr(\sim D \mid +)$ 18.52%
False – rate for classified −	$\Pr(D \mid -)$ 11.67%
Correctly classified	86.21%

or equal than the Codex (corresponding to two-thirds of the sample).

In the estimation, the coefficient of *Lngdp_cap*, the economic dimension of the countries is positive but not significant. However, the coefficient of *Lnpubhexp*, the share of public health expenditures is positive and significant. This model highlights also the nonneutrality of the political regime as the lack of democratic institutions (*Autoc_bin*) has a negative and significant coefficient. The perception of the quality of institutions by consumers (*Corruption*) is positive but not significant. Concerning the remaining variables, the coefficient of *RCA_veg* is negative and significant which means that countries less competitive tend to set stricter standards. And the coefficient of *MFN_veg* is also negative and significant meaning that countries with higher tariff rates have less restrictive standards.

In order to quantify the impact of each variables involved in the model, we compute the odds ratio and marginal effects (see Table 4). The odds ratios give information on the multiplicative effect of the variation, for a unit change, on the probability for the dependent variable to switch from zero to one. That is to say, odds ratios specify the determinants (independent variables) which make a country move from the group of countries less concerned with pesticide exposure to the group of countries more concerned with pesticides exposure.

The marginal effects measure discrete change for categorical variables while they measure the instantaneous rate of change for continuous variables; when all other variables are at mean. But interpreting the marginal effects is only straightforward for categorical variable because they change for each level of the independent variable, thus we will mainly focus on the interpretation of the odds ratios.

Focusing on odds ratios, a 1 percentage point increase in the share of public health expenditures (*Lnpubhexp*) increases by 69% the odds of setting a stringent standard, all other variables being constant. On the contrary, if *Autoc_bin* switch from 1 to 0 the odds of $\widetilde{s}^* = 1$ diminish by 94%. Finally, countries more competitive tend to resort less on the stringency of MRL and a unit increase in *RCA_veg* decreases by 62% the odds of a precautionary standard, in a similar way countries with higher MFN import duty rates are less likely to set stricter MRL (−8%).

5. Conclusion and discussion

Our analysis highlights some factors involved in the formation of MRL of pesticides. We first compute a HS reconciling data on MRL and data on chronic toxicity for several chemicals. Then, we transform this score in a binary variable in order to test with a logistic model the relation between this score and some economic, social, and political variables. We are interested in analyzing the factors that drive the setting of MRL for substances with the highest long-term toxicological impacts on human health and thus the level of health protection a nation wants to achieve. We want to know first if standards on MRL are driven by precautionary legitimate objectives or if it is the outcome of a political trade-off and what influences their divergence. In contrast with other research (particularly the work of Li et al., 2014), we find no statistical evidence on a positive link between the HS and the level of income or the consumer's risk perception but with the importance of public health expenditures. The results show here that it is not the absolute wealth of a nation that influences the level of health protection but rather the share of its wealth devoted to health. If the perception by consumers of the quality of the institutions does not matter (*Corruption* is not significant), the political regime matters, in the sense that a restriction in the openness and competitiveness in executive recruitment and participation diminishes the chance to set stricter standards. Finally, in line with other works, economic factors also matter. The competitiveness of the domestic industry limits the stringency in standards (the odds of setting stricter standards decreases by 62% when *RCA*_veg increases) while freeing trade has instead a positive impact on it (+8%).

We underline here, the important role of public health in the setting of MRL. These results are interesting as they show that at a same level of wealth, population, and democracy, a one unit increase in the share of public health expenses in GDP multiplies the probability of setting stricter MRL regulations by 69%. These results are not fully consistent with the recent outcomes of the literature dealing with this issue. Li et al. (2014) show that in higher per capita income countries, consumers' economic and sociodemographic characteristics are the main drivers of MRL. We shed light on the fact that public health expenditures also matter in limiting the residue of highly hazardous substances. Those authors measure the absolute stringency of the MRL while adding the level of toxicology (via the LTE), we provide a measure of their relative stringency. We are thus able to determine the way countries arbitrate between the level of the regulation and the health impact of pesticides.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Online Appendix
Table A1: Active substances with LTE > 2
Table A2: Descriptive statistics for MRL data
Figure A1: Distribution for MLR < 2 for LTE >2
Figure A2: Distribution of MRL ≤0.1 for LTE >2
Figure A3: Distribution for MLR > 2 and LTE > 2
Figure A4: Plot of the HS_c^7
Table A3: Value of the HS_c^7 by country
Table A4: Descriptive statistics
Table A5: Matrix of correlations

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EU Trade Regulation for Baby Food: Protecting Health or Trade?*

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1. INTRODUCTION

FOOD safety and food quality are the two sides of the same coin. Food safety is a fundamental requirement of food quality, and this is particularly relevant when children are involved. A large number of medical studies have shown that pesticides and contaminants contribute to various health problems including cancer, lung disease and reproductive, endocrinal and immune system disorders. They also agree that children are more vulnerable to the dangers of pesticides and contaminants because as soon as they start eating solids, they consume a limited number of food items, most of which are fruits and vegetables. This increases children's exposure to substances they are less capable of metabolising than adults (von Mühlendahl et al., 1996; Koletzko et al., 1999).

To protect children from deleterious substance intake, the European Union (EU) has laid down distinct rules for baby and infant processed food (hereafter called baby food). Since 2006, maximum residue limits (MRLs) of pesticides in baby and infant food in the EU have been covered by Directive 2006/125/EC on processed cereal-based foods and baby foods for infant and young children and Regulation EC 1881/2006 setting maximum levels for certain contaminants in foodstuffs. This legislation bans processed cereal-based food and baby food that contain residues of individual pesticides at levels exceeding 0.01 ppm (0.01 mg/kg). On the one hand, this legislation helps to protect the most vulnerable part of the population, but at the same time, non-European competitors may raise concerns about the trade barriers this can create. The issue is of particular interest as the EU trade of baby food has increased by 30 per cent in recent years according to UN COMTRADE data. According to Les Echos.fr (Schaub, 2007), the world average consumption of baby food was about 20 kg per baby and per year, but reached 119 kg in the United States, 135 kg in Western Europe and 215 kg/baby per year in France in 2006. There is still room for progress particularly in the emerging countries, and thus, this industry is considered a gold mine. Indeed, the baby food industry which is dominated by a small number of multinationals as Nestlé, Danone and Heinz, and Kraft has seen its production increases rapidly in parallel with the rise in the female employment rate. In 2010, the global baby food market represented US$36.7 billion,

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*This article is dedicated to the memory of Professor Giovanni Anania, without whom nothing would have been possible.

among which dried baby food accounted for 3.7 billion, milk formula 25.2 billion, prepared baby food 6.5 billion and other baby food 1.4 billion. This sector is forecast to reach US$ 55 billion by 2015. At the global level, the Asia–Pacific region accounted for 37 per cent, Western Europe 22 per cent and North America 18 per cent (Agriculture and Agri-Food Canada, 2011).

The impact of MRL on trade has largely been covered by the literature since the beginning of the 2000s. For instance, the works of Otsuki et al. (2001), Wilson et al. (2003), Wilson and Otsuki (2004) and Xiong and Beghin (2012) investigated the impact on trade of setting a stricter limit on a specific substance. But as Li and Beghin (2014, p. 58) state, 'picking just one of the NTMs may lead to subjective selection bias and a mischaracterisation of the set of NTMs regulating the market under study'. To tackle this issue, several authors have developed indicators that aggregate across food safety regulations and standards (Achterbosch et al., 2009; Rau et al., 2010; Drogué and DeMaria, 2012; Vigani et al., 2012; Winchester et al., 2012; Li and Beghin, 2014; Melo et al., 2014; Ferro et al., 2015). These indices can capture asymmetries or dissimilarities between importing and exporting countries' safety regulations and be further used in econometric analysis.

In their 2009 working paper, Achterbosch et al. developed a heterogeneity index to compare sanitary regulations and applied it to Chilean fruit exports. Rau et al. (2010) built a similar measure and applied it to various agricultural products among which cheese is the only processed food. Yet cheese does not raise the same kind of issues as baby food as the former is closer to milk. Winchester et al. (2012) introduced the heterogeneity index developed by Rau et al. (2010) in a gravity equation assessing trade impacts of dissimilarity in regulations between 10 regions and eight product groups (beef, pig meat, cheese, barley, maize, rape and some fruits and vegetables). Drogué and DeMaria (2012) proposed the regulatory distance measure, which is the Pearson distance between the MRL of pesticides in apples and pears. Winchester et al. (2012) studied the trade impact of genetically modified organisms' regulations and, finally, Li and Beghin (2014) built an original aggregation index of non-tariff measures and applied it to an impressive list of 340 raw products. Melo et al. (2014) innovated with an index that takes into account the subjective barriers, that is, the exporters' perception of the stringency of standards for Chilean fruits. Finally, Ferro et al. (2015) enhanced the literature with a time-series index of restrictiveness that takes into account all bilateral regulations on MRL over a set of 1,500 pesticides, 61 countries and 66 agricultural products.

In this paper, our objective is to take advantage of these recent contributions to the trade literature by building an index able to synthesise the regulation on MRL set by Directive 2006/125/EC in order to assess its impact on the EU imports of baby food. Our paper reinforces this literature as it is, to the best of our knowledge, the only one to apply this methodology to agro-food processed products. The other original aspect of this study is that it is the only one to deal with international trade in baby food, a market that in recent years has experienced notable annual growth in terms of consumption. In certain regions of the world (Brazil, Russia, China and Argentina), this growth has exceeded 10 per cent (Agriculture and Agri-Food Canada, 2011). Most papers dealing with baby foods analysed primarily consumer preferences (Maguire et al., 2006; Peterson and Li, 2011).

The paper is structured as follows. After introducing the EU specific regulation on baby and infant food in Section 2, we describe the construction of an index used to estimate the degree of severity imposed by the EU on pesticides in food for children under the age of three (Section 3). We propose the specification of a gravity equation and describe the set of data in Section 4. Then, we introduce the estimation techniques in Section 5. Section 6 presents the estimation results. Section 7 contains the conclusion.

2. A SPECIFIC REGULATION FOR BABY FOOD IN THE EU

Physicians have been warning policymakers about the health problems posed by pesticide exposure through food intake since the 1960s. From 1967 onwards, the World Health Organization (WHO, 1987) assembled a group of scientists to study the relationship between age and the toxic effects of chemicals. Even if studies of animals showed that younger ones seemed more sensitive to chemical exposure, the group stated that there was no evidence whatsoever against the safety of compounds that might be present in the babies' diet. It concluded that as babies constitute a specific population, further epidemiologic research on babies as well as chemical and reproductive studies on newborn and young animals should be conducted.

However, this concern has only recently been taken into account. Until 1999, the European Union had no unified policy regulating pesticide residues in baby food. MRLs of pesticides were set at national levels. Few countries had specific rules on food intended for infants (children under the age of 12 months) and toddlers (between one and three years old). von Mühlendahl et al. (1996) reported that in Europe, only France, Switzerland, Belgium, Germany and Luxembourg have specific lower limits. Food for babies or toddlers was regulated by the Directive 91/321/EEC concerning infant formulae and follow-on formulae establishing in Article 6 a vague recommendation on the safe quantity of substances remaining in baby milk and that the definition of maximum limits would be postponed. The legislation was rather ambiguous; there was no compulsion regarding specific limits and it referred only to milk.

However, in 1993 attention was drawn to the question of pesticide residues in baby food. Residues of lindane – an organochlorine insecticide – were found in imported vegetables from Spain prepared as baby food at concentrations of 0.04 ppm, well above the 0.01 ppm German MRL. The manufacturer whose product was withdrawn from the market complained to the European Community (EC) on the grounds that it constituted an illegal barrier to trade (von Mühlendahl et al., 1996). Thus, the EC commissioned a scientific report on pesticide residue and baby food. On 23 September 1994, the Scientific Committee for Food (SCF) concluded that there was no evidence on the danger of such a concentration of lindane per kg of baby food, considering intake (European Commission, 1996). In 1996, the EC set out a specific directive (Directive 96/5/EC) on processed cereal-based foods and baby foods for infants and young children wherein the previous Article 6 was revised to include processed cereal-based foods and baby foods. But a recommendation was made to establish maximum levels without delay. In 1997, the SCF met again and concluded that concerning certain pesticides even for a MRL set at 0.01 ppm in foods intended for infants and young children, there is a possibility that an infant could exceed the acceptable daily intake (ADI) (European Commission, 1999). The directive of 1996 was amended in 1998 but without altering limits on pesticides residues.

In 1999, the Directive 96/5/EC was once again amended by the Commission Directive 1999/39/EC of 6 May 1999, replacing the former Article 6. A limit of 0.01 mg by kg of baby food was explicitly set for all pesticides, except for those substances for which specific levels were set in Annex VII. However, the prohibition of trade in products not complying with this directive was delayed until 1 July 2002. It was later further amended by the Directive 2003/13/EC which has added new limits below 0.01 ppm for a limited number of substances.

Since 2006, MRLs of pesticides in baby and infant food in the EU have been covered by the Directive 2006/125/EC (which drew together the Directive of 1996 and its successive amendments) and the EC Regulation 1881/2006. These texts ban baby food products that contain pesticides over the 0.01 ppm limit. Thanks to this very stringent rule, a 2010 report from the Canadian Ministry of Agriculture pointed out that EU pesticide levels are so low in baby food that these products are 'virtually the same as organic varieties' (Agriculture and Agri-Food Canada, 2010, p. 4).

No other country specifically regulates foodstuffs for children. Some countries such as the United States or Canada consider sensitive subpopulations as children in their risk assessment process rather than setting specific MRL for them. In the Food Quality Protection Act of 1996, the United States integrated many recommendations issued in the National Research Council 1993 publication 'Pesticides in the Diets of Infants and Children'. This led, for instance, to a ban on the use of organophosphate pesticide for 'kid food' like apples (US EPA, 2010).

Hence, we find a difference in regulations between the EU and most of its competitors, the majority of whom do not differentiate food safety regulations according to age of the consumer. From this point, the specific European policy, albeit consumer-driven, may be seen as a form of protection constraining other countries to export primary products rather than processed products to the European markets. The Rapid Alert System on Food and Feed (RASFF) portal, which reports notifications and alerts concerning food safety risk at the EU borders, has released notifications of 86 alerts/rejections/information since 1980 on baby or infant food products (excluding formula), 21 involved overrun pesticide limits, 14 of which were issued between 2006 and 2013, and almost all concerned products originating from the EU. These figures would tend to highlight the fact that from 2006 onwards, the tightening of the EU regulation mostly impacted its own trade.

In this paper, we aim to quantify the impact of the specific European regulation concerning MRL of pesticides on the EU imports of baby food. This market is divided into two families of products, infant milks and weaning foods; hereafter we only focus on the latter. To this end, we first compare the EU regulation with the regulations of its major competitors through an indicator developed from the methodology described in Li and Beghin (2014). This measure is hereafter called the 'severity index' as it indicates the stringency of the EU regulation on MRL of pesticides in infant and baby food compared to the one of its major trade partners. Subsequently, we introduce this indicator as a variable in a gravity equation. Our objective is to assess the trade implications of the regulatory standard levels in the baby food sector.

3. CONSTRUCTION OF THE INDICATOR

$Severity^{k}_{EU-ROW} = Severity_{jk}$ is our index. As aforementioned, it has been developed from the methodology proposed by Li and Beghin (2014) and is a protectionism index which allows aggregation over a multitude of substances. Nevertheless, this measure must be adapted to meet our needs. In their paper, Li and Beghin consider the MRL to be protectionist if the values are lower than those set by the Codex Alimentarius. We also consider the European legislation as protectionist if the MRLs set by the EU are lower than the corresponding MRLs of its competitors. By adapting the methodology of Li and Beghin (2014), we can compute our index of severity as follows:

$$Severity_{EU-ROW}^{k} = \frac{1}{N}\left(\sum_{p=1}^{N} I_{\left(MRL_{EUp}^{k} < MRL_{ROWp}^{k}\right)} * exp\left(\frac{MRL_{ROWp}^{k} - MRL_{EUp}^{k}}{MAX\_MRL_{p}^{k}}\right)\right)$$

where MRL_{EUp}^{k} is the MRL set in the EU for pesticide p and product k, and MRL_{ROWp}^{k} stands for the MRL of exporting countries for pesticide p and product k. To normalise our index and avoid division by zero, $MAX\_MRL_{p}^{k}$ is the greatest MRL found in all regulations for products k and substance p, while N is the total number of substances and it is equal to 912. $I_{\left(MRL_{EUp}^{k} < MRL_{ROWp}^{k}\right)}$ is an indicator function that is equal to 0 when $MRL_{EUp}^{k} \geq MRL_{ROWp}^{k}$ and equal to 1 when $MRL_{EUp}^{k} < MRL_{ROWp}^{k}$.

The score of the severity index allows us to compare the regulations on the basis of their relative severity. As stressed by its designers, this index is invariant to scale and lower and upper bounded by 0 and $e \cong 2.72$. A value equal to 0 means that the EU regulation is equally or less stringent than the exporter's regulation; conversely, a higher value implies that the EU applies a stricter regulation, and a score equal to e means that the 'distance' between the EU regulation and the exporter is the longest within the sample. It is also convex in protectionism, and indeed, we consider that the difficulty in reaching the European standard increases at an increasing rate; in doing this, as quoted by Li and Beghin (2014), 'we put more weight on the MRL that are relatively more stringent'p. 60.[1] This regressor is also time-invariant: $Severity_{jtk} = Severity_{jk}$, as the MRL did not change between 2008 and 2010.

At this point, something must be said on the computation of our severity index. One difficulty stems from what Li and Beghin (2014) call regulatory intensity. Each country holds its own list of pesticides, but the absence of a certain pesticide from a list may have two interpretations: the 'missing' substance may be either unregulated (when the country considers it innocuous) or regulated by default (a default limit applies). To tackle this issue, they used a list of substances common for all countries, the one drawn up by the Codex Alimentarius, hereafter Codex. We believe that using this list leads to a loss of information because the Codex does not regulate many substances (127 overall). We decided, therefore, to work on the longest possible list of pesticides. To deal with missing substances, we follow Drogué and DeMaria (2012) who proposed: (i) when the country has information on the default value, to replace the missing value by the default value (see Table A1 in Appendix); and (ii) if the pesticide is not regulated and information on default limit is missing, to replace the missing value with the maximum value found in the data. But doing so may lead to a left-censored index. Thus, we have also computed the severity index only on the substances regulated by the Codex as Li and Beghin did. The differences between the two ways of computing the severity index are marginal.

Another aggregation issue arises because MRLs of pesticides are generally defined for raw products and very seldom for processed ones. However, this market is evolving in terms of variety and the range of products supplied by the baby and infant food industry has become considerable. For instance, Blédina (leader on the French market) has no less than 96 products in its range of baby food, and Nestlé (another important player in the French market for baby food) counts 18 brands (including all types of food and beverages). In the trade nomenclature of the European Union, baby foods (excluding baby formula) are defined at eight-digit level of the Combined Nomenclature (NC8) by six codes: 16021000 homogenised preparation of

[1] As mentioned by an anonymous referee, this relation can also be linear, but in such a case, we lose sight of the fact that it is more difficult to comply with lower MRLs.

meat; 20051000 homogenised preparation of vegetables; 20071010 and 20071099 homogenised preparation of fruits; 21041000 soups and broth preparations; and 21042000 homogenised composite food preparations. Our task now is to associate pesticide MRL with these six NC8 commodities (see Figure A1 in Appendix). As the focus is on baby food, we concentrate on foodstuffs which make up baby and infant 'ready-to-eat' meals, and select them on the basis of the various 'recipes' proposed by the two leading French companies Blédina and Nestlé on their website. This selection includes 26 raw products allocated among four classes (fruits, vegetables, cereals and meats). There are six fruits (apples, apricots, bananas, orange, peaches, pears); 11 vegetables (aubergines, green beans, carrots, leeks, peas, peppers, potatoes, spinach, squash, tomatoes, zucchini); five cereals (barley, corn, oats, rice, wheat); and four meats (bovine, pig, poultry and turkey). We compute the severity index for each raw product and country pair (EU versus its main sources of import). We then derive a severity index by class, considering the greatest index value among all the raw products within a class. Finally, we associate classes and NC8 commodities according to their main common ingredients: meats for NC8 (16021000), vegetables for NC8 (20051001) and fruits for NC8 (20071010 and 20071099). As far as NC8 (21041000), which is a composite of cereals and vegetables or cereals and fruits or meat and vegetables or meat, vegetables and cereals, we take the greatest index value over the four classes. MRLs for baby food are used for computing the severity index.

Table 1 shows the values of the severity index by NC8 commodity and country. They range from 0 to 1.24. South Africa, Norway and Switzerland report an index value equal to zero because they apply the same regulation as the EU. Argentina, Australia, China, Korea, Mexico, Russia and the United States report a value of severity between 0.1 and 0.6, which means that, in general, their regulations are close to those of the EU; this is due to the fact that these countries apply zero-tolerance provisions or a very low maximum level on a considerable number of substances. The remaining countries display higher values of 0.87 to 1.24. Most of these latter countries apply the Codex rules. Our hunch is that a higher index value should reduce trade. To verify this hypothesis, we define and estimate a gravity model in the next sections.

4. MODEL SPECIFICATION AND DATA

Gravity modelling is now a widely used tool in trade research, which allows researchers to take into account a wide range of trade issues from which those concerning food safety regulations constitute the core of a growing body of literature (DeMaria et al., 2011).

We slightly modify the traditional gravity equation given by:

$$\ln\left(M_{ij}\right) = \beta_0 + \beta_1 \ln(GDP_i) + \beta_2 \ln\left(GDP_j\right) + \beta_3 \ln\left(Dist_{ij}\right) + \beta_4 \ln\left(Tarif_{jk}\right) + \sum_{n=5}^{N} \beta_n Z_{ij}^n + \varepsilon_{ij}, \tag{1}$$

where M_{ij} is the trade flow between country i and country j, GDP_i and GDP_j are the countries i and j Gross Domestic Products, $Dist_{ij}$ reflects the impact of transport costs, proxied by the kilometric distance between countries. $Tarif_{jk} = 1 + tariff_{jk}$ is the EU applied ad valorem tariff on country j to commodity k and Z_{ij}^n is a set of variables related to trade barriers including common language, common border and past colonial relationships, ε_{ij} is the error term.

Our modified gravity equation is written as follows:

TABLE 1
EU Severity Index at NC8-Digit Level by Exporter

EU vs.	*16021000* *Meat*	*20051000* *Vegetable*	*20071000* *Fruit*	*21040000* *Composite*
Argentina	0.15	0.14	0.13	0.15
Australia	0.16	0.12	0.15	0.16
Brazil	0.91	1.24	1.22	1.24
Canada	0.87	1.15	1.06	1.15
Chile	0.91	1.24	1.21	1.24
China	0.14	0.12	0.13	0.14
Colombia	0.91	1.24	1.21	1.24
Egypt	0.91	1.24	1.21	1.24
European Union	0.00	0.00	0.00	0.00
India	0.91	1.24	1.22	1.24
Indonesia	0.91	1.24	1.21	1.24
Israel	0.91	1.24	1.20	1.24
Japan	1.00	1.05	1.05	1.05
Korea	0.43	0.60	0.59	0.60
Mexico	0.13	0.12	0.12	0.13
Malaysia	0.91	1.24	1.21	1.24
New Zealand	0.89	1.16	1.08	1.16
Norway	0.00	0.00	0.00	0.00
Philippines	0.93	1.24	1.23	1.24
Russia	0.14	0.12	0.12	0.14
Saudi Arabia	0.91	1.24	1.22	1.24
Singapore	0.91	1.24	1.22	1.24
South Africa	0.00	0.00	0.00	0.00
Switzerland	0.00	0.00	0.00	0.00
Taiwan	0.91	1.20	1.20	1.20
Thailand	0.91	1.24	1.21	1.24
Turkey	0.91	1.24	1.21	1.24
United States	0.26	0.23	0.24	0.26
Vietnam	0.91	1.24	1.21	1.24

$$
\begin{aligned}
ln(M_{ijtk}) &= \beta_0 + \beta_1 \ln(RetSale_{it}) + \beta_2 \left(RetSale_{jt}\right) + \beta_3 \ln\left(Dist_{ij}\right) + \beta_4 \ln\left(Tarif_{jtk}\right) \\
&\quad + \beta_5 ln(Severity_{jk}) + \sum_{n=6}^{N} \beta_n Z_{ij}^n + fe_i + fe_j + fe_t + fe_k + \varepsilon_{ijtk},
\end{aligned} \tag{2}
$$

where M_{ijtk} are the imports of EU country i from exporter j at time t of product k. As suggested by De Benedictis and Taglioni (2011), we keep this term in nominal values but we convert them in US$ to harmonise the monetary units of the various databases. $RetSale_{it}$ and $RetSale_{jt}$ are the current values in million US$ of prepared baby food retail sales in respectively the importing and exporting countries, at time t. They are used as a proxy of baby food consumption. $Tarif_{jtk}$, is the EU applied ad valorem tariff on country j to commodity k at time t as previously defined. $Severity_{jk}$ is our key variable.

Z_{ij}^n is a set of binary variables including $Border_{ij}$, $Lang_{ij}$ and $Colony_{ij}$ equal to 1 if countries i and j share the same border, speak the same language and have had past colonial relationships and zero otherwise. In the specification, importers, exporters, products and time fixed effects (fe_i, fe_j, fe_k, fe_t) are included. Following Anderson and van Wincoop (2003, 2004), we should include the multilateral resistance term (MRT) in our specification.

As suggested by Baldwin and Taglioni (2006), time varying importer and exporter fixed effects provide a solution to unobserved heterogeneity and account for MRT and provide consistent specification. However, these terms would be perfectly collinear with the severity index and thus totally absorb its effects; for this reason, we consider time-invariant fixed effects. Furthermore, the time period of our study is very short and the use of invariant fixed effects controlling for the consumption of baby food products in the importing and exporting countries as well could be another way to consider the MRT. Finally, ε_{ijtk} is the error term.

To perform alternative estimates (for robustness checks) and to test for endogeneity, we also considered the following.

$InfantPop_{it}$ and $InfantPop_{jt}$ which are respectively the importing and exporting countries infant (from 0 to 5 years old) populations at time t and are used as alternative proxies of consumption.

The POP_pt_t score (available at epi.yale.edu) summarises the performance of pesticide regulations and ranges between 0 and 100. This index considers whether a country has signed the Stockholm Convention and allows, restricts, or bans the 'dirty dozen' persistent organic pollutants (POP).[2] The higher the score, the greater the efforts a country makes to improve environmental quality.

The model is tested both on the set of variables and on the functional form. The *t*-test, Wald tests and Ramsey Reset test are carried out.

Another issue that we have to address is the existence of endogeneity. The EU regulation being more stringent than its partners' regulations could be implemented with the intent to limit imports of baby food products. For this reason, we need to check for the exogeneity of our severity index. If our severity index is endogenous, it violates the ordinary least squares (OLS) assumptions because it could be correlated with the error term. To test it, we use an instrumental variable approach (IVA). However, employing IVA is not an easy task, because we need to find an instrument correlated with the severity index but not with the trade flows. In this context we use the *POP_pt* score which, as previously said, is the country environmental quality score. We perform the Hausman endogeneity test where χ^2 (8) = 3.92 and the *p*-value = 0.86. This suggests that there is no endogeneity issue and the severity index can be considered exogenous. In the rest of the paper, all the estimations have been performed without using instruments. We also tested the endogeneity using the two-stage least squares and the exogeneity of the severity index is still confirmed.

Our focus is to assess the effects of the EU discipline over time. Unfortunately we do not have data on the evolution of the regulation of MRL of pesticides before 2008. Thus, the time dimension of our analysis is 2008–10, for which the MRLs were available. Variables are described in Table 2.

On a global level, the baby food market involves both developed and emerging countries. We consider the EU countries as the importing markets but due to the insufficient availability of certain data, we had to restrict the sample to only 20 EU countries: Austria, Belgium, Bulgaria, the

[2] Initially, twelve POP have been recognised as causing adverse effects on humans and the ecosystem, and these can be divided into three categories:

- pesticides: Aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene;
- industrial chemicals: hexachlorobenzene, polychlorinated biphenyls (PCBs); and
- by-products: hexachlorobenzene; polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/PCDF); and PCBs.

TABLE 2
Description of the Variables

Variables	*Description*
M_{ijtk}	Value of EU imports from country j of product k in year t
d_{ij}*	A binary variable such that $Z^*_{ij} = 1 \, if \, M^k_{ijt} > 0$
fe_i, fe_j, fe_t, fe_k	Respectively importing, exporting, year and product fixed effects
$Dist_{ij}$	Distance between partners
$Tarif_{jtk}$	EU's applied tariff for country j, products k and year t
$Severity_{jk}$	Measure identifying the severity between EU and its partners j for product k.
$RetSale_{it}$ $RetSale_{jt}$	Value of the retail sales of prepared baby food in the EU country i and its trading partners j
$InfantPop_{it}$ $InfantPop_{jt}$	Infant population in EU country i and its trading partners j
$Border_{ij}$	Binary variable equal to 1 if trading partners share the same border and 0 otherwise
$Colony_{ij}$	Binary variable equal to 1 if trading partners have had a colonial link and 0 otherwise
$Lang_{ij}$	Binary variable equal to 1 if trading partners share the same language and 0 otherwise
u_{ijtk} ε_{ijtk}	Error terms of the selection and outcome equation
IMR_{ijtk}	Inverse Mills ratio
POP_pt_t	Score on persistent organic pollutants regulation

Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden and the United Kingdom.

The exporters being considered in the analysis are the 20 EU countries previously mentioned, Argentina, Australia, Brazil, Canada, Chile, China, Colombia, Egypt, Indonesia, India, Israel, Japan, Korea, Mexico, Malaysia, New Zealand, Norway, Philippines, Russia, Saudi Arabia, Singapore, South Africa, Switzerland, Taiwan, Thailand, Turkey, the United States and Vietnam. These countries have also been chosen according to data availability.

We retrieved our data on EU imports from the Eurostat Comext database over the period 2008–10.

Our data on MRL come from the DG Sante (formerly called DG Sanco) for the EU and from FAS USDA for other countries. But since limits vary from one country to another, and policies regarding the implementation of international standards are not always transparent, we have cross-checked, as far as possible, all limits against the domestic regulations.

The remaining data are collected from several sources: consumption of baby food (proxied by the value of retail sales) comes from Agriculture and Agri-Food Canada (2011); infant populations come from the United Nations Population Information Network (UNPIN), and EU tariffs come from the EU Taric database. Distance, common language and colony are from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).

The combination of the different sources leads to an original database that associates trade, MRL and country variables at product line. We take the intra-EU trade into account.[3] The descriptive statistics of our variables of interest are displayed in Table A2 in Appendix. Table A3 in Appendix reports the simple correlations among the variables used in the empirical model. As expected, trade is positively correlated with retail sales of importing countries and negatively correlated with the retail sales of exporting countries. Yet, it is positively

[3] If we consider EU at an aggregated level, the Reset test detects misspecification of the gravity equation in all estimation strategies.

correlated with common border and common language and *POP_pt*, while trade, severity index, distance and tariff are negatively correlated.

5. ESTIMATION PROCEDURES

The simplest way to estimate equation (1) is using OLS. Yet in this case, a problem arises because too many zeros are present in the dataset. This is often the case when highly disaggregated data are used. Excluding zero observations creates a selection bias and adding a small constant to the trade flows introduces a measurement error. This matter has already been discussed extensively and several alternative approaches have been proposed to overcome it such as the pseudo-Poisson maximum-likelihood method (PPML), the two-step models (Helpman et al., 2008; Martin and Pham, 2008) and the zero-inflation models (ZIM; Burger et al., 2009).

As shown by Santos Silva and Tenreyro (2006), truncation of trade flows at zeros produces biased OLS estimations. In addition, if heteroscedasticity is present, the estimates from the log-linearised gravity equation may produce inconsistent estimates of the coefficients. The PPML estimator can overcome these problems, thanks to its multiplicative form, which provides a natural way to deal with zero trade flows. The estimation of the gravity model by PPML is consistent in the presence of heteroscedasticity and is reasonably efficient, especially when large samples are involved. The objective function is log-linear instead of log–log, implying that the dependent variable does not have to be transformed logarithmically. Therefore, the expected value of the trade flow, considering *Z*, is given by:

$$E\{M_{ijtk}|Z\} = exp\left(Z^{n}_{ijtk}\beta\right) + \varepsilon_{ijtk}. \tag{3}$$

With $M_{ijtk} > 0$ and $E\left[\varepsilon_{ijtk}|Z^{n}_{ijtk}\right] = 0$, where Z is the vector of the explanatory variables, β is the vector of the coefficients to be estimated, and ε is the error term.

If the trade flow variable M_{ijtk} is assumed to follow a Poisson distribution, then a likelihood function can be derived to obtain the vector of coefficients by solving the first and second-order moment conditions (Gourieroux et al., 1984).

Our specification can be written as follows:

$$E\left(M_{ijtk}|Z^{n}_{ijtk}\right) = exp\Big[\beta_0 + \beta_1 ln(RetSale_{it}) + \beta_2 \ln\left(RetSale_{jt}\right) + \beta_3 \ln\left(Dist_{ij}\right) + \beta_4 \ln\left(Tarif_{jtk}\right) + \beta_5 \ln\left(Severity_{jk}\right) + \sum_{n=6}^{N} \beta_n Z^{n}_{ij} + fe_i + fe_j + fe_t + fe_k + ln\varepsilon_{ijtk}\Big]. \tag{4}$$

The reliability of the PPML estimator is ensured if one assumes that the conditional mean is equal to the conditional variance: $var\left(M_{ijtk}|Z^{n}_{ijtk}\right) \infty \mathrm{E}\left(M_{ijtk}|Z^{n}_{ijtk}\right)$. Country time-invariant specific fixed effects (*fe*) are included to capture unobserved country heterogeneity such as a multilateral resistance term (Anderson and van Wincoop, 2003).

Our dependent variable has a mixed distribution characterised both by a long right-tail and a mass of zeros. As specified by Chaney (2008) or Helpman et al. (2008), zeros may reflect the existence of fixed costs or entry cost impeding countries from selling their products in specific markets.

As a further check we also use the Heckman two-step procedure (Heckman, 1979), which corrects the possible bias and allows us to investigate the effects of the variables on both the probability of trade (extensive margin) and the volume of trade (intensive margin). The full marginal effect of this variable is the sum of the extensive and intensive margins. The procedure includes two equations: a selection equation incorporating a binary decision variable 'whether to trade or not' and an outcome equation determining the intensity of trade.

The selection equation is given by:

$$d_{ij}^{*} = Z_{ij}\gamma' + u_{ij}, \tag{5}$$

where d_{ij} is a latent variable, Z_{ij} is a vector of explanatory variables influencing d_{ij}^{*} and u_{ij} is the error term. d_{ij} is not observed, but we can observe whether countries trade or not; therefore:

$$d_{ij} = \begin{cases} 1 \; if \; d_{ij}^{*} > 0 - there \; is \; trade \\ 0 \; if \; d_{ij}^{*} \leq 0 - no \; trade \; occurs \end{cases}.$$

The outcome equation determines the value of trade:

$$M_{ij}^{*} = x_{ij}\beta' + \varepsilon_{ij}, \tag{6}$$

where x_{ij} is a vector of independent variables determining the natural logarithm of M_{ij}, and it is observed if $d = 1$; the error terms u_{ij} and ε_{ij} are independent across observations and normally distributed jointly with covariance: $\rho\sigma_e$:

$$u_{ij}, \varepsilon_{ij} \sim N\left(0, \begin{bmatrix} 1 & \rho\sigma_e \\ \rho\sigma_e & \sigma_\varepsilon^2 \end{bmatrix}\right).$$

The variance of u is normalised to 1 because only d is observed, not d^*. The expected value of M_{ij} is the expectation of M_{ij}^{*} conditional on it being observed ($d_{ij} = 1$):

$$\begin{aligned} E\left(M_{ij}|x_{ij}, Z_{ij}\right) &= E\left(M_{ij}^{*}|d_{ij} = 1, x_{ij}, Z_{ij}\right) = x_{ij}\beta + \rho\sigma_\varepsilon \frac{\phi(Z_{ij}\gamma)}{\Phi(Z_{ij}\gamma)} \\ &= x_{ij}\beta + \rho\sigma_\varepsilon\lambda\left(Z_{ij}\gamma\right), \end{aligned} \tag{7}$$

where $\lambda(\alpha) \equiv \frac{\phi(\alpha)}{\Phi(\alpha)}$ is the inverse Mills ratio (Greene, 2008). The inverse Mills ratio, computed from the estimates in the first-stage selection equation, is included in the second stage as a regressor. It corrects for the sample selection bias in the outcome equation.

For robust identification, Helpman et al. (2008) suggested that both the selection and outcome equations include the same independent variables except one, that is, a variable influencing the fixed costs and not the costs of trade of the EU and competitors. In our case, the exclusion of common language ($Lang_{ij}$) from the outcome equation provides the exclusion restriction. Our empirical versions are thus:

$$\begin{aligned} d_{ij}^{*} = {} & \beta_0 + \beta_1 \ln(RetSale_{it}) + \beta_2\left(RetSale_{jt}\right) + \beta_3 \ln\left(Dist_{ij}\right) + \beta_4 \ln\left(Tarif_{jtk}\right) \\ & + \beta_5 \ln(Severity_{jk}) + \beta_6 Border_{ij} + \beta_7 Lang_{ij} + \beta_8 Colony_{ij} + fe_i + fe_j \\ & + fe_t + fe_k + u_{ijtk}. \end{aligned} \tag{8}$$

$$\begin{aligned} \ln(M_{ijtk}) = {} & \beta_0 + \beta_1 \ln(RetSale_{it}) + \beta_2\left(RetSale_{jt}\right) + \beta_3 \ln\left(Dist_{ij}\right) + \beta_4 \ln\left(Tarif_{jtk}\right) \\ & + \beta_5 \ln(Severity_{jk}) + \beta_6 Border_{ij} + \beta_7 Colony_{ij} + \beta_8 IMR_{ijtk} + fe_i + fe_j \\ & + fe_t + fe_k + \varepsilon_{ijtk}. \end{aligned} \tag{9}$$

Equation (9) includes the inverse Mills ratio (IMR_{ijtk}). The equations can be estimated simultaneously through the maximum-likelihood method, or successively (Cameron and Trivedi, 2009). For robustness we use both procedures; in the latter the selection equation is estimated by a probit. Finally, we use the standard OLS to estimate the outcome equation.

6. ESTIMATION RESULTS

This section is organised in two subsections providing the empirical analysis of two estimation techniques. In all estimations, observations have been clustered by distance. The estimation procedures (PPML and Heckman two-step) are performed for the period 2008–10, for which data on MRL are available. Importer, exporter, time and product fixed effects are considered in all the estimations even if they are not reported. Table 3 reports the PPML estimated coefficients, and Table 4 displays the results obtained from the Heckman two-step procedure.

a. Results from the Pseudo-Poisson Maximum-Likelihood Estimations

Table 3 shows the output from the PPML estimator. This model explains more than 50 per cent of the variation in EU baby food imports. The gravity equation is estimated with two different proxies of baby food consumption, the value of the retail sales (Table 3) and the size of the infant population in the importing and exporting countries (Table A6 in Appendix). These estimations include the index of severity between the EU and its trading partners (variable $Severity_{jk}$) previously presented. This variable must be read as an indicator of the regulatory distance between the EU and its partners. We also performed a cross-sectional analysis

TABLE 3
Results of the Pseudo-Poisson Maximum-Likelihood Estimation

	PPML on pooled data		*PPML cross section 2009*		*PPML cross section 2010*	
	β	*SE*	β	*SE*	β	*SE*
$RetSale_{it}$	0.43	0.40				
$RetSale_{jt}$	0.39	0.43				
$Severity_{jk}$	4.33*	2.36	5.65**	2.78	6.73**	2.89
$Dist_{ij}$	−0.69***	0.16	−0.68***	0.17	−0.69***	0.16
$Tarif_{jtk}$	−0.89***	0.15	−1.08***	0.25	−1.44***	0.21
$Border_{ij}$	0.66***	0.23	0.67***	0.25	0.69***	0.24
$Lang_{ij}$	1.35***	0.34	1.45***	0.32	1.35***	0.31
$Colony_{ij}$	0.13	0.35	0.17	0.28	0.11	0.35
Observations	13,228		4,495		4,458	
Adjusted R^2	0.53		0.51		0.58	
Reset Test	0.35		0.67		0.40	
Wald Test	Yes		Yes		Yes	

Notes:
(i) Dependent variable (M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported).
(iii) Standard errors in parentheses; significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

TABLE 4
Results of the Heckman Two-Step Estimation

	(1)		*(2)*	
	Extensive Margin		*Intensive Margin*	
	β	*SE*	β	*SE*
$RetSale_{it}$	−0.44	0.36	0.22	0.83
$RetSale_{jt}$	−0.00	0.29	0.11	0.80
$Dist_{ij}$	−0.52***	0.04	−1.08***	0.09
$Tarif_{jtk}$	−0.01	0.03	−0.06	0.13
$Severity_{jk}$	0.78**	0.30	−6.00***	1.83
$Border_{ij}$	0.76***	0.07	1.15***	0.13
$Lang_{ij}$	0.50***	0.08		
$Colony_{ij}$	0.10	0.09	0.07	0.17
IMR_{ijtk}			1.27**	0.61
Observations	13,487		4,496	
Adjusted R^2	0.40		0.43	
Reset Test			0.0001***	

Notes:
(i) Selection equation: dependent variable Prob($M_{ijtk} > 0$); outcome equation: dependent variable ln(M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported); Intercept (not reported).
(iii) Common language is the excluded variable.
(iv) Robust standard errors in parentheses; significance: **$p < 0.05$, ***$p < 0.01$.

for 2009 and 2010 specifying the error term *à la* Anderson and van Wincoop (2003) and compared the value of the coefficients to those of the panel analysis. For the severity index, the coefficient is equal to 5.65 in 2009 and 6.73 in 2010 against 4.3 in the panel (Table 3). Alternative estimations are reported in the Appendix in Tables A3–A7.

In all estimations, the severity index is positive and significant. It means that at an aggregate level, the severity of the EU regulation had a positive impact on trade and did not act as a barrier to it. The proxies of consumption are positive but not significant in the panel, while the importers' baby food consumption are captured by country specific fixed effects in the cross-sectional estimates. Distance and tariff display negative and significant coefficients. Conversely, shared border and/or a language had a positive trade effect. The existence of past colonial relationship did not impact trade.

At this point, we ran a Ramsey specification test (Ramsey, 1969) to detect whether the equation is correctly specified, and the significance of the test suggests that it is the case (0.35).

As the time period considered in the analysis is limited to only three years, the issue of multicollinearity between the severity measure and the fixed effects may arise. We have thus performed the variance inflation factor test after the OLS estimation to check for multicollinearity in our model. We have eliminated the fixed effects one after the other and the results of the estimations remained unaltered, with the key variables still significant. However, multicollinearity arises when the exporting country fixed effects are included in the specification and, as a consequence, the estimated coefficient of the severity index inflates. Including or excluding the group of exporting countries has an impact only on the size of the coefficient of the severity index, not on its significance.

b. Results from the Heckman Two-Step Estimation

To thoroughly explain the impact of our severity index, we performed the Heckman two-step procedure to measure its influence on the probability of exporting baby food to the EU market. Results are reported in Table 4.

The extensive margin displays non-significant coefficients for retail sales and tariff, a negative coefficient for distance and positive coefficients for severity, border, language and colony.

The estimates of the intensive margin show that coefficients of retail sales and tariff are still not significant, which can be explained in both estimations by the shortness of the time dimension of our dataset. The coefficient of past colonial relationships becomes non-significant. Severity and distance have negative and significant coefficients. Finally, common border is positive and significant.

These results provide evidence that, at an aggregated level, the EU requirement did not constitute a barrier to entry but could have influenced total imports to the EU negatively. Being positive the coefficient of the severity index in the extensive margin means that the probability of new trade relationships had been positively impacted by the EU baby food specific regulation. But this coefficient being negative in the intensive margin shows a negative impact on the volume of trade. It could be explained by the fact that when traditional exporters were not able to satisfy the EU requisites, they were replaced by new sources of supply, which globally made the whole trade decrease.

Given the result of the reset test for the Heckman two-step procedure, we need proof of the direction of the sign found in the selection equation; to this end, we estimated the gravity equation using various other techniques including the Poisson model, the negative binomial regression (NBR), the double-hurdle model (DHM) and the zero-inflation models (zero-inflation Poisson model – ZIPM; and zero-inflation negative binomial regression – ZINBR). The Vuong test has been implemented to discriminate against the Poisson and ZIPM and NBR and ZINBR, respectively. In both cases, the t-statistics of 62.58 and 50.38, respectively, with a one-sided *p*-value of 0.00 favour the ZIPM and ZINBR at a significance of 1 per cent. The results from NBR are coherent with the PPML estimation. The ZIPM and ZINBR confirm the direction of the sign found in the Heckman procedure. Once again, the severity measure has a positive impact on the probability of trade and a negative impact on the level of trade, and the coefficient is lower in magnitude in comparison with the Heckman coefficient. These results are reported in Tables A4 and A5 in the Appendix.[4]

We also estimated the gravity equation considering the infant population of the importing and exporting countries instead of the retail sales as a proxy of baby food consumption and results are still confirmed. The severity index has a positive and significant impact on trade flows (see Table A6 in the Appendix). Finally, we estimated the model using the generalised negative binomial regression model (GNBRM). The results are quite similar to the PPML technique (see Table A7 in the Appendix).

To discriminate against groups of exporters, we also added to equation (4) a term of interaction between the Severity index and a dummy equal to 1 if exporters belong to the group of high income countries, and equal to 0 otherwise. The estimation results show a beta coefficient that is positive and significant for the single variables (dummy high income country, and severity index) but not for the interaction term. Results are not reported but available upon request.

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[4] We did not report the results of the Poisson but those obtained with the PPML.

7. DISCUSSION AND CONCLUSION

The medical literature agrees on the fact that pesticides and contaminants can contribute to health problems including cancer, lung disease or reproductive, endocrinal and immune system disorders, and stresses the idea that children are more vulnerable to these dangers than adults (von Mühlendahl et al., 1996; Koletzko et al., 1999). For this reason, the EU imposes a very severe regulation concerning the MRL of pesticides in the food intended for infants and toddlers through its Directive 2006/125/EC, which imposes an MRL of 0.01 ppm of any pesticides in baby food. Yet for the advocates of free trade, this directive can be interpreted as a form of protectionism of the growing baby food market, which constrains would be exporters to concentrate on primary products rather than processed ones when dealing with the European markets. In this study, we assessed the impact of the EU food safety regulation on its imports of baby food using a gravity analysis. In the first two sections of the paper, we described the EU regulation and compared it to those of its main trading partners. Following the recent literature on food safety regulations and standards (Achterbosch et al., 2009; Rau et al., 2010; Drogué and DeMaria, 2012; Winchester et al., 2012; Li and Beghin, 2014), we built an index to assess the EU regulation's degree of severity in comparison to its competitors. The index ranges between 0 and 1.24: the higher the index, the stricter the EU regulation. We introduced this index in a gravity model. We ran the model on 20 of the EU member states, on the importing side and 47 exporting countries: Argentina, Australia, Brazil, Canada, Chile, China, Colombia, Egypt, India, Indonesia, Israel, Japan, Korea, Mexico, Malaysia, New Zealand, Norway, Philippines, Russia, Saudi Arabia, Singapore, South Africa, Switzerland, Taiwan, Thailand, Turkey, the United States, Vietnam and the 20 EU member states. We used the PPML estimator and the Heckman selection model at the NC8-digit level of trade. The robustness of the results has been confirmed by the use of different estimating techniques. The results of the PPML showed a positive impact of our index on trade. This is an interesting result but to better understand it, we performed the Heckman two-step estimation. This second procedure allowed us to analyse the impact of a variable not only on the volume of trade but also on the probability of trade. The estimated results showed that globally the EU regulation had favoured the emergence of new trade relationships between the EU and the rest of the world but had had a negative impact on the volume of trade. The regulation, essentially being more difficult to comply with, had a negative impact on traditional providers but a positive impact on new ones that were able to meet the European standards. Baby food market is dominated by few multinational firms that do not hesitate to outsource their inputs. The tightening of the EU regulation towards safer products could have increased the competitiveness of products and created better opportunities in non-traditional exporters. The severity of the EU regulation is not an obstacle to trade; indeed, it can even foster it because compliance with the EU requisites sends a positive signal to a particularly exigent sector of consumers. Parents have become more and more demanding in terms of the quality and safety of the food they give to their children. It has been shown that 'parents are concerned about the risk posed by pesticides in baby food, and for those who choose to purchase organic foods, the health benefits are a primary motivation' (Maguire et al., 2006; p. 189). Peterson and Li (2011) found in their study that consumers are ready to pay a premium for organic baby foods not for their organic qualities, but because of the restriction in the use of pesticides and genetically modified organisms.

From a policy perspective, we have tried to answer the following question: could the EU regulation be intended to protect trade in baby food? Our severity index was tested for endogeneity and it proved to be exogenous, showing that it cannot be considered as a policy instrument. Moreover, this study provides evidence that, at global level, the EU regulation on the MRL of pesticides did not constitute a barrier to entry and European providers could have been the 'first victims' of the tightening of the European rules, which is confirmed by the information provided by the RASFF portal. Thus, we can consider the EU requisite as a standard of safety and quality that aims to protect the health of the most vulnerable part of the population, not as a protectionist tool. From this perspective the EU regulation produces the desired effect.

The fact that a product has been allowed to cross European borders can be viewed as a guarantee of safety for consumers, as confirmed by the Heckman results. These results are also confirmed by the data market. Statistics show that in the EU 'baby food sales have steadily increased since 2003' (Agriculture and Agri-Food Canada, 2010, p. 2), with the EU regulation having entered into force the previous year.

This sense of safety will certainly be reinforced by the recent measures taken by the European Commission concerning the Food for Specific Groups. This recent legislation (Regulation EU 609/2013) adopted in 2013 is particularly targeted at vulnerable populations, namely infants and children up to three years old. It aims to provide a better protection of consumers, through clearer information on the composition and labelling. In particular it sets new rules for additives (as vitamins and minerals).

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APPENDIX

FIGURE A1
Construction of the Severity Index

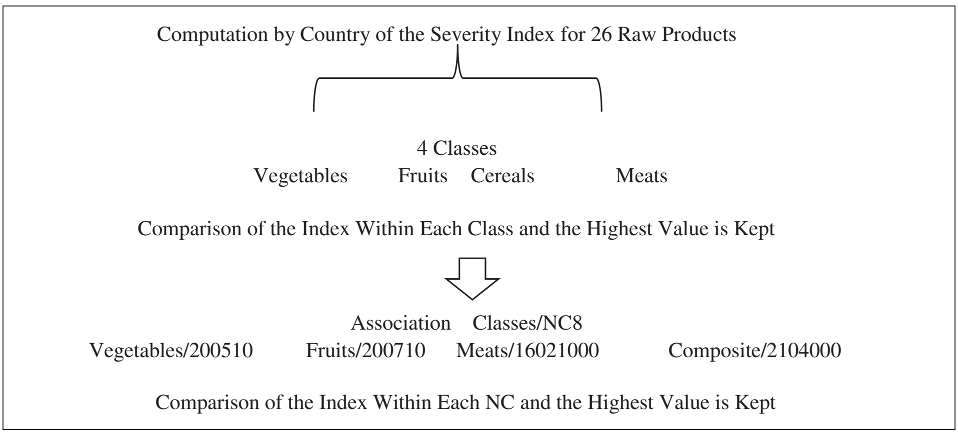

TABLE A1
Default value for Missing MRL by Country

	Rule when a pesticide is not registered
Argentina	1. Codex 2. Zero-tolerance
Australia	Zero-tolerance
Brazil	Codex
Canada	Default limit of 0.1 mg/kg
Chile	Codex
China	1. Codex 2. Limits applied by reference countries (EU, the United States)
Colombia	Codex
Egypt	Codex
EU	Default limit of 0.01 mg/kg
India	No default limit
Indonesia	No default limit
Israel	No default limit
Japan	Default limit of 0.01 mg/kg
Korea	1. Codex 2. Limit of most similar group of product 3. Default limit of 0.01 mg/kg
Malaysia	Codex
Mexico	Zero-tolerance

TABLE A1 *Continued*

	Rule when a pesticide is not registered
New Zealand	1. Codex recognised for imported food 2. Australian MRLs recognised for food imported from Australia. 3. Default limit of 0.1 mg/kg applies
Norway	EU limit
Philippines	No default limit
Russia	1. Codex 2. Memorandum with Chile and the EU 3. MRL of the most similar product 4. MRL of the country of origin
Saudi Arabia	Codex
Singapore	Codex
South Africa	EU limit
Switzerland	EU limit
Taiwan	No default limit
Thailand	No default limit
Turkey	Codex
The United States	Zero-tolerance

TABLE A2
Summary Statistics

Variables	*Mean*	*Standard Deviation*	*Min*	*Max*	*Number of Observations*
M_{ijtk}	340,499.3	2,106,396.0	0	5.5E+07	13,487
$RetSale_{it}$	441.0	509.9	28	1,793.0	13,487
$RetSale_{jt}$	722.7	1,266.2	28	6,392.0	13,487
$InfantPop_{it}$	1,410.7	1,298.6	269	3,974.0	13,487
$InfantPop_{jt}$	8,347.1	22,544.1	223	127,979.0	13,487
$Tarif_{jtk}$	5.8	7.4	0	19.5	13,487
$Severity_{jk}$	0.4	0.5	0	1.2	13,487
$Dist_{ij}$	4,508.9	4,257.7	59.6	19,586.1	13,487
$Border_{ij}$	0.0	0.2	0	1.0	13,487
$Lang_{ij}$	0.0	0.2	0	1.0	13,487
$Colony_{ij}$	0.0	0.2	0	1.0	13,487
PoP_pt	77.3	29.5	0	95.5	13,487

TABLE A3
Correlation Matrix Variables

	M_{ijtk}	$RetSale_{it}$	$RetSale_{jt}$	$InfantPop_{it}$	$InfantPop_{jt}$	$Tarif_{jtk}$	$Severity_{jk}$	$Dist_{ij}$	$Border_{ij}$	$Lang_{ij}$	$Colony_{ij}$	PoP_pt
M_{ijtk}	1											
$RetSale_{it}$	0.07*	1										
$RetSale_{jt}$	−0.00	−0.03*	1									
$InfantPop_{it}$	0.08*	0.93*	−0.03*	1								
$InfantPop_{jt}$	−0.04*	−0.00	0.40*	−0.00	1							
$Tarif_{jtk}$	−0.12*	0.03*	0.27*	0.03*	0.20*	1						
$Severity_{jk}$	−0.11*	0.06*	−0.08*	0.06*	0.18*	0.53*	1					
$Dist_{ij}$	−0.13*	0.07*	0.15*	0.08*	0.17*	0.67*	0.53*	1				
$Border_{ij}$	0.24*	0.03*	−0.05*	0.02*	−0.08*	−0.18*	−0.19*	−0.27*	1			
$Lang_{ij}$	0.11*	0.08*	−0.01*	0.10*	0.00	0.03*	0.03*	0.03*	0.26*	1		
$Colony_{ij}$	−0.02*	0.11*	0.02*	0.16*	0.00	0.03*	0.06*	0.05*	0.23*	0.45*	1	
PoP_pt	0.02*	0.00	−0.10*	−0.00	−0.43*	−0.15*	−0.05*	−0.17*	0.06*	−0.01	−0.00	1

Note:
Significance $^{*}p < 0.05$.

TABLE A4
Robustness check: Zero-Inflation Models

	ZIPM				*ZINBR*			
	Count Part β	*SE*	*Logit Part* β	*SE*	*Count Part* β	*SE*	*Logit Part* β	*SE*
$RetSale_{it}$	0.3360	0.4093	0.8172	0.5905	0.1454	0.4797	0.8254	0.6072
$RetSale_{jt}$	0.2545	0.4615	0.1026	0.4867	0.7682	0.5367	0.1069	0.4969
$Tarif_{jtk}$	−0.5423***	0.0842	0.0606	0.0847	−0.0985	0.1778	0.0584	0.0849
$Severity_{jk}$	−4.5463*	2.6590	−1.7069**	0.8171	−6.6171***	1.9105	−1.7413**	0.8217
$Dist_{ij}$	−0.6214***	0.1521	0.9326***	0.2073	−0.8984***	0.1321	0.9490***	0.2158
$Border_{ij}$	0.5920***	0.2163	−1.3537***	0.3537	0.4261**	0.1822	−1.3668***	0.3630
$Lang_{ij}$	1.2559***	0.3153	−0.9075***	0.2972	1.0770***	0.2465	−0.9127***	0.3044
$Colony_{ij}$	−0.0456	0.3106	−0.1921	0.3305	−0.4702*	0.2507	−0.1946	0.3389
lnalpha					1.0368***	0.0296		
N	13,487				13,487			
Vuong	Yes				Yes			

Notes:
(i) Dependent variable (M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported).
(iii) Robust standard errors in parentheses; significance: **$p < 0.05$, ***$p < 0.01$.

TABLE A5
Robustness Check: Double-Hurdle Model

	Logit part		*Count Part NBR*	
	β	*SE*	β	*SE*
$RetSale_{it}$	−0.8172	0.5905	0.1456	0.4804
$RetSale_{jt}$	−0.1026	0.4867	0.7708	0.5360
$Tarif_{jtk}$	−0.0606	0.0847	−0.1019	0.1765
$Severity_{jk}$	1.7069**	0.8171	−6.5866***	1.9052
$Dist_{ij}$	−0.9326***	0.2073	−0.9019***	0.1326
$Border_{ij}$	1.3537***	0.3537	0.4235**	0.1827
$Lang_{ij}$	0.9075***	0.2972	1.0772***	0.2466
$Colony_{ij}$	0.1921	0.3305	−0.4718*	0.2503
N	13,487			

Notes:
(i) Dependent variable (M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported).
(iii) Robust standard errors in parentheses; significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

TABLE A6
Robustness check: PPML

	PPML Pooled		*Cross Section 2009*		*Cross Section 2010*	
	β	*SE*	β	*SE*	β	*SE*
$InfantPop_{it}$	0.44	2.84				
$InfantPop_{jt}$	2.33	2.92				
$Dist_{ij}$	−0.70***	0.11	−0.69***	0.16	−0.69***	0.15
$Tarif_{jtk}$	0.90***	0.19	1.08**	0.25	1.45**	0.22
$Severity_{jk}$	4.65***	1.67	5.65**	2.71	6.74**	2.89
$Border_{ij}$	0.67***	0.14	0.67***	0.23	0.70***	0.25
$Lang_{ij}$	1.35***	0.19	1.46***	0.32	1.35***	0.31
$Colony_{ij}$	0.13	0.16	0.17	0.23	0.11	0.25
N	13,487		4,495		4,458	
R^2	0.53		0.51		0.58	

Notes:
(i) Dependent variable (M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported).
(iii) Robust standard errors in parentheses; significance: **$p < 0.05$, ***$p < 0.01$.

TABLE A7
Robustness Check: NBREG and GNBREG

	NBREG		*GNBREG*	
	β	*SE*	β	*SE*
$RetSale_{it}$	0.5021	0.9210	0.5021	1.3620
$RetSale_{jt}$	0.5006	0.9484	0.5006	1.0168
$Tarif_{jtk}$	−0.3697*	0.1982	−0.3697***	0.1293
$Severity_{jk}$	7.0968***	2.3649	7.0968***	1.5557
$Dist_{ij}$	−1.9977***	0.2915	−1.9977***	0.1545
$Border_{ij}$	0.0854	0.3295	0.0854	0.1968
$Lang_{ij}$	1.4712***	0.4110	1.4712***	0.2371
$Colony_{ij}$	0.6162	0.4686	0.6162**	0.2842
lnalpha	3.2317***	0.0520	3.2317***	0.0170
N			13,487	
Adjusted R^2			0.0238	

Notes:
(i) Dependent variable (M_{ijtk}).
(ii) Product, Importer, Exporter and time fixed effect (not reported).
(iii) Robust standard errors in parentheses; significance: $^{**}p < 0.05$, $^{***}p < 0.01$.

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Agricultural household effects of fertilizer price changes for smallholder farmers in central Malawi

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ABSTRACT

This simulation study explored the agricultural household effects of changes in the price of inorganic nitrogen fertilizer for farmers in central Malawi. We selected the Dedza district to conduct this study, which is a district reliant on maize production for household livelihoods. This study used data from a household survey to develop and calibrate an agricultural household model for a representative household. The survey focused on socio-economic and agronomic factors. This included plot-level agronomic details for crop inputs and yields. Using our dynamic model, we found a negative association between fertilizer prices and fertilizer use, maize area, and income. Removing fertilizer prices led to an increased use of nitrogen fertilizer at the household scale from 16.8 kg to 49.6 kg and this helped increase household income by 52%. We calculated an average own-price elasticity of fertilizer demand of − 0.92. Although higher fertilizer prices increased legume acreage, which had potential environmental benefits, household income fell. Our benefit-cost ratio calculations suggest that government actions that deliver changes in fertilizer prices are relatively cost effective. Our study highlights the reliance of households on maize production and consumption for their livelihood, and the effects that changes in fertilizer prices can have upon them.

1. Introduction

Governments in Africa south of the Sahara often pursue policies aimed at increasing food security and social welfare. One component of these policies includes subsidizing the purchase of inorganic nitrogen fertilizer. Despite these policy efforts, some countries in Africa south of the Sahara have recently experienced declining productivity of staple crops (Jayne et al., 2006; Tittonell and Giller, 2013), especially maize (*Zea mays*). Jayne et al. (2006) suggest the low use of external inputs as a contributor to declining productivity in staple crops. Farmers often desire to use more inorganic fertilizers but face cash constraints in purchasing it, as discussed by Duflo et al. (2011) in the example of Kenya. Poor and declining soil fertility presents a constraint to increasing the agricultural productivity of smallholder, maize-based farmers in Africa south of the Sahara (Place et al., 2003; Jayne and Rashid, 2013; Kihara et al., 2016). In this context, the improved management of nitrogen in cropping systems can help address challenges of sustainable food security and depends on both technological innovation and socio-economic factors (Zhang et al., 2015). Multiple options exist to improve the management of nitrogen in cropping systems including applying inorganic nitrogen fertilizer, growing legumes, applying manure to fields, and retaining crop residues in the field. These options have advantages and constraints, especially the use of fertilizer.

Our study examined the household effects of changes in the fertilizer subsidy component of Malawi's Farm Input Subsidy Program (FISP). The FISP aims to increase maize production, promote household food security, and enhance rural incomes. Beneficiaries of the FISP receive subsidized fertilizer and seed. Lunduka et al. (2013) found that most household-scale studies of the FISP used statistical approaches to show that the FISP generates relatively modest increases in maize production and yields. Earlier studies calculated the benefit-cost ratio (BCR) of fertilizer use. The BCR measures the change in income or value of maize production in relation to the (public) cost of fertilizer use under the subsidy. With the benefit-cost ratio (BCR) ranging from close to zero to over 10, conditional on local context, fertilizer response rates,

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relative prices, and study method (Dorward and Chirwa, 2011; Chirwa and Dorward, 2013; Lunduka et al., 2013; Arndt et al., 2015). Using a computational, economy-wide market model, Arndt et al. (2015) found that fertilizer response rates were the major factor determining the BCR of the FISP, with a BCR of approximately 1 or 1.62, depending on the calculation used. Ricker-Gilbert et al. (2014) showed that higher fertilizer prices reduced fertilizer demand. Holden and Lunduka (2012) showed that a 1% increase in fertilizer prices increased in the probability of manure use by approximately 0.5%. Chibwana et al. (2012) showed a positive association between household participation in the FISP and maize acreage, and that program participation reduced legume acreage. In Ethiopia, Louhichi et al. (2016) used a computational household model to show that changes in simulated fertilizer prices had a limited effect on crop production and household income. Taking into consideration this literature above, this study asked two questions:

- What are the agricultural household effects of changes in the price of inorganic nitrogen fertilizer for smallholder farmers in central Malawi?
- What are the benefit-cost ratios associated with fertilizer price support?

To answer these questions, we used a mathematical programming model of an agricultural household. The main effects considered were fertilizer use, land use, agricultural productivity, food consumption, and income. Our approach integrated economic and biophysical concepts and data; this included accounting for changes in nitrogen available to crops due to changes in crop management over time and hence any feedback effect this has on household indicators. Our approach complements the statistical and economy-wide studies of Malawi's FISP mentioned above to show BCRs from the alternative perspective of using a farm-household simulation approach. Our approach traces out the linkages between changes in fertilizer prices and its income effects. Our study complements Snapp et al. (2010) and Smith et al. (2016) who analyse partial profitability and grain balances related to the use of fertilizers in Malawi by providing a farm-household perspective on the effects of fertilizer price changes on different indicators of household performance and welfare.

2. Methods

2.1. Characterization of the case study

We conducted this study in the Dedza district of central Malawi. Households in this district are maize-focused, smallholder farmers. We characterized these households by using data collected as part of a participatory agricultural research for development program called Africa Research In Sustainable Intensification for the Next Generation (Africa RISING). The Malawi Africa RISING Baseline Evaluation Survey provided the household data. The survey design involved a stratified random sample, with stratification based on capturing diversity in agroecological potential and then a random selection of households within the diverse villages (IFPRI, 2015). The survey was conducted in the summer of 2013. The survey interviewed 550 households in the Dedza district. The survey collected baseline household data on, among others, crop management including area cultivated and inputs used, grain yields, livestock numbers, family demographics, off-farm income, human food consumption, and prices and costs of all inputs and outputs in the model. The agricultural production data referred to the cropping season October 2012 to May 2013. We divided the surveyed households into three types using Principal Component Analysis and subsequent Hierarchical Cluster Analysis. Our study followed the approach suggested by Norman et al. (1995) and used by Chenoune et al. (2016) for developing household types. This included considering three groups of factors: household resource endowments, production goals, and production intensification. We selected 10 variables related to the three groups of factors that capture household livelihoods and expected ability to respond to changes in fertilizer prices, for example, off-farm income, fertilizer use, and farm size. We retained four principal components that had an eigenvalue greater than one. These components explained 68% of total variability in the original data. We used these principal components in a Hierarchical Cluster Analysis that resulted in us identifying three types of households. We examined the household type that covered 72% of the surveyed households, 395 households from the 550 households. We used data on the mean survey characteristics for this type of household to calibrate our model. We call this household a “representative household”.

Table 1
Characteristics of the representative household simulated in this study.

Characteristics	Units	Mean	Coefficient of variation
Arable land	ha	0.6	0.03
Land planted to legumes	% of arable total	42	0.26
Maize grain yield	t ha^{-1}	1.8	0.65
Fertilizer applied to maize	kg [N] ha^{-1}	51	0.9
Household size	total number people	4.8	0.77
Off-farm income	US $ $year^{-1}$	155	1.35

Notes: Coefficient of variation is the standard deviation divided by mean, based on spatial variation among surveyed households. At the time of study, 1 US $ = 364 Malawian Kwacha (MWK). [N] represents nitrogen.

Table 1 shows the arable land, the percent of land planted to legumes, maize grain yield, inorganic nitrogen fertilizer (hereafter referred to as fertilizer) quantities applied to maize, household size, and off-farm income for the household during the summer of 2012 to 2013. Our data appear broadly representative of farming systems in Malawi. Household maize yields averaged 1.8 t ha^{-1} and were generally below the average yield for Malawi of 2.1 t ha^{-1} in 2013 (FAO, 2016), although yields in Malawi display a wide range. For example, Tamene et al. (2016) report yields in Dedza range from 0.4 t ha^{-1} to 12 t ha^{-1} and range from 0.8 t ha^{-1} to 2.65 t ha^{-1} for the national average. The average household applied 51 kg [N] ha^{-1} of fertilizer to maize plots, where [N] represents nitrogen. Sheahan and Barrett (in press) reported 53 kg [N] ha^{-1} of fertilizer applied to maize among fertilizer users in Malawi. Mungai et al. (2016) reported that farmers in Dedza who used fertilizer applied approximately 61 kg [N] ha^{-1}. This indicates our surveyed fertilizer rates are like rates among other smallholders in Malawi. The average household cultivated approximately 0.6 ha. Maize occupied on average 58% of arable land and legumes occupied the remaining 42%. In 2013, legumes occupied approximately 30% of arable land in Malawi (FAO, 2016). The average household and owned one adult breeder goat, had 4.8 members living on the farm, and generated US $ 155 $year^{-1}$ in off-farm income.

To examine food consumption, we categorized food consumption goods into the groups used by Ecker and Qaim (2011), with the full list of foods in our study listed in the Appendix. The proportion of total calories consumed in our survey coming from cereals was 79%, for pulses was 10%, for fruit and vegetables was 4%, for animals was 3%, and for meal complements was 4%. This compared to 73%, 11%, 3%, 3%, and 9% reported in Ecker and Qaim (2011), who analysed nationally-representative household data from Malawi.

2.2. Modelling approach

We used a Dynamic Agricultural Household SImulation Model (DAHBSIM) to examine the ex-ante effect of changes in the price of fertilizer on different indicators for the household. Indicators included average yearly fertilizer use (kg $household^{-1}$), area of maize (ha) and legumes (ha), maize production (kg $household^{-1}$), legume production (kcal ha^{-1}), total income (US $ $household^{-1}$), and the proportion of calories consumed from maize (%). Field-level indicators included maize grain yield (kg ha^{-1}) and crop absorbed nitrogen (kg [N] ha^{-1}).

DAHBSIM is a non-linear, programming model that optimizes an intertemporal objective function subject to a set of constraints, given the prevailing market conditions and historical precipitation (Flichman et al., 2016). The model design benefited from the development of earlier models such as FSSIM (Janssen et al., 2010) and FSSIM-Dev (Louhichi and Gomez y Paloma, 2014). Janssen et al. (2010) and Louhichi and Gomez y Paloma (2014) provided the implementation framework for modelling alternative scenarios of households using a static approach. Our model used a dynamic recursive approach similar to Mosnier et al. (2009), Louhichi et al. (2010), and Belhouchette et al. (2012). Our model maximizes the net present value of household net income for a specified number of years, subject to constraints on resource use by linking modules related to household crop production, food consumption, and economic and resource-use factors. The model allocates land, labour, and cash to different crops given a set of constraints. In the model the household determines its crop production, household food consumption, and labour allocation decisions simultaneously. The Appendix contains additional information on our modelling approach, as does Flichman et al. (2016).

2.2.1. Crop module

We followed the logic of Vanuytrecht et al. (2014) and Adam et al. (2012) when developing the crop module. This involved simplifying the cropping systems according to the aspects that were relevant to the objective of the study and the availability of data. The nitrogen content of soil is a major factor limiting yields in Malawi (Carr, 2014). We used simplified functions to simulate the effect of crop management on yield (Appendix). Flichman et al. (2016) provides a full description of the crop module. We integrated the summary functions into a household-scale analysis that focused on the behavioural consequences of different scenarios.

The crop module simulates cropping systems for multiple years and multiple crops using a monthly time step. It simulates, in a summary manner, soil water (including water use and drainage) and nitrogen budgets and their effect on crop yields. The nitrogen budgets include, if an option for the studied household, crop residue production and its decomposition, and livestock manure. The module has a generic crop simulator that enables the simulation of different crops and crop rotations using a single set of parameters. Precipitation, soil proprieties, crop characteristics, and crop management options including rotation, cultivar (variety) selection, irrigation, and nitrogen fertilization all affect crop growth. The module simulates crop cycles on a single parcel of land with uniform soil, precipitation, crop rotation and management, at the whole-plant level. This study used Dedza-specific monthly precipitation data from Harris et al. (2014). Crop input parameters used in the crop module were extracted from Doorenbos and Kassam (1979), calculated from the household survey, or calculated during the module calibration. Soil organic matter, soil water holding capacity, and initial soil water and nitrogen contents for different soil types were extracted from the Dedza-specific studies of Ollenburger (2012) and Ollenburger and Snapp (2014). We held the proportion of crop residues retained in the field at a constant 20% in our simulations. The module determines an unstressed (potential) yield based on crop potential evapotranspiration. The module then adjusts this potential yield for water and nitrogen limitations, if any, to determine actual yield (Appendix). The module takes the actual yield for specific years as the minimum of the yield limited by water and by nitrogen, as suggested by Stöckle et al. (2003).

We divided crops into two management intensities: extensive and intensive. The activities associated with the two management intensities were defined based on data collected in the household survey. Defining these activities involved three steps. First, we selected factors that we believed could explain yield variability: soil type (reported by households as either clay, loam, sand, or other), crop variety (local or improved) and input quantities (seed, fertilizer, and labour). In our study, cropping was rainfed and mechanization was limited. Second, we clustered the management activities (crop variety and input quantities) for different soil types to derive, for a specific crop, a potential yield. In the study sites, soil types differ in their texture, water holding capacity, and initial organic matter (Flichman et al., 2016). Third, we performed a Principal Component Analysis and subsequent Hierarchical Cluster Analysis based in the intensification factors for each soil type and crop. From this analysis we defined the list of activities associated with different management intensities (extensive and intensive). An example showing differences in yields and inputs used for different maize management intensities is shown in Table A1. For most soils and crops there were two intensities, however for some crops and soils there was only one. Yields differed based on management intensity and varied according to soil type (Table A1).

We compared predicted grain yields for a range of crops, soils, and management intensities with farmer-reported grain yields for the same crops, soils, and management. For each crop, this involved calculating the normalized root mean squared error and examining the scatter plots of predicted and farm-reported grain yields (Appendix).

2.2.2. Food consumption

The model allows for potential non-separability between production and consumption decisions. A Linear Expenditure System calculates human food consumption, as used in Louhichi and Gomez y Paloma (2014). In this system food and non-food expenditures are increasing in income, and food and non-food consumption quantities are decreasing in own price. The system describes household expenditures for a set of 31 food items and a non-food bundle (Appendix).

2.2.3. Economics and resources

Our model combines aspects of biophysically-based limitations of yield potential with an examination of the economic trade-offs that households might face when trying to maximize their welfare subject to the limits of material resources and a household budget constraint that takes full income into account. Fig. 1A, below, shows the main biophysical and socio-economic components of the model, and their linkages. In this study the term income is used to capture the economic activity of the household. These income values represent total household income. This equals the sum of net crop income (sales value minus incurred financial costs), off-farm earnings, and the value of the household's food consumption from on-farm production (Appendix). Our income values are designed to provide an indication of the economic value of household activities.

Our model has a dynamic recursive structure that optimizes across a set of specified years (Fig. 1B). The model explicitly accounts for dynamic interactions across the years by using the end values of the previous year as the starting values in the current year. The model updates the water content of soil, soil organic matter, and the nitrogen content of soil each year by considering the previous crop and its management. Soil conditions of nitrogen and organic matter are the key dynamic variables that are updated and re-initialized between years, as well as the carryover of seed stocks. The model maximizes the net present value of net household income (which includes the value of home-consumed foods) over an intertemporal planning horizon of Y years. The model repeats the intertemporal optimization for Z successive periods, with dynamic variables updated recursively. We examined the results of the first year of each intertemporal loop, as capturing how the farm-household behaves over Z successive periods. For example, if there were 2 years in the intertemporal optimization horizon (Y = 2) and 5 periods (Z = 5), the model would run for 5 recursive steps (years), taking the planning horizons of 2005–2007, 2006–2008, 2007–2009, 2008–2010 and 2009–2011 into account during the intertemporal optimization phase. In this case, we would report the results in $t_{1,1} = 2005$, $t_{1,2} = 2006$, $t_{1,3} = 2007$, $t_{1,4} = 2008$, and $t_{1,5} = 2009$ (Fig. 1B). In each intertemporal optimization step, there

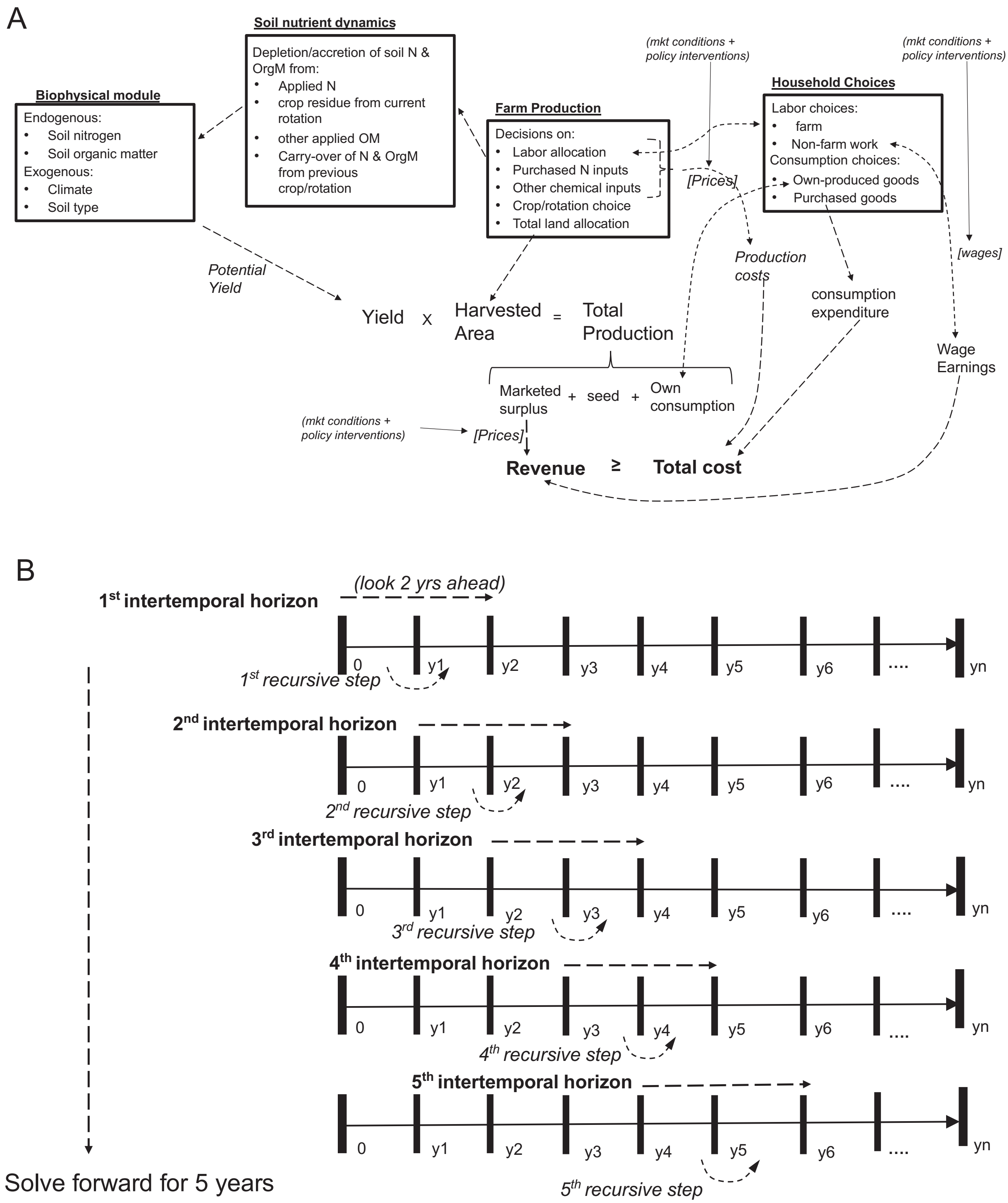

Fig. 1. A. The general structure of DAHBSIM.B. The intertemporal horizon over which DAHBSIM is solved.

is perfect foresight regarding prices and precipitation at the start of the decision-making period.

Model calibration involved using a variation of the mean-standard deviation approach of Hazell and Norton (1986) for risk analysis. Semaan et al. (2007) and Blanco-Gutiérrez et al. (2011) also used this approach to calibrate their model. Our Appendix contains details on the risk module formulation.

2.3. Simulation scenarios

We examined two scenarios: 1) a base-case scenario and 2) a scenario for a change in the price of fertilizer. The base-case scenario intended to replicate current household livelihoods based on observed prices, costs, and household resources. The base-case scenario maintained all prices as observed in the survey. Prices were fixed in the base-case scenario and precipitation varied based on the observed historical data. We compared our base-case results to the farmer-reported data.

The second scenario examined changes in the price of fertilizer. The FISP has been providing famers with discounted fertilizer. This subsidy was 64% in 2005 and 93% in 2012 (Chibwana et al., 2012; Chirwa and Dorward, 2013; Arndt et al., 2015). In 2012 a 50 kg bag of fertilizer cost 6536 MWK (Malawian Kwacha) on the open market and 500 MWK with

Table 2
Household-scale simulated (model predicted) vs. farmer-reported (observed) indicators.

Indicator	Observed	Predicted	PAD (%)
Maize production (10^6 kcal)	2.29	2.43	6.24
Legume production (10^6 kcal)	0.49	0.45	9.12
Caloric consumption from cereals (% of total)	73.5	74.4	1.20

Notes: the percent absolute deviation (PAD) for an indicator is the absolute deviation between predicted and observed indicator levels per unit of observed indicator level, expressed as a %.

a FISP redemption voucher (Chirwa and Dorward, 2013), a 93% subsidy. In our study site, farmers reported paying an average of 130 MWK kg^{-1} for a bag of ammonium nitrate in 2012. This price closely matched the unsubsidized price for a bag of chemical fertilizer in 2012 (Chirwa and Dorward, 2013). Even though many farmers in Malawi receive subsidized fertilizer, in our study site this was not prevalent. Not all farmers have access to subsidized fertilizer because of the FISP design and its implementation. For example, Arndt et al. (2015) outline that the FISP recipients should be the productive poor, but identifying the productive poor is challenging and eligibility is often determined by local leaders. The local leaders do not always use a consistent criterion. Shee et al. (2016) support this finding, they find that the most important agricultural challenge reported by surveyed farmers was the high price of agricultural inputs. We explored what could happen to farm-household indicators if fertilizer prices fell to zero or increased by 100%, relative to the current observed price of 130 MWK kg^{-1} for a bag of ammonium nitrate. These price changes would alter production costs and this may have implications for the farm and household system. Our simulations started in each year from 2008 to 2013 and included a two-year horizon for each intertemporal optimization.

To inform the FISP, we simulated relatively large changes in fertilizer prices, i.e., a 100% increase and a total removal of prices. In addition, we calculated the own-price elasticity of fertilizer demand, defined as the percentage change in the quantity of fertilizer used by the household if fertilizer prices increased by 1%. We calculated this elasticity for incremental 1% changes in the observed price of fertilizer, and examined 5 incremental changes both above and below the observed price of fertilizer.

2.4. Benefit-cost ratios

Government can induce changes in the price of fertilizer paid by farmers through providing subsidies, which are complex and controversial in Malawi (Jayne and Rashid, 2013). Earlier studies have mainly used statistical and economy-wide models to calculate the benefit-cost ratio (BCR) of Malawi's FISP (Lunduka et al., 2013; Arndt et al., 2015). We complement these existing BCRs with our own back-of-the-envelope BCR calculations to provide an additional perspective on understanding the potential cost effectiveness of fertilizer policies. We calculated the BCR for providing free fertilizer using a household-scale simulation model. We calculated an income-based BCR as the increase in total household income divided by the cost of providing free fertilizer to the household. We calculated a production-based BCR as the increase in the value of maize production divided by the cost of providing free fertilizer to the household. We calculated the increases in total household income or value of maize production as the difference in either total household income or value of maize production between the base-case scenario and the scenario with a price of fertilizer set to zero. We calculated the cost of providing free fertilizer to the household as the quantity of fertilizer used by the household if prices were zero multiplied by the open-market price (the base-case price of fertilizer).

3. Results and discussion

3.1. Crop module comparison

We compared the grain yields of the crops simulated in our model to farmer-reported grain yields. This comparison involved examining how the model simulated the observed variation in yield across all crops from the household survey, as well as how maize yields responded to fertilizer. The normalized root mean squared error for bean (*Phaseolus vulgaris*) was 27%, for cowpea (*Vigna unguiculata*) was 32%, for groundnut (*Arachis hypogaea*) was 17%, for maize was 25%, and for soybean (*Glycine max*) 35% (Fig. A2). Our study highlights the nitrophilic nature of maize; with a positive association between yield and fertilizer applied, as has been shown regularly in Malawi (Snapp et al., 2010; Smith et al., 2016). The range of simulated yields differed based on farmer-reported soil types. For example, on sandy soils the yields for all crops ranged from 10 kg ha^{-1} to 6077 kg ha^{-1}, and on loam soils ranged from 69 kg ha^{-1} to 7000 kg ha^{-1}. The average yield for maize on a loam soil was 2804 kg ha^{-1} and was 2555 kg ha^{-1} on a sandy soil. The Appendix and Flichman et al. (2016) provides additional details on the procedure used to calibrate and evaluate the model.

3.2. Household model comparison

Table 2 reports how our base-case scenario compared to observed indicators of household production and consumption, including the percent absolute deviation (PAD). The PAD for an activity is the absolute deviation between predicted and observed activity levels per unit of actual activity. The PAD for maize and legume production was below 10%. To calculate the proportion of caloric consumption from staples we multiplied average daily farmer-reported per person food consumption from the survey by the Malawi-specific calories in food reported in Ecker and Qaim (2011). Farmer-reported food consumption in the survey relates to average consumption of food over the week prior to the survey occurring. In our survey cereals comprised approximately 79% of total per person caloric intake, compared to the 73% reported in Ecker and Qaim (2011). The PAD for total caloric consumption was 9%.

3.3. Simulation results and discussion

This section presents our assessment of how changes in fertilizer prices affected the simulated behaviour of the representative household. Table 3 presents the simulated household-scale effects of changes in fertilizer prices. We observed a negative association between fertilizer prices and the fertilizer used. If fertilizer had no cost to the household, fertilizer use would rise from 16.8 kg [N] to 49.6 kg [N], whereas a 100% increase in fertilizer prices caused fertilizer use to fall from 16.8 kg [N] to 14.9 kg [N]. Looking at incremental changes in fertilizer prices around the observed price, we found that a 1% increase in fertilizer price led to a (on average) 0.92% decrease in the quantity of fertilizer used. This own-price elasticity of fertilizer demand of -0.92 was similar to results in Chembezi (1990), who econometrically estimated an own-price elasticity of fertilizer demand for Malawian smallholders of -0.82 (for a two-step procedure) and -1.08 (using a single equation method).

As fertilizer prices increased the area of maize declined. Changes in fertilizer prices had the direct effect of altering fertilizer use and hence grain yields. The changes in fertilizer prices had the additional economic effect of altering the relative returns of different crops, and hence the areas of maize and legumes (Table 3). Applying fertilizer can help maintain and increase crop yields. Combining multiple practices can also help maintain and increase yields, for example, integrated soil fertility management advocates combining the use of appropriate germplasm, fertilizer, and organic resources with good agronomic

Table 3
Simulated household-scale effects of changes in fertilizer prices.

	Zero price		Base price		100% increase	
	Mean	SD	Mean	SD	Mean	SD
Fertilizer price (US $ [N] kg^{-1})	0	0	1.08	0	2.16	0
Fertilizer applied ([N] kg)	49.6	5.94	16.8	0.73	14.9	0.48
Maize area (ha)	0.44	0.013	0.34	0.0090	0.34	0.0090
Legume area (ha)	0.16	0.013	0.26	0.0090	0.25	0.011
Legume production (10^6 kcal)	0.37	0.025	0.35	0.018	0.33	0.031
Maize productivity (kg ha^{-1})	2557.7	141.2	1642.0	184.4	1227.7	54.6
Maize production (kg)	1116.7	37.5	549.2	50.7	419.6	19.0
Total household income (US $)	412.6	7.09	271.9	9.20	229.2	3.98
Caloric consumption from cereals (% of total)	73.5	0.035	74.4	0.076	74.8	0.038

Notes: all values are an average yearly value. SD represents standard deviation. The mean and SD are calculated using all simulation years. [N] represents nitrogen.

practices (Vanlauwe and Giller, 2006; Vanlauwe et al., 2015). Our findings showed that subsidizing fertilizer had a disincentive effect on using organic means of maintaining soil fertility because removing the price of fertilizer reduced the area of legumes–a source of biological nitrogen fixation.

As fertilizer prices increased maize production declined (Table 3), explained by less maize acreage and lower yields due (in part) to less fertilizer applied. With a zero price for fertilizer the average maize yield was 2.56 t ha^{-1}—1117 kg produced on 0.44 ha. This is the average of yields across all maize plots; the household has different soil types and management intensities. With a zero cost of fertilizer the household shifted towards higher-yielding maize activities (the intensive management option in Table A1). These activities also required more labour and financial costs for other maize-specific inputs. We saw the expected relationship between fertilizer cost and fertilizer use, maize productivity, and maize area. Household fertilizer use appears sensitive to reductions in the cost of fertilizer.

Fig. 2 presents the evolution of maize yields (panel A), fertilizer used by all crops (panel B), nitrogen absorbed by all crops (panel C) over time, and seasonal precipitation (panel D). Yields did not vary greatly over time as seasonal precipitation was relatively constant. Water is often less of a limiting factor than nutrients for crop growth in Malawi (Carr, 2014). Fig. 2 shows the linkages between the fertilizer price and the yield of maize. At higher fertilizer prices the household applied less fertilizer (panel B) and this translated into crops absorbing less nitrogen (panel C). Consequently, maize yield declined (panel A).

Higher fertilizer prices had a negative effect on total household income (Table 3). If fertilizer had no cost, the household's income each year rose by an average 52% from US $ 272 to US $ 413, whereas a 100% increase in fertilizer prices caused a 18% decline in income from US $ 272 to US $ 229. In other similar studies, a 50% subsidy on the cost of buying fertilizer in Ethiopia had a limited effect on simulated crop area and production, with cheaper fertilizer increasing simulated incomes by an average 1%, although some individual farmers experienced income gains of over 40% (Louhichi et al., 2016). Specifically in Malawi, Lunduka et al. (2013) summarized multiple studies on the income effect of fertilizer subsidies for smallholder farmers. In general, evidence suggests modest gains in income from exposure to fertilizer subsidies, for example, an 8% increase in annual per person expenditure for households receiving fertilizer subsidies.

Fertilizer price changes did not have a sizeable effect on the simulated proportion of total calories consumed derived from cereals, which remained at approximately 75% in all scenarios (Table 3). Maize made up almost all the cereal calories consumed. As fertilizer prices rose incomes fell and total consumption changed. There were no

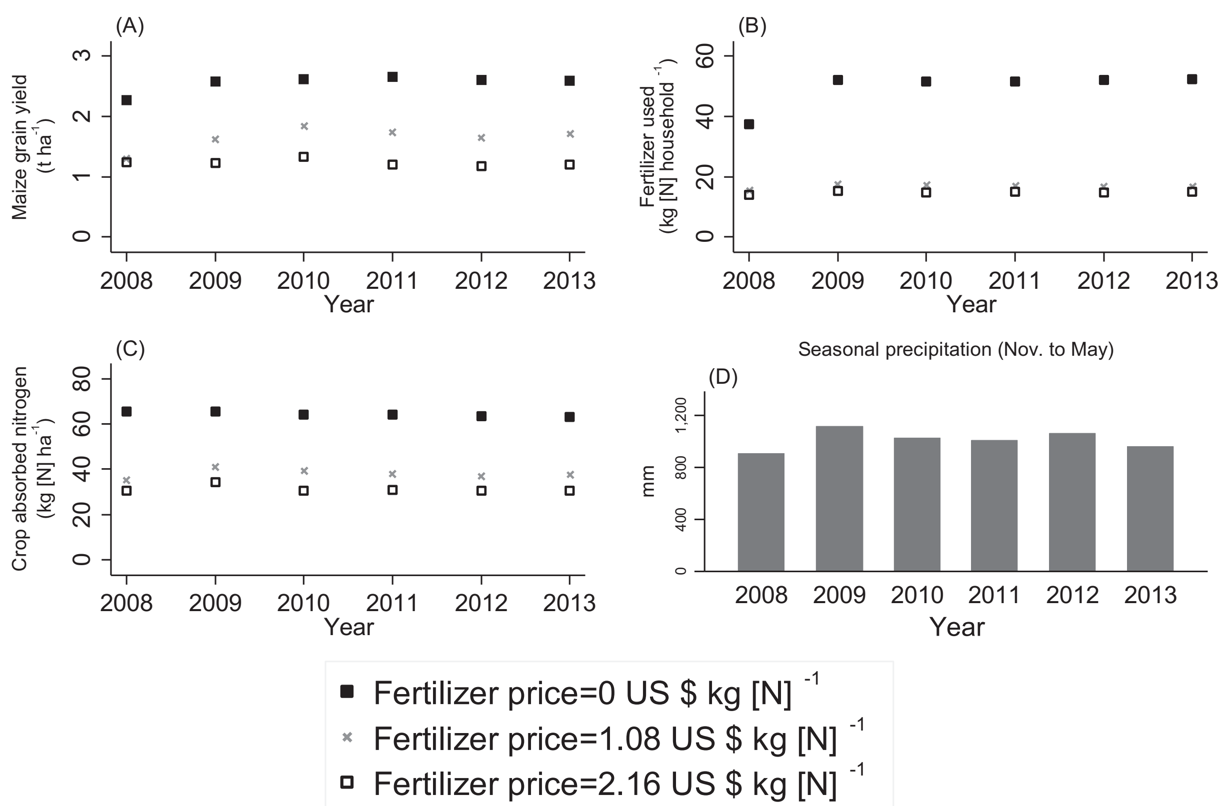

Fig. 2. Simulated effect of fertilizer price changes on maize yields (A, kg ha^{-1}), fertilizer used (B, kg [N] household^{-1}), nitrogen absorbed by crops (C, kg ha^{-1}), and precipitation (D). [N] represents nitrogen.

changes in the relative importance of different food groups to total consumption.

In our study, the income-based benefit-cost-ratio (BCR) was 2.6 and the production-based BCR was 2.9. Other studies on the BCRs of the FISP in Malawi exist. Lunduka et al. (2013) highlighted that BCRs ranged from less than one to over ten. The BCRs in Malawi are contingent on, among others, the price of fertilizer, price of grain, the responsiveness of maize production to fertilizer applied (nitrogen-use efficiency), and the methodology used (Lunduka et al., 2013). For example, prices for maize grain (US \$ kg^{-1}) ranged from 0.14 to 0.21 between 2005 and 2008. In our study, the price of maize grain was US \$ 0.27 kg^{-1}. Using the average price of maize grain from 2005 to 2008 from Lunduka et al. (2013), our production-based BCR became 1.8. Arndt et al. (2015) find a production-based BCR of approximately 1, and an economy-wide BCR of 1.62.

Our BCRs (reported above) do not consider the administration costs of a fertilizer policy, political economy issues, or possible changes in maize prices resulting from the increased supply of maize associated with lower prices of fertilizer. The method we used to calculate the BCR of the fertilizer policy used a farm-household simulation model, this method complements other statistical and structural, model-based economy-wide approaches that have been used to evaluate fertilizer policies in Malawi. Examples of contrasting methods include how nitrogen-use efficiency was used. Our model calculates this, while other studies use values from the literature, for example in Dorward and Chirwa (2011), and Lunduka et al. (2013) indicate that nitrogen-use efficiency can be calculated statistically or taken from household survey data. Nitrogen-use efficiency varies depending on, among other factors, management ability and agroecological conditions. In addition, to calculate the production-based BCR we use the same formula as in Arndt et al. (2015). Our simulated change in production was based on a household-scale analysis which incorporates farm-specific constraints on key financial and physical relationships that define both consumption and production possibilities. The change in production simulated in the analysis of Arndt et al. (2015) was based on a national-scale model which uses reduced-form relationships that capture the overall macro-scale, market equilibrium among the various sectors of the economy, and the flows of payments between the different economic agents of the macro-economy. The behavioural differences between this macro-scale, general-equilibrium framework and the farm-scale, partial-equilibrium approach we use would account for the differences in the BCR ratio. The year of reported data in individual studies is crucial to the BCR as prices for maize and fertilizer vary each year (Lunduka et al., 2013).

To put the results into a different context, other options to achieve lower fertilizer prices exist through exploiting economies of scale in transportation and removing marketing inefficiencies. IFDC (2013) report approximately 40% of the inland fertilizer cost structure from seaports to Malawi relate to transport, 45% relate to middleman marketing margins, with the remainder related to loading costs. Investments in infrastructure and other policy-driven interventions that can lower these costs would have benefits beyond just fertilizer use, and could also affect the markets for both inputs and outputs. Calculation of the implied benefits and costs for such a case are beyond the scope of our study, but would make an interesting comparison with the benefits and costs of a pure input subsidy policy such as the FISP, in future work.

4. Conclusion

This study simulated the effects of changes in inorganic fertilizer prices on different household indicators of performance and welfare. Our results provide useful insights into the barriers that farmers encounter when trying to increase their use of fertilizer. We showed that removing fertilizer costs had a positive effect on the area of higher-yielding (and higher-input) maize. Our results also add to earlier studies in Malawi on the benefit-cost ratio associated with fertilizer policies and earlier studies on the own-price elasticity of fertilizer demand by using an alternative method (i.e., a farm household model). We found that the benefit-cost ratios (BCRs) associated with fertilizer-support programs exceeded one, and here our findings complement the studies discussed in Section 3.3.

We emphasize two points, here. First, lower open-market fertilizer prices appear to benefit smallholder farmers, as shown in our simulations by the positive income effect of lower prices. Second, although surveyed households in our study grew legumes, owned livestock, and worked off-farm, maize production dominated their overall on-farm, livelihood strategy because it contributed the most to their food consumption. We recognize the important cultural and historical reasons why maize has become such a dominant crop for Malawian smallholder farmers – such as the long-standing food security policies that emphasized the importance of cultivating maize as the staple food crop, and the fact that maize grain can be stored more easily than other foods, given limited household-scale technologies. Exploring options to increase the diversity of household livelihoods, from an economic perspective, through improving legume and livestock productivity and better off-farm opportunities appears another avenue for further research, that a model like DAHBSIM can be applied towards. As was the case in this study, the structural nature of DAHBSIM can help point out potential constraints that limit diversification.

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Appendix A

This Appendix contains the main elements of the model used in our study.

Objective function

Based on the mean-standard deviation analysis, Eq. (1) specifies the objective function of the individual household modelled in this study:

$$Max\ U = NPV - \phi \times \sigma \tag{1}$$

where U is expected household utility, NPV is the net present value of (net) household income, Ø is the risk aversion coefficient (set at 0.45), and σ is the standard deviation of the net present value of income. The household must have non-negative activity levels, for example, non-negative crop areas, fertilizer and seed quantities, and food consumption quantities. Eq. (2) specifies the net present value of income for the household:

$$\text{NPV} = \sum_{y=1}^{Y} \left(\frac{\text{CI}_y + \text{OI}_y + \text{VFC}_y}{(1 + i)^y} \right) \tag{2}$$

where y denotes a specific year of the simulation (indexed to the value of 1 for the first year, for example, 2008 = 1 and 2009 = 2, in which case Y = 2), CI_y represents net crop income in year y, OI_y represents off-farm income in year y, and VFC_y represents the household's value of food consumption from on-farm production in year y. In this study the term income is used to capture the economic activity of the household. The income values reported in this study are total household income and are the sum of the terms in the numerator of Eq. (2), i.e., in year y income = $CI_y + OI_y + VFC_y$. The household had a discount rate, i, of 4%. Net crop income is the value of all crop sales (based on their market price and quantity sold) minus all variable input costs that had an actual financial cost, for example seed, fertilizer, and hired labour. The household had a fixed amount of off-farm income each year, set at the amount observed in the household survey. Fig. A1 shows the evolution of prices over time.

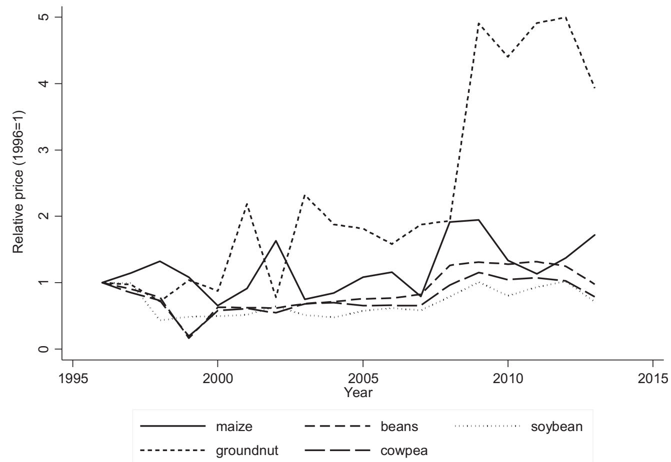

Fig. A1. Relative prices of the crops used in this current study.
Source: FAO (2016)

This study used a set of states of nature for prices to calculate the standard deviation of the net present value of income. Our standard deviation calculation, as specified in Eq. (3), follows the approach taken by Blanco-Gutiérrez et al. (2011). The states of nature are defined by crop price variability, as defined in FAO (2016). The standard deviation from Eq. (1) equals:

$$\phi = \left[\frac{(\sum_{sn} NPV_{sn} - NPV)^2}{SN} \right]^{1/2} \tag{3}$$

where NPV_{sn} is the net present value of (net) household income given a specific state of nature of prices (sn) and actual modelled input and output quantities. NPV is the actual net present value of income based on observed prices and actual modelled input and output quantitates. SN represents the number of states of nature, set at 50. To calculate NPV_{sn} we calculated a “price deviation” parameter for each crop in the model. To calculate this “price deviation” parameter we took nominal historical prices from FAO (2016) for each crop and calculated the difference between the average price and the maximum and minimum price. Fig. A1 shows the range of prices. The “price deviation” parameter for each crop equalled the absolute value of the difference between the average price and the maximum price or minimum price (whichever had the largest absolute value) divided by the average price and expressed as a percentage. We then generated a variable “price parameter$_{sn}$” from this “price deviation” parameter for SN different states of nature for each crop and for each crop this parameter equalled, as specified in Eq. (4). To calculate NPV_{sn}, we multiplied modelled sales quantity by observed prices and the price parameter$_{sn}$ for different states of nature (sn).

$$\text{price parameter}_{sn} = 1 + \left(\frac{\text{uniform}(-1, 1) \times \text{“price deviation” parameter}}{100} \right). \tag{4}$$

A Linear Expenditure System, as used in Louhichi and Gomez y Paloma (2014), calculates the quantity of food consumed by the household each year using Eq. (5):

$$\begin{aligned} & p_i q_i = \gamma_i + \beta_i (I - \sum \gamma_j p_j) \\ & \text{with} \\ & 0 < \beta_i < 1 \\ & \sum_i \beta_i = 1 \\ & q_i - \gamma_i > 0 \end{aligned} \tag{5}$$

where p_i is the price of good i, q_i is the quantity of good i consumed by the household; I is household income from crops and off-farm activities. β_i and Υ_i are the parameters in the Linear Expenditure System. This system considers $\Sigma \gamma_j p_j$ as subsistence expenditure and $I - \Sigma \gamma_j p_j$ as *supernumerary* income (Sadoulet and de Janvry, 1995). To compute β_i and Υ_i we adapted the income elasticities of food demand from Ecker and Qaim (2011) and the Frisch parameter for Africa south of the Sahara from Aguiar et al. (2016). Our study considered a set of 31 food items and a non-food bundle: bean, soybean, beverage, bovine meat, cabbage, cassava, goat meat, groundnut, maize, mango, millet and sorghum, milk, nuts, oils and fat, other animal products, other cereals, other fruits, other meats, other pulses, other spices, other vegetables, pork, potato, poultry, rice, salt, spinach, starch, sugar, sweet potato, and non-food.

Constraints

Here we present the main resource constraints for the household in our model.

Land. The cultivated area each year on a specific soil type cannot exceed potential arable land for that soil type. The model includes four soil types: clay, loam, sand, and other. The household cannot rent land in this model. The household cannot grow beans, cowpea, or soybean on the same plot of land, for a specific soil type, in two consecutive years.

Labour. The household must have enough labour from family sources and from hiring in labour to meet monthly labour requirements for agricultural tasks. Hired labour has a cost and this affects net crop income (the net value of crop production).

Cash. Spending on market purchases, for example, agricultural inputs and food items not produced on farm, cannot exceed the crop income plus off-farm income in any specific year.

Supply and demand balances. For each product, total consumption cannot exceed consumption from farm production plus consumption from market purchases. The household can save seed for future years to reduce the need to purchase seed from the market, so seed is a dynamic variable.

Crop module

The household can grow bean, cowpea, groundnut, maize, and soybean. The module uses the logic of Doorenbos and Kassam (1979) to calculate water-limited yields for these crops (Eq. (6)):

$$\left(1-\frac{Y_w}{Y_m}\right)=K_y\left(1-\frac{ET_a}{ET_m}\right)$$

where:

Y_w is water-limited yield (kg ha^{-1})

Y_m is maximum yield (kg ha^{-1})

K_y = yield response factor ($K_y = 1$ if yield reduction is directly proportional to reduced water use,

$K_y > 1$ if crop response is sensitive to water deficits and,

$K_y < 1$ if crop is more tolerant to water deficit)

ET_a = actual evapotranspiration (mm day^{-1})

ET_m = maximum evapotranspiration (mm day^{-1}) (6)

The module uses the logic of Godwin et al. (1991) to calculate nitrogen-limited yield (Eq. (7)):

$$Y_N = Y_W\left(1-\frac{NC_{crit}-NCONC_a}{NC_{crit}-NC_{min}}\right)$$

where:

Y_N = nitrogen-limited yield (kg ha^{-1})

Y_W = potential growth after water limitation considerations (kg ha^{-1})

NC_{crit} = plant critical nitrogen concentration (kg ha^{-1})

$NCONC_a$ = plant nitrogen concentration after new growth (kg ha^{-1})

NC_{min} = minimum plant nitrogen concentration at which point growth stops (kg ha^{-1}) (7)

The household module uses the minimum of the nitrogen-limited (Y_N) and water-limited (Y_W) yield as the actual yield in the simulations. The crop module updates parameters related to water stress, nitrogen stress, and organic matter each year based on farmer management and external conditions, for example, fertilizer application or precipitation. Both water and nitrogen affect yield. In our study, the main factor limiting yield was nitrogen. Total precipitation each year was often greater than 1000 mm (Fig. 2D). The previous crop affects the current crop yield through its effect on the nitrogen content of soil, as presented in Flichman et al. (2016). In the crop module, the final nitrogen content of soil for the current year equals the initial nitrogen content of soil (which equals the final nitrogen content of soil from the previous year) plus mineralization from organic matter for the current year plus nitrogen fertilization (which could be mineral or organic) plus nitrogen from previous crop residues minus nitrogen uptake from the crop minus nitrogen leaching.

For each activity, our crop module was evaluated in two steps. In the first step, we parametrized the module by calibrating the module for each activity cultivated with the extensive technique on a clay soil. In the second step, we evaluated the module for the same activity in step one but for different crop management (intensive technique) and soil types (loam, sand and other). By doing the above, the conversion of nitrogen to crop yield coefficient (K_n) and the yield response factor to water stress (K_y) were determined by calibration since the module was sensitive to these parameters under rainfed conditions. Values of K_n and K_y were adjusted within a reasonable range of variation based on previous research, knowledge, or experience to have the best model estimation of the yield observed for each activity from the survey. To ensure a good correlation between observed and simulated data, the adjustment process was stopped when further modification of crop parameters values generated little or no change in the normalized root mean square error. Specific parameters for crop phenology, water, nitrogen, and organic matter were taken from the literature (Doorenbos and Kassam, 1979; Ollenburger, 2012; Ollenburger and Snapp, 2014), calculated from the survey or calculated from the calibration. Flichman et al. (2016) provides more details on this procedure, including on the coefficient for nitrogen conversion to crop yield (K_n).

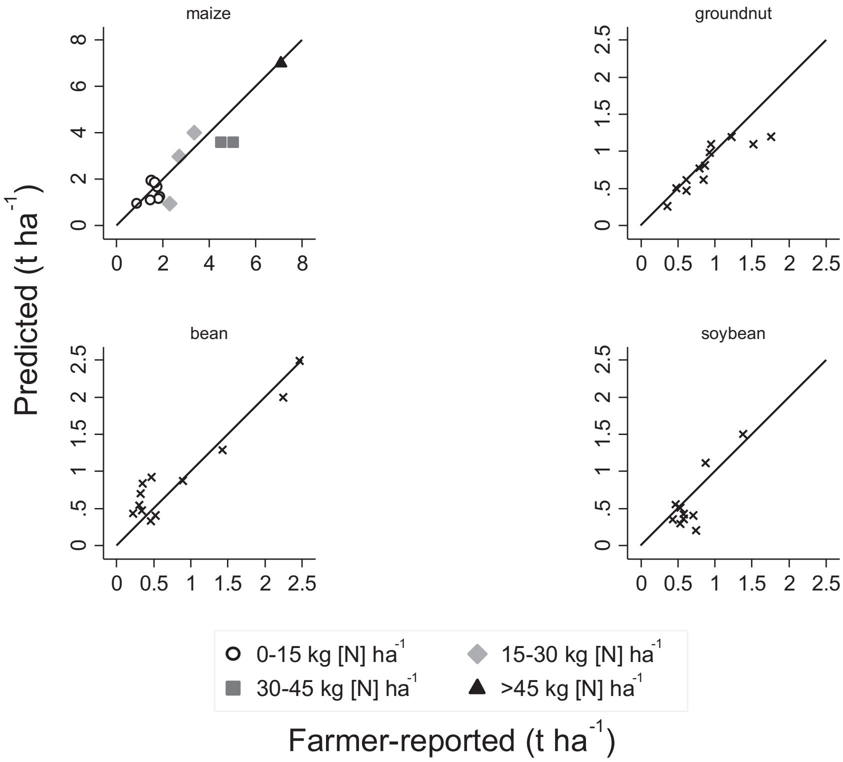

Fig. A2. Association between farmer-reported and predicted grain yields. Solid line is 1:1 line (the 45° line). Predicted refers to 2013 grain yields simulated in the crop module. Farmer-reported refers to farmer-reported grain yields in 2013 reported by the representative household. Non-cross markers represent different amounts of fertilizer applied to maize where [N] represents nitrogen.

Table A1
Observed maize yield and inputs use, and simulated areas by intensification level.

	Extensive	Intensive
Observed maize yield (kg ha^{-1})	1648	4269
Observed fertilizer (kg [N] ha^{-1})	37	131
Observed seed (kg ha^{-1})	30	49
Observed labour (days ha^{-1})	212	464
Observed costs of non-fertilizer, non-seed inputs (US $ ha^{-1})	0.5	3.6
Simulated maize area (fertilizer price = 0)	0.24	0.20
Simulated maize area (fertilizer price = 1.08 US $ kg^{-1} [N])	0.32	0.02
Simulated maize area (fertilizer price = 2.16 US $ kg^{-1} [N])	0.34	0

Note: [N] represents nitrogen. Yields in each intensity level are the average across different soil types (sand, loam, clay, or other) and seed varieties (local or improved) and range from 872 kg ha^{-1} to 2299 kg ha^{-1} for the extensive level and from 2687 kg ha^{-1} to 7075 kg ha^{-1} for the intensive level.

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Pesticide residues and trade, the apple of discord?

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ABSTRACT

In this paper we study the impact of the regulations on Maximum Residue Levels (MRLs) of pesticides on the trade of apples and pears and related processed products with the aim of understanding how their similarity (or dissimilarity) affect trade. Most studies investigate the impact of sanitary regulations introducing directly in the analysis the MRL put in force in the importing country. They introduce in the analysis the level of the regulation in the importing country without taking into account the rule in force in the exporting country. Rather than focusing on a particular pesticide we take into account the entire list of substances set out by the various regulations. We then build a similarity index and introduce it into a gravity equation to assess the impact of the differences in MRL of pesticides on trade. Results suggest that the differences between regulations matter and may, in some case, hinder trade.

Introduction

Previous research has addressed how food safety standards affect international trade (Henson et al., 2000; Otsuki et al., 2001a,b; Moenius, 2006; Wilson and Otsuki, 2003, 2004; Winchester et al., 2012). Generally, economists try to assess trade losses borne by exporters when importing countries impose stricter regulations. Standards affect trade competitiveness insofar as they imply a cost of compliance on producers which increases the price of a product. Furthermore it is a commonly accepted result in the literature that standards are trade-impeding; at least for agrofood trade from developing countries. However there are some studies that highlight a positive impact on trade. Moenius (2006) has sought to show a positive impact of exporter standards on agrofood trade as they "can establish trust and reduce search costs for consumers". Disdier et al. (2008) report the "dual effects of SPS and TBTs in agriculture which can have no impact on trade or even facilitate it as they carry information and confidence on the imported products". Following Li and Beghin (in press), "the literature shows a wide range of estimated effects from significantly impeding trade to significantly promoting it". Henson and Jaffee (2008) argue that exporters facing strict food safety standards incur a cost of compliance which may be "offset by an array of benefits from the enhancement of food management capacity".

Departing from this argument, we assess the impact of the regulations on Maximum Residue Levels (MRLs) of pesticides on the trade of apples and pears and related processed products. "The MRL is an index which represents the maximum concentration of a pesticide residue (expressed as mg/kg) legally permitted in food commodities and animal feeds. MRL on food imports are set by each country and are imposed as regulatory standards at the border" (Wilson and Otsuki, 2004). We consider that apples and pears are a good case-study as these fruits are affected by numerous phytosanitary treatments and are also among the most traded fruits in the world along with oranges. The objective is to compare the "closeness" of standards. We seek to understand how the similarity (or dissimilarity) in regulations affects trade. Indeed, most studies examine the regulations put in force in the importing country. We assume that what matters is the difference in the tolerance levels of the importing and exporting country. A country which already imposes strict domestic tolerance levels on pesticide residues may have fewer difficulties in complying with the requisites of a stringent importer, given that its producers have already coped with the cost of compliance of maintaining low residue levels. This is done using a similarity index. A similarity index has already been used in the literature to compare regulations on Genetically Modified Organisms (GMOs) (Vigani et al., 2010) or varieties of grapes and wines (Anderson, 2009, 2010) and more recently on food safety standards (Winchester et al., 2012). We use a similar

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measure: the distance associated to Pearson's correlation coefficient to capture the proximity between regulations; then we introduce this index as an exogeneous variable into a gravity model to assess the bilateral impact of MRL of pesticides for forty trading partners (Argentina, Australia, Brazil, Canada, Chile, China, the 27 member states of the European Union (EU), Japan, Korea, Mexico, New Zealand, South Africa, Russia, and the USA). These countries represent more than 80% of traded fresh and processed[2] apples and pears.

The paper is organized as follows. Section 2 presents an overview of the MRL regulations in force in the chosen countries and details the construction of the similarity index. Section 3 deals with data and the econometric model. Section 4 presents the results. Section 5 concludes.

Maximum Residue Levels of pesticides: an unharmonized frame

Pesticide is a generic term which includes all substances used to avoid or control pests. The Food and Agriculture Organization defines it as: "any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport."

Furthermore pesticides are often hazardous substances that cause harmful or deleterious effects on human or animal and plant health through exposure or dietary intake as they tend to stay in the products in which they have been sprayed even when they are peeled or washed. In order to safeguard consumer health and to promote good agricultural practices, maximum levels of residue of pesticides have been set worldwide. Public authorities regulate these levels based on scientific prediction of an acceptable daily intake (ADI) of residues. When science is not able to derive an ADI some countries decide to set their MRL at a very low default level on the basis of the precautionary principle.

International harmonization of MRL does not exist at a global level. Even though the Codex Alimentarius provides MRL, they are not statutory. National authorities hold the sovereignty in fixing these limits. Therefore these legal limits can widely vary across countries. Regarding pesticide residues, there are as many regulations as countries. The number of pesticides registered and the MRL set, greatly vary from one country to another. Some countries have adopted very severe rules with MRL well below the Codex settings and zero-tolerance provisions for disallowed or prohibited substances or for which a MRL cannot be established due to the lack of toxicological data. This is the case of the Russian Federation which was the target of complaints for the stringency of its standards, whereas other countries have decided to adopt international standards set up by the Codex. This is for example the case in Argentina, Brazil, Chile, Korea, New Zealand or South Africa. Another important difference is the list of substances registered in regulations. These provisions are summarized in Table 1. Some countries (e.g. the USA or the EU) have a very detailed list while others provide a limited number of pesticides but zero tolerance provisions or a very low tolerance level for those which are not explicitely listed (as in Australia, Canada or Mexico).

Other countries have an even more complicated system. For example, Korea imposes 236 limits for apples and 210 for pears. If a limit is not set for a product, the Codex standard shall be applied, otherwise the limit for the most similar product is applied. If none of these solutions is applicable, Korea imposes a default value of 0.01 mg/kg.

New Zealand has 112 limits for apples and 107 for pears; codex MRL are recognized for imported food, Australian MRL recognized for food imported from Australia. If no MRL exists, a default MRL of 0.1 mg/kg is used.

In Russia limits are set for 124 pesticides for apples and 122 for pears. In 2008 Russia signed two bilateral memorandums with the EU and Chile. They stipulate that "if there is no Maximum Residue Level for pesticide residues, nitrates and nitrites specified for a certain type of product in the Russian legislation, the MRL for the most similar product included in the same commodity group (as defined in the Codex Alimentarius) is applied, and that if there is no MRL for the commodity group, the MRL of the Codex Alimentarius is used. If there is no MRL of the Codex Alimentarius, the MRL of the country of origin is applied".

The issue of international discrepancies between food safety regulations and their possible impact on trade has already been studied. Wilson and Otsuki (2003) have estimated that adopting the Codex standard on Aflatoxin B1 would raise world cereal and nut exports up to US$ 38.8 millions. Wilson and Otsuki (2004) assessed the impact on trade of harmonizing the MRL of chlorpyrifos on banana trade between 21 exporting countries and 11 OECD importing countries. They found that increasing the stringency of the MRL of this pesticide would have a negative impact on trade.

We investigate the influence of MRL of pesticides on the fresh and processed apples and pears trade flows between 40 trading partners. Countries in the sample have been chosen on the basis of four non exclusive criteria: (i) their share in the international trade of apples and pears; (ii) their consumption level concerning these fruits; (iii) their presumed stringency in regulations; and (iv) the availability of data on the MRL of pesticides they have set. We measure the "regulatory distance" of MRL of pesticides between the countries of the sample and assess how it affects the trade of these two fruits. We assume that concerning MRL, the main point is the similarity between regulations more than the absolute level of stringency and we presume that producers operating in a country which already impose stringent standards would have fewer difficulties in complying with stringent importing standards.

We use a direct measure of standards to compute an index evaluating the (dis)similarity in regulations, assuming that similar regulations may enhance trade while different regulations might impede trade. An index is then built based on the MRL of pesticides set by each country on apples and pears. The main difference from previous studies (Otsuki et al., 2001a,b; Wilson et al., 2003; Wilson and Otsuki, 2004 or Xiong and Beghin, 2011) is that we compute our index based on all pesticides found in those regulations rather than just one or two main substances. In the literature, the similarity index has been used by Anderson (2009, 2010) and Vigani et al. (2010). Vigani et al. (2010) have adapted the Jaffe (1986) methodology to investigate how the similarity or dissimilarity in GMO regulation affects bilateral trade. Their index is computed as the angular separation or uncentered correlation of the vectors of the variables under scrutiny (Jaffe, 1986, p. 986). More recently Winchester et al. (2012) propose a heterogeneity index adapted from the Gower (1971) index of similarity to analyze the trade impact of differences on food safety standards. Both studies show that countries with strong differences in regulations trade less, suggesting that an international harmonization is needed. We use a similar

[2] Dried apples, apple juice and preserved pears.

Table 1
Number of pesticides registered in countries' regulations.

	Nb. of pesticides registered for apples	Nb. of pesticides registered for pears	Rule when a pesticide is not registered
Argentina	108	92	1-Codex 2-Zero-tolerance
Australia	175	160	Zero-tolerance
Brazil	175	12	Codex
Canada	93	83	Default limit of 0.1 mg/kg
Chile	103	91	Codex
China	57	66	1-Codex 2-Limits applied by reference countries (EU, USA)
EU	526	526	Default limit of 0.01 mg/kg
Japan	391	767	Default limit of 0.01 mg/kg
Korea	236	210	1-Codex 2-Limit of most similar group of product 3-Default limit of 0.01 mg/kg
Mexico	72	105	Zero-tolerance
New Zealand	112	107	1-Codex recognized for imported food 2-Australian MRLs recognized for food imported from Australia. 3-Default limit of 0.1 mg/kg applies
Russia	124	122	1-Codex 2-Memorandum with Chile and the EU 3-MRL of the most similar product 4-MRL of the country of origin
South Africa	130	107	Codex
USA	799	799	Zero-tolerance

Source: Homologa, national regulations and expert comments for China.

methodology as in Vigani et al., computing the distance associated to Pearson's correlation coefficient.

SIM_{ij}^k is Pearson's distance and it is computed as follows:

$$SIM_{ij}^k = 1 - \left(\frac{1}{n}\sum_{p=1}^{n}\left(\frac{x_{ip}^k - \bar{x}_i^k}{\sigma_i^k}\right)\left(\frac{x_{jp}^k - \bar{x}_j^k}{\sigma_j^k}\right)\right) \quad (1)$$

where n is the total number of pesticides registered, x_{ip}^k and x_{jp}^k are the MRL of the exporting country i and the MRL of the importing country j for pesticide p and product k, respectively. $\bar{x}_i^k$ and $\bar{x}_j^k$ are the sample means for country i and country j and product k. σ_i^k and σ_j^k are the sample standard deviations for product k in country i and j, respectively.

The Pearson's correlation coefficient is a very classical way of measuring the proximity between vectors of variables. Its value lies in the range $[-1,1]$, the corresponding distance falls between $[0,2]$. A value of *SIM* equal to 0 means that the two compared samples are similar while a value of 2 denotes the contrary.

Something must be said on the building of the MRL database from which we derived our *SIM* index. As pointed out in the first section, regulations are very dissimilar among countries and n is different from one country to another. However Pearson's coefficient impedes us to use vectors of different size and n must be equal for all countries. Therefore, to compute our index we take all the substances referenced in the database. A total of $n = 749$ pesticides are registered. But if some pesticides are common to all regulations, it is not the case for all. When a pesticide is not explicitely listed by a country, we must find a way to replace the missing value. When the country has declared a default value, we replace the missing value by the default MRL (e.g. 0.01 for the EU). But when no default value is available the treatment of missing MRL is tougher. This situation may arise in three cases: (i) the data are incomplete, the MRL exists but the data collector failed to collect it; (ii) the default MLR exists but the data collector failed to collect it; and (iii) the substance is exempted by the country. For the ease of our analysis we only consider the third case. Unlike Winchester et al. (2012), we consider that if a country does not regulate a pesticide this means that the pesticide is exempted from any maximal limit and we arbitrarily attribute it a value of 75 corresponding to the maximum MRL found in the database. Values of the index of similarity are reported in Tables 2 and 3.

The first lesson of these two tables is that regulations on MRL of pesticides are "rather" but not "very" dissimilar among the countries. The value of the *SIM* index is on average equal to 1. The second lesson is that there are clear differences between countries referring only to the Codex (Brazil, Chile, China, South Africa) and the other ones. The value of *SIM* is almost always greater than 1 when comparing countries which use the Codex as default value and countries which do not. This result shows that national regulations and the Codex Alimentarius are rather "far" from each other, national regulations being always more stringent – often in the name of the principle of precaution – than the Codex.

Data and model specification

Apples and pears are particularly interesting to study as these fruits are greatly affected by contaminants such as pesticides because of the numerous phytosanitary treatments they are subject to and because these substances tend to stay in the products even when they are peeled or washed. Moreover, they are products of the temperated zone involving countries both from developed and developing areas. They are the most-highly consumed fruits (along with oranges) in the USA and the EU. They are easily shipped and represent important levels of trade both in value and volume. On the global apple market few players are involved (See Tables A.1–A.4 in the appendix). China, the EU, Chile and the USA capture the lion's share of 75% of apple's world exports. In 2009, China was the first world provider of apples with 1 million tons of fresh apples sold, followed by the EU. From the import side, the EU and Russia distinguish themselves as they represent almost half of the total imports of apples. In 2009, the first apple trade partner of the EU was Russia. The same actors are involved in the trade of pears (USDA/FAS, 2011).

The dataset covers 40 importers (the 27 EU's member states, Argentina, Australia, Brazil, Canada, Chile, China, Japan, Korea, Mexico, New Zealand, Russia, South Africa and the USA) and 38 exporters (the same countries except Mexico and Russia which are mainly importing countries). The time period covered by our estimation starts from the year 2000 and ends in 2009. In our model k is defined at the 6 digit-level of the 1996 harmonized system and represents five products: fresh apples (080810), fresh

Table 2
Apples matrix of "distance" between national regulations on pesticide MRL (value of the *SIM* index).

APPLES	Austr.	Brazil	Canada	Chile	China	EU27	Japan	Korea	Mexico	N. Zeal.	Russia	USA	S. Africa
Argentina	0.85	1.33	0.79	1.31	1.32	1.02	0.88	0.53	0.87	0.94	0.17	0.90	1.28
Australia		1.06	0.95	1.05	1.06	1.03	0.96	0.91	1.00	0.99	0.83	0.97	1.06
Brazil			1.16	0.30	0.26	0.90	1.23	1.27	0.99	0.97	1.30	1.05	0.30
Canada				1.14	1.15	1.03	0.89	0.86	0.95	1.00	0.79	0.93	1.15
Chile					0.28	0.88	1.10	1.26	0.98	0.95	1.29	1.01	0.37
China						0.88	1.11	1.19	0.98	0.95	1.29	1.01	0.34
EU							0.93	0.97	1.01	0.93	1.02	0.93	0.87
Japan								0.50	0.97	1.00	0.89	0.94	1.11
Korea									0.98	0.95	0.54	0.94	1.16
Mexico										0.84	0.90	0.99	1.00
New Zealand	0.00										0.94	1.02	0.96
Russia				0.23		0.00						0.93	1.24
USA													1.03

Source: Author's own calculations from HOMOLOGA database.
Note: The matrix is not symmetric because New Zealand recognizes MRL for food imported from Australia and Russia for those from the EU and Chile.

Table 3
Pears Matrix of "distance" between national regulations on pesticide MRL (value of the *SIM* index).

PEARS	Austr.	Brazil	Canada	Chile	China	EU27	Japan	Korea	Mexico	N. Zeal.	Russia	USA	S. Africa
Argentina	0.78	1.38	0.88	1.33	1.32	0.96	0.67	0.49	0.92	0.93	0.16	0.89	1.30
Australia		1.09	0.95	1.07	1.08	1.01	0.88	0.87	0.98	0.98	0.76	0.95	1.07
Brazil			1.14	0.26	0.20	0.92	1.22	1.28	0.97	0.99	1.35	1.02	0.25
Canada				1.11	1.13	1.03	0.90	0.87	1.00	1.01	0.89	0.97	1.14
Chile					0.30	0.89	1.17	1.27	0.96	0.95	1.27	1.01	0.36
China						0.89	1.17	1.21	0.97	0.95	1.28	1.01	0.33
EU							0.93	1.02	1.01	0.92	0.95	0.93	0.89
Japan								0.71	0.99	0.98	0.79	0.90	1.17
Korea									1.01	0.94	0.50	0.96	1.18
Mexico										0.79	0.94	1.01	0.99
New Zealand	0.00										0.93	1.01	0.96
Russia				0.24		0.01						0.92	1.25
USA													1.01

Source: Author's own calculations from HOMOLOGA database.
Note: The matrix is not symmetric because New Zealand recognizes MRL for food imported from Australia and Russia for those from the EU and Chile.

pears (080820), dried apples (081330), apple juice (200970) and preserved pears (200840). This level of disaggregation is imposed by the use of the United Nation database on trade (UN COMTRADE) dataset for trade. Our sample has 53560 observations, 20246 are non zero observations and 33314 are zero observations, some of these zero may be due to rounding errors or incompleteness of UN COMTRADE data, but others reflect the absence of trade between country pairs.

In order to assess the impact of pesticide residue standards on trade of apples and pears, we use a gravity model. Gravity modeling has already been widely used to estimate the effect of regulations on hazardous substances on trade. For example, Wilson and Otsuki (2004) use gravity modeling to assess the impact of regulations on MRL of pesticides for 11 OECD countries on banana trade from 21 developing countries. They include in their equation a direct measure of the food safety standard using the level of the MRL of the hazardous substance imposed by the importing country. We assume here that what matters is more the proximity between the regulations of both countries rather than the sole level of tolerance of the importing country. If a country imposes stringent rules on its producers, they will bear a cost in order to comply with these rules. This cost will certainly affect their price-competitiveness but at the same time they will be more capable of accessing a country which also imposes tight rules. This argument has been supported by Harris et al. (2002) who have evidenced that stringent environmental regulations do not have a significant impact on trade.

We estimate a gravity equation with fixed effects using both linear and non linear estimators. The log-linear version of our model has the following specification:

$$\begin{aligned}\ln(X^k_{ijt}) = {} & \beta_0 + \beta_1 \ln(GDP_{jt}) + \beta_2 \ln(PROD^k_{it}) + \beta_3 \ln(Dist_{ij}) \\ & + \beta_4 Border_{ij} + \beta_5 Lang_{ij} + \beta_6 \ln(SIM^k_{ij}) + \beta_7 \ln(Tarif^k_{ijt}) \\ & + \beta_8 Transp_{ijt} + \beta_9 DispJapUsa_t + \beta_{10} DispAusNzl_t \\ & + \beta_{11} SPS^k_{ijt} + \beta_{12} EU_t + \alpha_i + \alpha_j + \alpha_k + \alpha_t + \varepsilon^k_{ijt} \qquad (2)\end{aligned}$$

where i stands for exporter, j for importer, k for product and t for the time. X^k_{ijt} is the export flow in thousand of US dollars[3] of product k from country i to country j in year t. Data on trade are obtained from UN COMTRADE. GDP_{jt} is the Gross Domestic Product in current US dollars of importing country j in year t. The GDP measures the potential import demand of country j, hence the coefficient of β_1 is expected to be positive. GDP comes from the World Development indicators (WDIs) of the World Bank (WB). As a proxy of the sectoral supply, we use the production of apples and pears rather than the GDP for exporting countries. $PROD^k_{it}$ is the production of product k in country i in year t and has been retrieved from the Food and Agriculture organization (FAO) datasets and β_2 is expected to be positive. $Dist_{ij}$ is the distance between the capitals of country i and country j. This variable is a proxy of trade costs and β_3 is expected to be negative. Distances come from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPIIs). $Bord_{ij}$ is a dummy variable equal to 1 if country i and j share the same land border, and 0 otherwise. The sign of the corresponding coefficient β_4 should be positive. $Lang_{ij}$ is a dummy variable equal to 1 if a country pair shares the same language and 0 otherwise. Sharing a common language means that there are some cultural links between the countries

[3] The use of nominal values is suggested by De Benedictis and Taglioni (2011).

which are favorable to trade, hence the sign of the corresponding coefficient β_5 should be positive.

Our key variable SIM_{ij}^k measures the (dis)similarity between regulations on pesticide residues in force in country *i* and country *j* for product *k*. This regressor is time invariant $SIM_{ijt}^k = SIM_{ij}^k$ for all *t* because the values of MRL in the database do not change over the whole period. The sign of β_6 is expected to be negative because the lower SIM_{ij}^k, the higher the similarity between country *i* and country *j* regulations. In an alternative specification, we specify an interaction term between our key variable SIM_{ij}^k and the exporter fixed effects adding to the equation (2), the term: $\beta_{13}(SIM_{ij}^k) * \alpha_i$. This new specification is given by the equation (3). The resulting effect of the dissimilarity between regulations on a specific exporting country is given by $\hat{\beta}_6 + \hat{\beta}_{13}$.

$$\begin{aligned}\ln(X_{ijt}^k) = {} & \beta_0 + \beta_1 \ln(GDP_{jt}) + \beta_2 \ln(PROD_{it}^k) + \beta_3 \ln(Dist_{ij}) \\ & + \beta_4 Border_{ij} + \beta_5 Lang_{ij} + \beta_6 \ln(SIM_{ij}^k) + \beta_7 \ln(Tarif_{ijt}^k) \\ & + \beta_8 Transp_{ijt} + \beta_9 DispJapUsa_t + \beta_{10} DispAusNzl_t \\ & + \beta_{11} SPS_{ijt}^k + \beta_{12} EU_t + \beta_{13} \ln(SIM_{ij}^k) * \alpha_i + \alpha_i + \alpha_j + \alpha_k \\ & + \alpha_t + \varepsilon_{ijt}^k \end{aligned} \quad (3)$$

$Tarif_{ijt}^k$ is the applied ad-valorem customs tariff imposed by country *j* on imports from country *i*. β_7 is expected to be negative. Data come from CEPII's MacMAps database, national regulations and World Trade organization. $Transp_{ijt}$ is the difference between country *j* and *i*'s corruption perception index. This index ranges between 10 (high degree of perceived transparency) and 0 (high level of perceived corruption) and the associated absolute difference lies also between 10 and 0. Using the difference allows to take into account not only the willingness to take bribes of the importing country but also the willingness to pay bribes of the exporting country (Lambsdorff, 2007). The sign of β_8 is expected to be negative as this variable reflects the effect of similarity in the quality of the institutions "which may give rise to similar norms of behavior and similar levels of trust in doing business" (de Groot et al., 2004). Similar behavior in business practices will impact trade positively and *vice versa*. The corruption perception index comes from www.transparency.org.

$DispJapUsa_t$ is a dummy variable taking into account the Japanese phytosanitary protocol prohibiting imports of apples from the USA in order to prevent the introduction of fire blight and ruled by the WTO in 2005 (Calvin and Krissof, 1998, 2005). $DispAusNzl_t$ is another dummy variable used to introduce the Australian measures affecting the imports of apples from New Zealand to prevent the introduction of fire blight, European canker and apple leaf curling midge and ruled by the WTO in 2010. SPS_{ijt}^k is a dummy variable used to introduce the effect of other measures affecting these fruits over the period under scrutiny.

EU_t is a dummy variable accounting for the enlargement of the European Union. This variable is equal to 1 for the countries inside the EU and 0 otherwise. The data cover the years 2000 to 2009. Within this period the EU has been enlarged twice in 2004 and 2007. Therefore, from 2000 to 2003 the EU_t variable is equal to 1 for the 15 EU's member states; from 2004 to 2006 this variable is equal to 1 for the 15 + 10 EU's member states and 0 otherwise and from 2007 to 2009, this variable is equal to 1 for the 25 + 2 EU's member states and 0 otherwise.

The terms α_i, α_j, α_t, and α_k are the exporter, importer, time and product fixed effects,[4] respectively. Finally, ε_{ijt}^k is the error term that is assumed to be normally distributed with zero mean.

[4] The use of fixed effects for each importer, exporter and year makes the gravity's specification more consistent (Baldwin and Taglioni, 2006).

Estimation results

The simplest way to estimate a gravity equation is by Ordinary Least Squares (OLSs). But OLS suffer from a lot of econometric issues. Among them, the log-linearization of the variables can lead to biased estimations in presence of heteroskedasticity as showed by Santos Silva and Tenreyro (2006, 2010). They suggest to use the Poisson Pseudo Maximum Likelihood (PPML) method instead. PPML can help dealing with heteroskedasticity but assumes that the dependent variable is equidispersed and then fails in the presence of overdispersion (i.e. when the variance of occurences exceeds their mean). This issue can be resolved using the Negative Binomial Regression (NBR) where the unobserved heterogeneity among observations is included in the conditional mean by adding a dispersion parameter in the specification of the variance (Cameron and Trivedi, 1998).

Another issue is that of the presence of too many zeros. PPML and NBR assume that all pairs of countries have a positive probability of trading (Burger et al., 2009). But the presence of zeros may come either from roundings or from what is called self-selection (Xiong and Beghin, 2011). Self-selection occurs when the complete lack of trade between country pairs is due to a lack of resources or to distances, differences in specialization, seasonality, etc. To overcome this issue, zero-inflated models (ZIMs) may help. These models allow the zeros to be produced by two different processes. They consider the existence of two latent groups. The first one has strictly zero counts while the second one has a non zero probability of counts different from zero. Zero-inflated models are two-step models. The first step uses a binary model and the second step a count model. The binary model can be estimated using either a probit or a logit estimator while PPML or NBR can be used for the count model (including zero).

The specification of the ZIP model is:

$$Pr(X_{ijt}^k = x | z_{ijt}^k) = \begin{cases} \Phi(z_{ijt}^k \gamma^k) + (1 - \Phi(z_{ijt}^k \gamma^k)) exp(-exp(z_{ijt}^k \beta^k)) \text{ if } x = 0 \\ \frac{(1-\Phi(z_{ijt}^k \gamma^k)) exp(-exp(z_{ijt}^k \beta^k) exp(z_{ijt}^k \beta^k X))}{x!} \text{ if } x > 0 \end{cases} \quad (4)$$

where $\Phi(z_{ijt}^k)$ is the probability of zero trade flows due to exporters' self-selection behavior, $exp(-exp(z_{ijt}^k \beta^k))$ is the probability of drawing a zero from a Poisson process with parameter $exp(z_{ijt}^k \beta^k)$.

The specification of the ZINB is:

$$Pr(X_{ijt}^k = x | z_{ijt}^k) = \begin{cases} \Phi(z_{ijt}^k \gamma^k) + (1 - \Phi\left(\frac{\alpha^{-1}}{\alpha^{-1} + exp(z_{ijt}^k \beta^k)}\right)^{\alpha^{-1}} \text{ if } x = 0 \\ (1 - \Phi) \frac{\Gamma(X_{ijt}^k + \alpha^{-1})}{X_{ijt}^k ! \Gamma(\alpha^{-1})} \left(\frac{\alpha^{-1}}{\alpha^{-1} + exp(z_{ijt}^k \beta^k)}\right)^{\alpha^{-1}} \left(\frac{exp(z_{ijt}^k \beta^k)}{\alpha^{-1} + exp(z_{ijt}^k \beta^k)}\right)^{x_{ijt}^k} \text{ if } x > 0 \end{cases} \quad (5)$$

Table A.5 in the appendix shows the main results for three methods of estimations (OLS, PPML, and ZINB). Two statistic tests allow us to choose between the estimations' method (OLS, PPML, and ZINB). First, to check the adequacy of the estimated models, we performed the Reset test (Ramsey, 1969) which can be used to detect whether the outcome equations are correctly specified. The ZINB is the only regression to pass the Reset test. Then the Vuong test (Vuong, 1989) helps to discriminate against the use of zero-inflated models searching for significant evidence of excessive zero counts. We then focus on the estimations performed using the zero inflated negative binomial counterpart on pooled data. The specification includes country pairs fixed effects and time fixed effects to control the time and country variations.

Table 4 shows two sets of parameter estimates, the first set for the count part and the second set for the logit model. The count part reports the negative binomial regression coefficients, while the inflation part specifies logit coefficients for predicting excess zeros. The first set of coefficients are direct elasticities, while the

Table 4
Estimated elasticities of trade and probability of zero trade.

Varibales	Main NBREG count part (estimated elasticities)	SE	Inflation Logit part (probability of zero trade)	SE
GDP IMP	1.64[c]	(0.07)	−0.48[a]	(0.26)
PROD EXP	0.78[c]	(0.12)	−0.68[c]	(0.10)
DIST	−0.54[c]	(0.17)	1.05[c]	(0.30)
BORDER	0.88[c]	(0.08)	−2.07[c]	(0.28)
LANGUAGE	0.27[b]	(0.12)	−1.25[c]	(0.05)
CORRUPTION	0.03[a]	(0.02)	0.10[a]	(0.05)
TARIFF	−0.01	(0.03)	0.11[c]	(0.04)
EU	−0.61	(0.83)	−1.12	(0.88)
SIMILARITY	−0.16[c]	(0.03)	−0.02	(0.07)

Note: In all the estimations, observations have been clustered at product line.
[a] Indicate that coefficients are statistically significant, respectively, at 10% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[b] Indicate that coefficients are statistically significant, respectively, at 5% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[c] Indicate that coefficients are statistically significant, respectively, at 1% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).

second set may be considered as the probability of zero trade. Globally, the coefficients have the expected signs, but more interesting are the results of distance, tariffs and similarity. The results show that physical distance has an impact both on the volume of trade (−0.54) and on the probability of zero trade (+1.05), "regulatory distance" (similarity) impacts the volume of trade (−0.16) but not its existence (the coefficient of −0.02 is not significant), while tariff only impacts the odds of no trading (+0.11). Lowering the regulatory distance between countries by 100% would increase trade by 16%. This means that totally harmonizing regulations would increase the volume of trade but does not constitute *per se* a sufficient condition for the existence of trade, while tariffs do.

Then, we reestimate our model adding a set of interaction terms between the *SIM* index and the exporting country fixed effect. Table 5 reports the results. As previously indicated in the general case, the lower the regulatory distance, the greater the trade; this is the case for Australia (−0.12), Canada (−14.49), China (−2.179), New Zealand (−16.20) and the EU (−0.09). For Argentina, Brazil, Chile, Korea and South Africa the coefficients are not significant, meaning that harmonizing regulations (i.e. lowering the distance) would have no impact on trade. This result can be explained if exporters in these countries have already internalized the costs associated to stricter regulations and are well adapted to their trade environment. Finally, the USA and Japan (to a lesser extent) display a positive value of the similarity index reporting total effects equal respectively to 32.83, and 21.803. This means that the harmonization of trade can be, in certain cases, trade-diverting. Adopting an international standard – particularly if it is less stringent than the previous national regulations – is not always desirable as pointed out by Winchester et al. (2012) in their conclusion. The USA take advantage of their high level of food safety standards but also show higher production prices according to FAO data. In the event of an international harmonization the USA might lose ground on less costly competitors because of the loss of differentiation.

Table 5
Estimated marginal effects of the similarity index by country.

Variables	*Zinb*			
	Nbreg		*Logit*	
	Beta	(SE)	Beta	(SE)
SIMILARITY	−0.31[c]	(0.06)	−0.14[c]	(0.04)
Similarity[a]Argentina	−0.13	(0.09)	0.27	(0.36)
Similarity[a]Australia	0.19[c]	(0.04)	0.25	(0.45)
Similarity[a]Brazil	−0.90	(0.84)	−0.37	(0.66)
Similarity[a]Canada	−14.18[b]	(5.82)	0.13	(1.92)
Similarity[a]Chile	−0.55	(0.73)	−0.58	(0.55)
Similarity[a]China	−1.87[c]	(0.46)	−1.85[b]	(0.91)
Similarity[a]Korea	3.65	(2.57)	1.19	(2.84)
Similarity[a]Japan	2.12[b]	(1.07)	−0.42	(0.91)
Similarity[a]New Zealand	−15.87[c]	(5.00)	5.46	(4.36)
Similarity[a]South Africa	2.66	(2.87)	−0.98	(1.19)
Similarity[a]USA	33.15[c]	(5.48)	−14.63[c]	(3.19)
Similarity[a]EU	0.22[c]	(0.06)	0.15[b]	(0.07)

Note: In all the estimations, observations have been clustered at product line.
[a] Indicate that coefficients are statistically significant, respectively, at 10% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[b] Indicate that coefficients are statistically significant, respectively, at 5% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[c] Indicate that coefficients are statistically significant, respectively, at 1% level. In all the estimations Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).

In order to test the robustness of our analysis, we replicate all the estimations using a Zero-inflated Poisson model, a Double Hurdle Model and the Heckman estimator. Based on the Akaike Information Criteria (AIC) and Bayes information criteria (BIC), the ZINB provides the best fitting and the most parsimonious specification. Results are not reported but are available on request. In all the estimations, the standard gravity covariates have the expected signs; distance and tariff are negative and significant; GDP, Production, Border and Language are positive and significant. Focusing on our variable of interest, in all estimates, the coefficient of *SIM* is negative and significant, meaning that reducing the distance between MRL regulations is trade-enhancing. In addition, since our key variable is time invariant, we replicate all the estimations by interacting similarity measure with time fixed effects; even in this case, results tend to be confirmed, being the effects significant in 2001, 2002, 2007 and 2009. As a further robustness check, we have re-estimated our gravity equation by OLS considering the dependent variable as $\ln(X_{ijt}^{k}+1)$ and $\ln(X_{ijt}^{k}+0.0001)$ respectively and again the results are confirmed.[5]

Conclusion

The impact of MRL of pesticides on trade has been widely studied, but the focus is often put on trade from developing countries

[5] Since the zero-inflated regression models have the important drawback of not being invariant to the scale of the dependent variable, we checked if the re-scaling of the dependent variable affects the results on zeros. We have rescaled trade from thousand dollars to dollars and results on zeros are confirmed. This check has not been included in the paper; however, results are available from the authors upon request.

Table A.1
Trade in apples (fresh) in 2009.

Main exporters	Value	Quantity	Main importers	Value	Quantity
	$US Mo	1000 tons		$US Mo	1000 tons
Italy (EU)	758.06	798.30	United Kingdom (EU)	640.42	523.02
France (EU)	695.08	693.22	Germany (EU)	621.93	668.84
USA	651.29	663.47	Russian Federation	453.23	931.23
China	512.65	1019.80	Netherlands (EU)	366.91	358.42
Chile	489.11	774.56	Spain (EU)	260.51	258.91
Netherlands (EU)	354.35	378.26	Mexico	247.96	219.81
Belgium (EU)	268.11	342.05	Belgium (EU)	210.88	227.63
New Zealand	265.30	322.49	USA	210.53	206.60
South Africa	212.66	334.34	Canada	178.70	180.49
Poland (EU)	173.29	449.73	Lithuania (EU)	91.93	172.38

Source: UN COMTRADE (EU's figures contain intra-EU trade).

Table A.2
Trade in pears (fresh) in 2009.

Main exporters	Value	Quantity	Main importers	Value	Quantity
	$US Mo	1000 tons		$US Mo	1000 tons
Netherlands (EU)	319.28	320.01	Russian Federation	314.25	379.15
Argentina	271.29	454.71	Germany (EU)	224.98	177.67
Belgium (EU)	264.19	284.49	United Kingdom (EU)	159.23	130.01
Italy (EU)	226.88	180.23	USA	146.28	107.69
China	161.71	405.29	Netherlands (EU)	138.80	138.63
USA	157.93	155.07	France (EU)	130.58	128.80
South Africa	118.39	174.95	Italy (EU)	117.20	112.44
Spain (EU)	91.36	96.41	Brazil	98.05	137.44
Chile	74.92	119.72	Mexico	88.39	85.85
Rep. of Korea	49.18	19.98	Canada	83.12	79.19

Source: UN COMTRADE (EU's figures contain intra-EU trade).

Table A.3
Trade in apples (juice) in 2009.

Main exporters	Value	Quantity	Main importers	Value	Quantity
	$US Mo	1000 tons		$US Mo	1000 tons
China	655.51	799.52	USA	486.40	296.66
Germany (EU)	228.39	316.17	Germany (EU)	340.72	375.80
Austria (EU)	139.46	110.75	United Kingdom (EU)	132.70	142.84
Italy (EU)	67.52	78.49	Japan	116.21	80.67
Argentina	41.44	42.23	Netherlands (EU)	99.83	65.34
Chile	40.32	38.15	Russian Federation	88.60	88.52
USA	38.35	31.24	Austria (EU)	82.03	112.65
Turkey	38.20	37.59	France (EU)	77.47	107.23
Netherlands (EU)	38.16	23.14	Canada	62.22	39.53
Belgium (EU)	28.05	24.30	Belgium (EU)	46.86	52.73

Source: UN COMTRADE (EU's figures contain intra-EU trade).

Table A.4
Trade in pears (preserved) in 2009.

Main exporters	Value	Quantity	Main importers	Value	Quantity
	$US Mo	1000 tons		$US Mo	1000 tons
China	50.54	54.42	France (EU)	39.00	27.19
Italy (EU)	47.74	35.70	USA	36.99	28.03
South Africa	29.99	52.23	Germany (EU)	30.42	23.38
Netherlands (EU)	9.71	6.44	United Kingdom (EU)	14.82	9.65
Thailand	9.09	4.20	Canada	10.11	8.12
USA	8.12	7.16	Belgium (EU)	8.96	5.73
Germany (EU)	8.04	5.02	Thailand	8.03	7.81
Australia	6.64	4.41	Japan	7.43	5.28
France (EU)	4.32	2.09	Netherlands (EU)	7.27	5.30
Argentina	3.05	3.46	Austria (EU)	5.68	5.06

Source: UN COMTRADE (EU's figures contain intra-EU trade).

affected by the stringency of developed countries' regulations. Moreover, in most studies only one or two substances are taken into account whereas the list of pesticides settled down in the regulations is often impressive as it is the case for apples and pears.

Table A.5
Results of the estimation of the main gravity model on pooled data.

	OLS		PPML		ZINB			
					NBREG		LOGIT	
	Beta	(SE)	Beta	(SE)	Beta	(SE)	Beta	(SE)
GDP IMP	1.76[c]	(0.15)	1.02[c]	(0.18)	1.64[c]	(0.07)	−0.48[a]	(0.26)
PROD EXP	0.70[c]	(0.03)	1.04[c]	(0.11)	0.78[c]	(0.12)	−0.68[c]	(0.10)
DIST	−0.57[c]	(0.05)	−0.66[c]	(0.07)	−0.54[c]	(0.17)	1.05[c]	(0.30)
BORDER	0.83[c]	(0.07)	0.58[c]	(0.19)	0.88[c]	(0.08)	−2.07[c]	(0.28)
LANGUAGE	0.36[c]	(0.08)	−0.17	(0.24)	0.27[b]	(0.12)	−1.25[c]	(0.05)
CORRUPTION	0.03	(0.04)	−0.02[c]	(0.01)	0.03[a]	(0.02)	0.10[a]	(0.05)
TARIFF	−0.06[c]	(0.01)	−0.13[c]	(0.02)	−0.01	(0.03)	0.11[c]	(0.04)
EU	0.63	(0.43)	1.71[c]	(0.50)	−0.61	(0.83)	−1.12	(0.88)
SIMILARITY	−0.13[c]	(0.01)	−0.05	(0.04)	−0.16[c]	(0.03)	−0.02	(0.07)
DISPUTE JPN-USA	−0.43[c]	(0.10)	−0.27[c]	(0.04)	−0.03	(0.09)	0.66[c]	(0.21)
DISPUTE AUS_NZL	0.16	(0.11)	0.14	(0.18)	−0.04	(0.10)	−0.11	(0.07)
SPS	0.12	(0.09)	0.05	(0.11)	0.08	(0.07)	−0.23[b]	(0.10)
_cons	−48.62[c]	(3.84)	−31.80[c]	(5.73)	−42.52[c]	(2.53)	13.77[a]	(8.18)
lnalpha								
_cons							1.62[c]	(0.27)
No. of bs.	20246		52647		53560			
R-Sq	0.36		0.23					
Reset test	0.0000		0.0000		0.1818			
Vuong test					Yes			

Note: The dependent variable is ln(trade) in OLS and trade in PPML and ZINBREG. In all estimations, observations have been clustered at product line.
[a] Indicate that coefficient are statistically significant respectively at 10%. In all estimation Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[b] Indicate that coefficient are statistically significant respectively at 5%. In all estimation Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).
[c] Indicate that coefficient are statistically significant respectively at 1%. In all estimation Country fixed effects, Time fixed effects and Products fixed effects have been included (not reported).

The aim of our analysis is to understand the role of pesticides MRL regulations on trade. We are interested in the way (dis)similarity in regulations can affect trade. We focus on apples and pears which are the mainly traded fruits between developing and developed countries as they principally grow in the temperated zone. As a first step, we build an index of similarity between exporters and importers regulations for forty countries. This index is based on the values of MRL for all the pesticides found in the regulations of countries under scrutiny. Then we introduce this index as an exogeneous variable in a gravity equation.

The values of the similarity index are on average equal to 1, half the way between 0 (identical regulation) and 2 (completely different regulation). This means that regulations on MRL of pesticides are rather heterogeneous. The estimated results show, as expected, that increasing the similarity between regulations increases the trading odds. However regulatory distance does not *per se* impede trade. The values of the marginal effects of the interaction term between the similarity index and the exporting countries fixed effects are more ambiguous, harmonization has a positive impact for Australia, Canada, China, New Zealand and the EU, no impact for Argentina, Brazil, Chile, Korea and South Africa and a negative impact for USA, and Japan. We concur on the point raised by Winchester et al. (2012): a complete harmonization may not always be feasible or desirable because consumers in developed countries might consider as a food safety breach a global agreement on MRL.

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Appendix A

See Tables A.1–A.5.

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Calibrating spatial models of trade☆

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ABSTRACT

Empirical spatial models of trade that are based on a mathematical programming specification often exhibit a large discrepancy between the equilibrium solution and the observed demand, supply and levels of trade flows among countries. This discrepancy may be due to several causes. Assuming, however, that a trade model is not misspecified – in the sense that behavior of the economic agents involved in the specific commodity markets has been included in the study and that the relevant policy instruments have been properly taken into account – the cause of discrepancy may be traced either to imprecision of unit transaction costs or to imprecision in the measurement of the demand and supply functions' parameters, or both. Policy assessments based on this type of imprecise models are distorted. This paper presents a methodology for calibrating mathematical programming spatial trade models of increasing complexity, from the one-commodity case to a multi-commodity model with asymmetric slope matrices of demand and supply functions. The proposed calibration procedure identifies corrections of imperfectly measured parameters. The calibrated models generate solutions that exactly reproduce quantities produced and consumed in all countries, as well as trade flows among all pairs of countries, observed in a given base year. Such models may then serve as a springboard for assessing the impact of various policy changes on economic agents in the countries under study.

1. Introduction

In the area of trade, modelers have a wide variety of tools at their disposal: spatial and non-spatial partial equilibrium models, computable general equilibrium models. There is no superiority among them but rather a better adequacy to deal with a specific issue. Pros and cons of different classes of models are addressed, among others, in Francois and Reinert (1997), Anania (2001), van Tongeren et al. (2001), and Bouët (2008). Partial equilibrium models tend to better accommodate explicit representations of complex policy instruments, allow for a more detailed representation of markets and require less restrictive assumptions.

This paper presents and discusses spatial partial equilibrium models that are capable of reproducing observed aggregate demand and supply, as well as bilateral trade flows in each country, in a base year, without having to resort to the Armington assumption (Armington, 1969), i.e. without having to assume, often unrealistically, that products produced in different countries are always perceived as different commodities by consumers (while products produced in a given country are always perceived as perfectly homogeneous). These models are particularly appropriate when a market (or markets) under scrutiny is (are) relatively small with respect to the countries' overall economy and relevant trade policies include discriminatory instruments. These are policies that discriminate by country of origin (destination) of imports (exports), such as preferential tariffs, country specific tariff rate quotas or embargos. The focus of this paper is on mathematical programming models of spatial partial equilibrium.

Traditional empirical models of this type (such as those, for example, suggested by Takayama and Judge, 1971) are subject to a common pitfall: the discrepancy between observed and optimal (equilibrium) quantities. More specifically, the discrepancy between realized quantities of produced and consumed commodities and their trade flows, in a given year, and production, consumption and import–export patterns generated by the model for the same year. As a consequence, country net trade positions and prices generated by these traditional models differ from realized ones. The main cause of this discrepancy often originates in the transaction costs per unit

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of commodity bilaterally traded between two countries. In general, this piece of crucial information is measured with a degree of imprecision which is well above that of other parameters (demand and supply functions' parameters) in the model. In addition, mathematical programming models (without proper adjustments) tend to suffer from over-specialization of the optimal solution with respect to observed trade flows. This paper proposes a methodology which addresses these issues in the framework of mathematical programming spatial trade models by identifying – using an approach similar to that used in Positive Mathematical Programming (PMP) (Howitt, 1995a, 1995b) – the corrections of the transaction costs used in the model which generate solutions that reproduce the market equilibrium observed in a given base year. Furthermore, the procedure is extended to the case when the discrepancy between the observed equilibrium and the model solution may be traced to imprecision in the measurement of the demand and supply functions' parameters. Calibration of the mathematical programming trade model for a given base year – as suggested in this paper – allows for policy simulations based on a model which fully exploits the available information.

In the past, different approaches have been used to calibrate mathematical programming trade models. The more common methods have been either the inclusion of additional constraints limiting the space of feasible solutions, or making *ad hoc* assumptions on some parameters. Bauer and Kasnakoglu (1990) used the PMP approach to construct a quadratic programming model of Turkish agriculture with endogenous supply functions that perfectly calibrates observed production quantities. Bouamra-Mechemache et al. (2002, 2008) used the PMP approach to calibrate two different mathematical programming spatial models of the dairy sector (one representing the European Union market alone, the other including international markets and trade). In both instances they found that the solutions which perfectly calibrate quantities were unsatisfactory in terms of implied prices of intermediate products and opted to introduce further adjustments in the models. As a result, these models do not perfectly calibrate observed quantities and prices. Jansson and Heckelei (2009) propose a calibration procedure for mathematical programming spatial equilibrium models based on the estimation of stochastic transportation costs and prices with measurement errors independent and identically distributed with known variances. The procedure does not aim at making the model perfectly replicate observed prices and quantities and it is assumed that no information is available regarding trade flows.

The original contribution of the present paper is the introduction of a calibration procedure which exploits all available information to make spatial trade models generate solutions that perfectly reproduce observed supply and demand quantities as well as prices and trade flows for a given base year.

We distinguish between two types of models. The first model involves either a single or many commodities with demand and supply functions whose slope matrices are symmetric and positive semi-definite. The second type of models deals with demand and supply functions whose slope matrices are not symmetric. This distinction has to do with the integrability conditions of systems of demand and supply functions. The first type of models can be stated as a dual pair of optimizing programming models, similar – but with adjustment – to those discussed by Takayama and Judge (1971). The models of the second type are not explicitly optimizing models because the asymmetry of the demand and supply slope matrices prevents the integration of the corresponding systems into objective revenue and cost functions to be either maximized or minimized. In this case, the model of choice is given by a (partial) Equilibrium Problem, a derivation of the competitive general Equilibrium Problem as developed by Walras (1926), Schlesinger (1933–1934), Zeuthen (1933), Wald (1933–1934), and a long list of successors (Takayama, 1985, pp. 255–294).

When dealing with a multi-commodity scenario where the slope matrices of demand and supply functions are symmetric, Samuelson (1952), first, and Takayama and Judge (1971), after him, have shown that the preferred specification of a spatial trade model among R regions corresponds to the maximization of a quasi welfare function (*QWF*) subject to two sets of constraints regarding the demand and the supply of the various regions. The *QWF* objective function is defined as the integral of the inverse demand function(s) minus the integral of the inverse supply function(s) and the total transaction costs.

Economic theory, however, does not require the symmetry of the Jacobian matrix in Marshallian systems of three or more commodities' aggregate demand functions. Hence, these asymmetric systems are not integrable into a quasi-welfare function and no suitable objective function to be optimized is available for analyzing the markets. In these cases, the specification of an Equilibrium Problem will replace the formulation of a dual pair of optimization problems.

The paper is structured in two parts. The first part discusses the proposed calibration procedure with reference to two types of spatial trade models proposed by Takayama and Judge (1971) based on the work by Samuelson (1952). In particular, Section 2 introduces the procedure with specific reference to the standard model for a single product case. Section 3 extends the proposed calibration procedure to the general multi-commodity case when the matrices of supply and demand slopes cannot be assumed to be symmetric. The specification of this structure takes the form of an Equilibrium Problem. Two variants are discussed. In the first case, measurement imprecision is confined to transaction costs. The second variant considers a more general case when also demand and supply functions are subject to measurement errors. The second part of the paper (Section 4) presents a numerical example that illustrates an implementation of the calibration procedure for a rather general specification of the trade model such as the Equilibrium Problem.

2. A model of international trade with one commodity

We assume R importing and exporting countries. When supply and demand functions are available for each country, the classification between importing and exporting countries cannot be done in advance of solving the problem. Let us, therefore, define indices that cover all the regions (countries) without distinction between importers and exporters, $i, j = 1,\ldots, R$. The known inverse demand function of a single commodity for the jth country is assumed as $p_j^D = a_j - D_j x_j^D$, while the known inverse supply function for the same homogeneous commodity is assumed as $p_i^S = b_i + S_i x_i^S$. Coefficients a_j, D_j, S_i are known positive scalars. Parameter b_i is also known but may be either positive or negative. In this specification, quantities x_j^D and x_i^S are unknown and must be determined as part of the solution together with the trade flows x_{ij}. We assume, however, the availability of information concerning realized (observed) trade flows, $\bar{x}_{ij}$, and – as a consequence – knowledge of total quantities demanded, $\bar{x}_j^D$, and supplied, $\bar{x}_i^S$, for each country. We also assume knowledge (albeit imperfect) of unit transaction costs, t_{ij}, $i, j = 1,\ldots, R$.

The Samuelson–Takayama–Judge (STJ) model (Samuelson, 1952; Takayama and Judge, 1971) exhibits an objective function that maximizes a *QWF* given by the difference between the area below the inverse demand and the area below the inverse supply functions, diminished by total transaction costs. This specification corresponds to the maximization of the sum of consumer and producer surpluses netted out of total transaction costs.

The two components of the *QWF* – demand and supply functions, on one side, and unit transaction costs, on the other side – may be subject to imprecise measurements. In this first specification, we assume that only unit transaction costs are measured with imprecision. In fact, this is a crucial source of discrepancy between observed and optimal traded quantities and total quantities demanded and supplied in each country that are obtained from the solution of the STJ model.

When information about a realized (observed) trade pattern, $\bar{x}_{ij}$, is available, a phase I PMP-like specification of the primal model takes on the following structure:

$$\max QWF = \sum_{j=1}^{R}\left(a_j - D_j x_j^D/2\right)x_j^D - \sum_{i=1}^{R}\left(b_i + S_i x_i^S/2\right)x_i^S - \sum_{i=1}^{R}\sum_{j=1}^{R} t_{ij}x_{ij} \quad (1)$$

dual variables

$$\text{subject to} \quad x_j^D \le \sum_{i=1}^{R} x_{ij} \qquad p_j^D \quad (2)$$

$$\sum_{j=1}^{R} x_{ij} \le x_i^S \qquad p_i^S \quad (3)$$

$$x_{ij} = \bar{x}_{ij} \qquad \lambda_{ij} \quad (4)$$

and nonnegative variables, $x_j^D \ge 0$, $x_i^S \ge 0$, $x_{ij} \ge 0$, $i, j = 1, 2, \dots, R$. Constraints (2) establish the condition that the quantity consumed in the jth country must always be less-than-or-equal to the total quantity shipped to it by all countries. Constraints (3) specify that the total quantity shipped from the ith country must not exceed production of that country. By their mathematical specification, constraints (4) are called calibrating constraints and characterize all the models discussed in this paper. The tautological nature of constraints (4) should not deceive the reader. Their primary role is to elicit the measurement of a dual variable, λ_{ij}, that may be either positive or negative and whose level will adjust the corresponding unit transaction cost in a phase II specification of the model. Differently from the calibration procedure proposed in this paper, PMP (Howitt, 1995a, 1995b) modifies a linear objective function by introducing a quadratic function which accounts for additional costs, that are inferred based on the difference between the observed realization and the solution from the uncalibrated model. In addition, in this paper, the calibrating constraints involving the realized trade flows are stated as a set of equations, rather than inequalities. As a result, while the PMP procedure generates corrections which are always nonnegative in sign, the procedure proposed in this paper leaves the sign of λ_{ij} as *a priori* undetermined. This specification is based on the consideration that, if accounting transaction costs are measured incorrectly, then they may be either over or under estimated. Thus, the magnitude and sign of the estimated λ_{ij} will determine the effective unit transaction costs that will produce a calibrated solution of the quantities produced and consumed in each country.

The calibration procedure proposed in this section assumes that the model is well specified in all its parts except in the parameters t_{ij} that will be subject to a calibration. This means that if a model is misspecified, for example with respect to the representation of existing policies, these errors will be captured by the estimated λ_{ij} and subsequent policy simulations will yield distorted results.

The specification of the dual model (1)–(4) requires the statement of a Lagrangean function and the derivation of the associated Karush–Kuhn–Tucker (KKT) conditions. The Langrangean function of problem (1)–(4) can be stated as

$$L = \sum_{j=1}^{R}\left(a_j - D_j x_j^D/2\right)x_j^D - \sum_{i=1}^{R}\left(b_i + S_i x_i^S/2\right)x_i^S - \sum_{i=1}^{R}\sum_{j=1}^{R} t_{ij}x_{ij} + \sum_{j=1}^{R} p_j^D\left(\sum_{i=1}^{R} x_{ij} - x_j^D\right) + \sum_{i=1}^{R} p_i^S\left(x_i^S - \sum_{j=1}^{R} x_{ij}\right) + \sum_{i=1}^{R}\sum_{j=1}^{R}\lambda_{ij}\left(\bar{x}_{ij} - x_{ij}\right) \quad (5)$$

with KKT conditions

$$\frac{\partial L}{\partial x_j^D} = a_j - D_j x_j^D - p_j^D \le 0 \quad (6)$$

$$x_j^D \frac{\partial L}{\partial x_j^D} = x_j^D\left(a_j - D_j x_j^D - p_j^D\right) = 0 \quad (7)$$

$$\frac{\partial L}{\partial x_i^S} = -\left(b_i + S_i x_i^S\right) + p_i^S \le 0 \quad (8)$$

$$x_i^S \frac{\partial L}{\partial x_i^S} = x_i^S\left[-\left(b_i + S_i x_i^S\right) + p_i^S\right] = 0 \quad (9)$$

$$\frac{\partial L}{\partial x_{ij}} = -t_{ij} + p_j^D - p_i^S - \lambda_{ij} \le 0 \quad (10)$$

$$x_{ij}\frac{\partial L}{\partial x_{ij}} = x_{ij}\left(-t_{ij} + p_j^D - p_i^S - \lambda_{ij}\right) = 0. \quad (11)$$

KKT conditions associated with the Lagrange multipliers p_j^D, p_i^S, λ_{ij} are not derived because they simply correspond to the primal constraints (2), (3) and (4). Hence, relations (6), (8) and (10) constitute the dual constraints. Relations (7), (9) and (11) specify the complementary slackness conditions corresponding to the dual constraints. In fact, using this complementary slackness information in the form of

$$\sum_{j=1}^{R} a_j x_j^D = \sum_{j=1}^{R} D_j\left(x_j^D\right)^2 + \sum_{j=1}^{R} p_j^D x_j^D \quad (12)$$

$$-\sum_{i=1}^{R} b_i x_i^S = \sum_{i=1}^{R} S_i\left(x_i^S\right)^2 - \sum_{i=1}^{R} p_i^S x_i^S \quad (13)$$

$$\sum_{i=1}^{R}\sum_{j=1}^{R} x_{ij}t_{ij} = \sum_{i=1}^{R}\sum_{j=1}^{R} x_{ij}p_j^D - \sum_{i=1}^{R}\sum_{j=1}^{R} x_{ij}p_i^S - \sum_{i=1}^{R}\sum_{j=1}^{R} x_{ij}\lambda_{ij}, \quad (14)$$

the Lagrangean function (5) can be simplified to become the objective function of the dual problem corresponding to model (1)–(4) as follows:

$$\min TCMO = \sum_{j=1}^{R} x_j^D D_j x_j^D \Big/ 2 + \sum_{i=1}^{R} x_i^S S_i x_i^S \Big/ 2 + \sum_{i=1}^{R}\sum_{j=1}^{R}\lambda_{ij}\bar{x}_{ij} \quad (15)$$

dual variables

$$\text{subject to} \quad p_j^D \ge a_j - D_j x_j^D \qquad x_j^D \quad (16)$$

$$b_i + S_i x_i^S \ge p_i^S \qquad x_i^S \quad (17)$$

$$p_i^S + \left(t_{ij} + \lambda_{ij}\right) \ge p_j^D \qquad x_{ij} \quad (18)$$

and $x_j^D \ge 0$, $x_i^S \ge 0$, $x_{ij} \ge 0$, λ_{ij} is a free variable, and $i, j = 1, 2, \dots, R$. The economic interpretation of the objective function (15) is given by the minimization of the "Total Cost of Market Options" (*TCMO*) adjusted by the differential total transaction costs. When interpreting a dual model, it is convenient to suppose that a second economic agent – external to the primal problem – wishes to "take over the enterprise" of the primal economic agent. In this case, the dual agent will have to quote prices and quantities that will reimburse the primal agent of its "potential profit" (consumer and producer surpluses) plus the differential total transaction costs. The dual constraints express the demand and supply functions as well as the condition that the supply price in the ith country plus the unit effective transaction cost $(t_{ij}+\lambda_{ij})$ of the traded commodity between each pair of countries must be greater-than-or-equal-to the demand price in the jth country.

The solution of primal model (1)–(4) (or, alternatively, of the dual model (15)–(18)) provides an estimate of the dual variables, λ^*_{ij}, associated with the calibration constraints that can be utilized in phase II of the calibrating procedure for adjusting the unit transaction costs, as in the following calibrating model:

$$\max QWF = \sum_{j=1}^{R}\left(a_j - D_j x_j^D/2\right)x_j^D - \sum_{i=1}^{R}\left(b_i + S_i x_i^S/2\right)x_i^S - \sum_{i=1}^{R}\sum_{j=1}^{R}\left(t_{ij}+\lambda^*_{ij}\right)x_{ij} \tag{19}$$

dual variables

$$\text{subject to} \quad x_j^D \le \sum_{i=1}^{R} x_{ij} \qquad p_j^D \tag{20}$$

$$\sum_{j=1}^{R} x_{ij} \le x_i^S \qquad p_i^S \tag{21}$$

and, $x_j^D \ge 0$, $x_i^S \ge 0$, $x_{ij} \ge 0$; $i, j = 1, 2,\ldots, R$. The adjustment of the unit transaction costs in the objective function (19) is a direct consequence of constraint (18) where the component $(t_{ij}+\lambda_{ij})$ constitutes the *effective* unit transaction cost between the ith and jth countries. The stylized nature of the above model may be enriched with an appropriate specification of an international trade model involving the paraphernalia of tariffs, subsidies, quotas, penalties, preferential trade treatments, exchange rates, etc. Hence, model (19)–(21) – augmented by the appropriate trade policy constraints – can be used to evaluate the likely effects of changes in policy interventions regarding tariffs, subsidies and other control parameters of interest.

Model (19)–(21) calibrates the observed total quantities consumed, $\bar{x}_j^D$, and supplied, $\bar{x}_i^S$, in each country. When all the available information is fully exploited and the observed trade flows $\bar{x}_{ij}$ are used as initial values of the trade flow variables for the search of a solution to the problem (in the software program GAMS, Generalized Algebraic Modelling System, (Brooke et al., 1988), for example), the model calibrates perfectly production, consumption and prices in all countries and trade flows among all pairs of countries. However, in general, a trade model may show multiple optimal solutions of trade flows, that is, solutions where different sets of trade flows are associated to the same quantities supplied and demanded in each country, the same prices, the same total incurred adjusted transaction costs (calculated over all trade flows), and, as a result, the same value of the objective function. Notice, however, that the dual variables λ^*_{ij} are unique since they are determined in phase I of the calibration procedure where the observed trade flows $\bar{x}_{ij}$ are unique. The possibility of multiple optimal solutions in terms of trade flows being associated to the unique optimal solution in terms of countries' net imports and exports is a common feature of this class of models (Dantzig, 1951; Koopmans, 1949; Paris, 1983; Takayama and Judge, 1971). In general, a good mathematical programming solver ought to have the capability of detecting and generating all the optimal solutions implicit in the model being solved. Hence, whether or not a given solver returns a solution that calibrates also the observed trade flows is an empirical matter. The λ^*_{ij} being unique, the theoretical model (19)–(21) is uniquely identified as well and the set of its solutions contains a solution which perfectly calibrates, in addition to prices and consumed and produced quantities, also the trade flows.

The above model can be easily extended to all the multi-commodity scenarios where the slope matrices of demand and supply functions are symmetric and positive semi-definite. It can also be extended to a two-commodity case where the slope matrices of demand and supply functions are not symmetric because these two-variable functions can be integrated regardless of symmetry of their Jacobian matrix.

3. A multi-commodity model of international trade — Equilibrium Problem

When the slope matrices $\mathbf{D}_j$ and $\mathbf{S}_i$ of the demand and supply function systems are not symmetric, the extension of international trade models to multi-commodity exchanges requires a substantial adjustment of the mathematical programming model discussed above. First of all, it requires a considerably larger quantity of information that, if and when available, imposes the need of a careful management. The major shift from the previous one-commodity model is constituted by the specification of systems of demand and supply functions for each country. It follows that a properly defined system of demand and supply functions – for each country involved in the commodity exchange – ought to exhibit full matrices of demand and supply cross-price parameters. This is a formidable information requirement that, when overcome, may produce adequate empirical results as well as sensible policy analyses. Secondly, a special comment regards matrices $\mathbf{D}_j$ and $\mathbf{S}_j$, the matrices of cross-derivatives of the jth country systems of demand and supply functions. In principle, demand and production theory requires neither the symmetry nor the positive semi-definiteness of such matrices. However, the specification of a STJ problem in the form of maximizing a QW objective function that assumes a quadratic structure imposes the requirement that matrices $\mathbf{D}_j$ and $\mathbf{S}_j$ be symmetric and positive semi-definite. This is quite a strong assumption, since there is no reason why $\mathbf{D}_j$ and $\mathbf{S}_j$ should satisfy these conditions. Hence, we will present and discuss a structure, called the Equilibrium Problem, that will admit asymmetric $\mathbf{D}_j$ and $\mathbf{S}_j$ matrices. What we call Equilibrium Problem is a partial equilibrium problem that derives its legitimacy from the general competitive equilibrium problem discussed by a long list of distinguished economists from Walras (1926) to Takayama (1985, pp. 256–280). As Akira Takayama (1985, p. 256) wrote:

> "A partial equilibrium analysis is convenient for a deeper analysis of some particular segment of the economy. However, it should be realized that any partial equilibrium analysis presupposes a general equilibrium analysis. For without knowing precisely under what conditions 'other things are equal,' the partial equilibrium analysis is rather meaningless."

We assume K homogeneous commodities, $K \ge 3$. Each country owns a system of K inverse demand functions, $\mathbf{p}_j^D = \mathbf{a}_j - \mathbf{D}_j\mathbf{x}_j^D, j = 1,\ldots, R$, and a system of K inverse supply functions, $\mathbf{p}_j^S = \mathbf{b}_j + \mathbf{S}_j\mathbf{x}_j^S, j = 1,\ldots, R$. The matrix of nominal unit transaction costs is defined in three dimensions as $\mathbf{T} = [t_{ijk}]$, $i, j = 1,\ldots, R$, $k = 1,\ldots, K$, where $\mathbf{t}_{ij}$ is the vector of unit transaction costs from country i to country j for the K commodities. We assume that information about the trade pattern for all commodities, $\bar{\mathbf{x}}_{ij}$, and, hence, total demands, $\bar{\mathbf{x}}_j^D$, and total supplies, $\bar{\mathbf{x}}_i^S$, is available for a given base year.

When matrices $\mathbf{D}_j$ and $\mathbf{S}_j$ are asymmetric, the system of demand and supply functions cannot be integrated and no suitable objective function exists for a STJ-type model. The Equilibrium Problem constitutes the appropriate mathematical programming structure for analyzing this trade scenario.

3.1. Definition of the Equilibrium Problem

Let us consider the demand (*Dem*) and supply (*Sup*) of a commodity with quantity (*Q*), price (*P*) and marginal cost (*MC*). Then, the Equilibrium Problem is jointly defined by the following two sets of primal and dual relations: for any commodity,

$$\text{Primal:}\quad Dem \le Sup \qquad \text{quantity equilibrium} \tag{22}$$

$$P \ge 0 \qquad \text{nonnegative price} \tag{23}$$

$$(Sup - Dem)P = 0 \qquad \text{complementary slackness} \tag{24}$$

$$\text{Dual:}\quad MC \ge P \qquad \text{price equilibrium} \tag{25}$$

$$Q \ge 0 \qquad \text{nonnegative quantity} \tag{26}$$

$$(MC - P)Q = 0 \qquad \text{complementary slackness.} \tag{27}$$

Hence, following the above template, the phase I Equilibrium Problem with systems of demand and supply functions exhibiting asymmetric matrices $\mathbf{D}_j$ and $\mathbf{S}_j$ is specified as follows, for $i = 1,\dots, R$; $j = 1,\dots, R$:

$$\text{Primal relations:}\quad \mathbf{p}_j^D \ge 0,\ \mathbf{x}_j^D \le \sum_{i=1}^R \mathbf{x}_{ij},\quad \left(\sum_{i=1}^R \mathbf{x}_{ij} - \mathbf{x}_j^D\right)'\mathbf{p}_j^D = 0 \tag{28}$$

$$\mathbf{p}_i^S \ge 0,\quad \sum_{j=1}^R \mathbf{x}_{ij} \le \mathbf{x}_i^S,\quad \left(\mathbf{x}_i^S - \sum_{j=1}^R \mathbf{x}_{ij}\right)'\mathbf{p}_i^S = 0 \tag{29}$$

$$\boldsymbol{\lambda}_{ij} \text{ free},\quad \mathbf{x}_{ij} = \overline{\mathbf{x}}_{ij},\quad \left(\overline{\mathbf{x}}_{ij} - \mathbf{x}_{ij}\right)'\boldsymbol{\lambda}_{ij} = 0 \tag{30}$$

$$\text{Dual relations:}\quad \mathbf{x}_j^D \ge 0,\quad \mathbf{a}_j - \mathbf{D}_j\mathbf{x}_j^D \le \mathbf{p}_j^D,\quad \left(\mathbf{p}_j^D - \mathbf{a}_j + \mathbf{D}_j\mathbf{x}_j^D\right)'\mathbf{x}_j^D = 0 \tag{31}$$

$$\mathbf{x}_i^S \ge 0,\quad \mathbf{p}_i^S \le \mathbf{b}_i + \mathbf{S}_i\mathbf{x}_i^S,\quad \left(\mathbf{b}_i + \mathbf{S}_i\mathbf{x}_i^S - \mathbf{p}_i^S\right)'\mathbf{x}_i^S = 0 \tag{32}$$

$$\mathbf{x}_{ij} \ge 0,\quad \mathbf{p}_j^D \le \mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \boldsymbol{\lambda}_{ij}\right),\quad \left[\mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \boldsymbol{\lambda}_{ij}\right) - \mathbf{p}_j^D\right]'\mathbf{x}_{ij} = 0. \tag{33}$$

The asymmetry of the $\mathbf{D}_j$ and $\mathbf{S}_i$ matrices causes neither theoretical nor computational difficulties since the systems of demand and supply functions appear directly into the dual relations (31) and (32) without the need of passing through an integral of the system – that does not exist in this case – and the corresponding (nonexistent) primal objective function.

3.2. Imprecision of unit transaction costs

When parameter imprecision is assumed to regard only transaction costs, the solution of Equilibrium Problem (28)–(33) can be obtained by introducing primal and dual slack variables into the structural constraints and exploiting the complementary slackness conditions – that add up to zero – in the form of an auxiliary objective function to be minimized, since each term is nonnegative. Thus, using nonnegative slack variables $\mathbf{z}_{jP1}, \mathbf{z}_{iP2}, \mathbf{z}_{jD1}, \mathbf{z}_{iD2}, \mathbf{z}_{ijD3}$, (where the subscript of $\mathbf{z}_{jP1}, \mathbf{z}_{iP2}$ stands for primal constraints 1 and 2 and the subscript of $\mathbf{z}_{jD1}, \mathbf{z}_{iD2}, \mathbf{z}_{ijD3}$ stands for dual constraints 1, 2 and 3) the solution of the phase I Equilibrium Problem can be obtained by solving the following specification:

$$\min \sum\nolimits_{ij}\left[\mathbf{z}_{jP1}'\mathbf{p}_j^D + \mathbf{z}_{iP2}'\mathbf{p}_i^S + \mathbf{z}_{jD1}'\mathbf{x}_j^D + z_{iD2}'\mathbf{x}_i^S + \mathbf{z}_{ijD3}'\mathbf{x}_{ij}\right] = 0 \tag{34}$$

dual variables

$$\text{subject to}\quad \mathbf{x}_j^D + \mathbf{z}_{jP1} = \sum_{i=1}^R \mathbf{x}_{ij}, \qquad \mathbf{p}_j^D \ge 0 \tag{35}$$

$$\sum_{j=1}^R \mathbf{x}_{ij} + \mathbf{z}_{iP2} = \mathbf{x}_i^S, \qquad \mathbf{p}_i^S \ge 0 \tag{36}$$

$$\mathbf{x}_{ij} = \overline{\mathbf{x}}_{ij}, \qquad \boldsymbol{\lambda}_{ij} \text{ free} \tag{37}$$

$$\mathbf{a}_j - \mathbf{D}_j\mathbf{x}_j^D + \mathbf{z}_{jD1} = \mathbf{p}_j^D, \qquad \mathbf{x}_j^D \ge 0 \tag{38}$$

$$\mathbf{p}_i^S + \mathbf{z}_{iD2} = \mathbf{b}_i + \mathbf{S}_i\mathbf{x}_i^S, \qquad \mathbf{x}_i^S \ge \mathbf{0} \tag{39}$$

$$\mathbf{p}_j^D + \mathbf{z}_{ijD3} = \mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \boldsymbol{\lambda}_{ij}\right), \qquad \mathbf{x}_{ij} \ge 0. \tag{40}$$

One advantage of this mathematical programming specification is that the optimal value of the auxiliary objective function is known *a priori* and is equal to zero since it is the sum of all the complementary slackness conditions. Once again, the crucial task of a phase I Equilibrium Problem is to obtain estimates of the dual variables $\boldsymbol{\lambda}_{ij}$ associated to the calibrating constraint (37), say $\boldsymbol{\lambda}_{ij}^*$. With such estimates, a calibrating Equilibrium Problem can be stated as the following phase II specification:

$$\min \sum\nolimits_{ij}\left[\mathbf{z}_{jP1}'\mathbf{p}_j^D + \mathbf{z}_{jP2}'\mathbf{p}_i^S + \mathbf{z}_{jD1}'\mathbf{x}_j^D + \mathbf{z}_{jD2}'\mathbf{x}_i^S + \mathbf{z}_{jD3}'\mathbf{x}_{ij}\right] = 0 \tag{41}$$

dual variables

$$\text{subject to,}\quad \mathbf{x}_j^D + \mathbf{z}_{jP1} = \sum_{i=1}^R \mathbf{x}_{ij}, \qquad \mathbf{p}_j^D \ge 0 \tag{42}$$

$$\sum_{j=1}^R \mathbf{x}_{ij} + \mathbf{z}_{iP2} = \mathbf{x}_i^S, \qquad \mathbf{p}_i^S \ge 0 \tag{43}$$

$$\mathbf{a}_j - \mathbf{D}_j\mathbf{x}_j^D + \mathbf{z}_{jD1} = \mathbf{p}_j^D, \qquad \mathbf{x}_j^D \ge 0 \tag{44}$$

$$\mathbf{p}_i^S + \mathbf{z}_{iD2} = \mathbf{b}_i + \mathbf{S}_i\mathbf{x}_i^S, \qquad \mathbf{x}_i^S \ge \mathbf{0} \tag{45}$$

$$\mathbf{p}_j^D + \mathbf{z}_{ijD3} = \mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \boldsymbol{\lambda}_{ij}^*\right), \qquad \mathbf{x}_{ij} \ge 0. \tag{46}$$

This calibrating model can now be used to estimate the response to changes in specific policy measures.

3.3. Imprecision of unit transaction costs, demand and supply functions

We now assume that demand and supply functions as well as unit transaction costs are measured with imprecision; demand and supply functions are measured at the same market level (i.e. $\mathbf{t}_{jj} = 0$, for $j = 1,\dots, R$) and are inconsistent with the condition that $\mathbf{x}_{ij}^* = \overline{\mathbf{x}}_{ij}$ and that ($\mathbf{p}_j^{D*} = \mathbf{p}_j^{S*}$) for $j = 1,\dots, R$, as required by theory. As a remedy, we associate vectors and matrices of deviations to both the intercepts and the slopes of the supply and demand functions, as well as to the unit transaction costs. All these deviations are jointly estimated in a least-squares model subject to appropriate constraints.

The relevant phase I model can be specified as follows: vectors $\mathbf{u}_j$ and $\mathbf{v}_i$ are unrestricted adjustments to the intercept vectors defining the demand and the supply functions, respectively. Similarly, matrices $\mathbf{W}_j$ and $\mathbf{Y}_i$ are unrestricted adjustments to the slope matrices defining demand and supply functions, respectively. All these parameters will be estimated by a least-squares approach subject to the economic relationships of the Equilibrium Problem. The complementary slackness conditions of the Equilibrium Problem (which are equal to zero) will appear in the objective function together with the sums of squared adjustments:

$$\min LS = \sum_{j=1}^{R} \mathbf{u}_j'\mathbf{u}_j / 2 + \sum_{i=1}^{R} \mathbf{v}_i'\mathbf{v}_i / 2 + \sum_{j=1}^{R} trace\left(\mathbf{W}_j'\mathbf{W}_j\right) / 2 + \sum_{i=1}^{R} trace\left(\mathbf{Y}_i'\mathbf{Y}_i\right) / 2$$
$$+ \left\{ \sum_{j=1}^{R} \sum_{i=1}^{R} \overline{\mathbf{x}}_{ij}\boldsymbol{\lambda}_{ij} - \left[\sum_{j=1}^{R} \left(\left(\mathbf{a}_j + \mathbf{u}_j\right) - \left(\mathbf{D}_j + \mathbf{W}_j\right)\mathbf{x}_j^D \right)' \mathbf{x}_j^D \right.\right.$$
$$\left.\left. - \sum_{i=1}^{R} \left((\mathbf{b}_i + \mathbf{v}_i) + (\mathbf{S}_i + \mathbf{Y}_i)\mathbf{x}_i^S \right)' \mathbf{x}_i^S - \sum_{i=1}^{R}\sum_{j=1}^{R} \mathbf{t}_{ij}'\mathbf{x}_{ij} \right] \right\} \tag{47}$$

$$\text{subject to} \quad \sum_{i=1}^{R} \mathbf{x}_{ij} \geq \mathbf{x}_j^D \tag{48}$$

$$\sum_{j=1}^{R} \mathbf{x}_{ij} \leq \mathbf{x}_i^S \tag{49}$$

$$\mathbf{x}_{ij} = \overline{\mathbf{x}}_{ij} \tag{50}$$

$$\mathbf{p}_j^D \geq \left(\mathbf{a}_j + \mathbf{u}_j\right) - \left(\mathbf{D}_j + \mathbf{W}_j\right)\mathbf{x}_j^D \tag{51}$$

$$(\mathbf{b}_i + \mathbf{v}_i) + (\mathbf{S}_i + \mathbf{Y}_i)\mathbf{x}_i^S \geq \mathbf{p}_i^S \tag{52}$$

$$\mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \boldsymbol{\lambda}_{ij}\right) \geq \mathbf{p}_j^D \tag{53}$$

$$\mathbf{p}_j^S = \mathbf{p}_j^D. \tag{54}$$

The complementary slackness conditions of the Equilibrium Problem appear in the portion of Eq. (47) within the curly brackets which should achieve a zero value when an optimal solution is reached. The remaining components of the objective function are the sums of squared deviations.

The phase II calibrated model includes the estimates of the adjustment parameters obtained in phase I, $\hat{\mathbf{u}}_j$, $\hat{\mathbf{v}}_i$, $\hat{\mathbf{W}}_j$, $\hat{\mathbf{Y}}_i$ and $\hat{\boldsymbol{\lambda}}_{ij}$, in the minimization structure of the Equilibrium Problem:

$$\min \sum\nolimits_{ij} \left[\mathbf{z}'_{jP1}\mathbf{p}_j^D + \mathbf{z}'_{iP2}\mathbf{p}_i^S + \mathbf{z}'_{jD1}\mathbf{x}_j^D + \mathbf{z}'_{iD2}\mathbf{x}_i^S + \mathbf{z}'_{ijD3}\mathbf{x}_{ij} \right] = 0 \tag{55}$$

dual variables

$$\text{subject to, } \mathbf{x}_j^D + \mathbf{z}_{jP1} = \sum_{i=1}^{R} \mathbf{x}_{ij}, \qquad \mathbf{p}_j^D \geq 0 \tag{56}$$

$$\sum_{j=1}^{R} \mathbf{x}_{ij} + \mathbf{z}_{iP2} = \mathbf{x}_i^S, \qquad \mathbf{p}_i^S \geq 0 \tag{57}$$

$$\left(\mathbf{a}_j + \hat{\mathbf{u}}_j\right) - \left(\mathbf{D}_j + \hat{\mathbf{W}}_j\right)\mathbf{x}_j^D + \mathbf{z}_{jD1} = \mathbf{p}_j^D, \qquad \mathbf{x}_i^S \geq 0 \tag{58}$$

$$\mathbf{p}_i^S + \mathbf{z}_{iD2} = (\mathbf{b}_i + \hat{\mathbf{v}}_i) + \left(\mathbf{S}_i + \hat{\mathbf{Y}}_i\right)\mathbf{x}_i^S, \qquad \mathbf{x}_i^S \geq 0 \tag{59}$$

$$\mathbf{p}_j^D + \mathbf{z}_{ijD3} = \mathbf{p}_i^S + \left(\mathbf{t}_{ij} + \hat{\boldsymbol{\lambda}}_{ij}\right), \qquad \mathbf{x}_{ij} \geq 0\,. \tag{60}$$

Problem (55)–(60) calibrates the observed total demand and supply quantities, $\overline{\mathbf{x}}_j^D$, $\overline{\mathbf{x}}_j^S$ and – when realized trade flows and total demands and total supplies are used as initial values in the search by the solver of the equilibrium solution – the realized trade flows, $\overline{\mathbf{x}}_{ij}$.

Adjustment vectors $\hat{\mathbf{u}}_j$ and $\hat{\mathbf{v}}_i$, matrices $\hat{\mathbf{W}}_j$ and $\hat{\mathbf{Y}}_i$ and $\hat{\boldsymbol{\lambda}}_{ij}$ constitute an over-parameterization of the model. In general, therefore, it is sufficient to adjust the demand and supply functions by modifying either the corresponding intercepts or slopes.

4. A numerical example and empirical implementation

To illustrate the calibrating methodology developed in previous sections, we present a numerical example with four countries, potentially either export or import traders of three commodities; only unit transaction costs are measured with imprecision.

In general, systems of demand and supply functions do not exhibit symmetric Jacobian matrices of first derivatives (slopes). When three or more commodities are involved, these systems cannot be integrated into a meaningful *QW* objective function as suggested by Samuelson (1952) and Takayama and Judge (1971). The solution of such trade models relies upon the specification and solution of an Equilibrium Problem, as illustrated in Section 3.2. The following numerical example exhibits asymmetric matrices of demand and supply slopes. The solution of this Equilibrium Problem was obtained using the commercially available GAMS software (Brooke et al., 1988), implementing phase I problem (34)–(40), first, and the calibrating phase II model (41)–(46), in a second step.[1]

Each of the four countries (A, B, U, E) produces and consumes the three commodities. The relevant data are as follows:
Matrices of inverse demand and supply intercepts:

$$\mathbf{A} = \begin{array}{c} \\ A \\ B \\ U \\ E \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 30.0 & 25.0 & 20.0 \\ 22.0 & 18.0 & 15.0 \\ 25.0 & 10.0 & 18.0 \\ 28.0 & 20.0 & 19.0 \end{bmatrix} \end{array} \quad \mathbf{B} = \begin{array}{c} \\ A \\ B \\ U \\ E \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 0.4 & 0.1 & 0.7 \\ 0.2 & -0.4 & 0.3 \\ -0.6 & 0.2 & -0.4 \\ -0.5 & -1.6 & -1.2 \end{bmatrix} \end{array}.$$

Matrices of inverse demand and supply slopes:

$$\mathbf{D} = \begin{array}{c} \\ A.1 \\ A.2 \\ A.3 \\ B.1 \\ B.2 \\ B.3 \\ U.1 \\ U.2 \\ U.3 \\ E.1 \\ E.2 \\ E.3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 1.2 & 0.2 & -0.2 \\ 0.3 & 2.1 & 0.2 \\ -0.1 & 0.1 & 0.7 \\ 0.8 & -0.1 & 0.2 \\ -0.2 & 1.6 & 0.4 \\ 0.3 & 0.3 & 2.6 \\ 0.8 & 0.2 & 0.5 \\ 0.3 & 0.9 & -0.1 \\ 0.4 & 0.0 & 1.7 \\ 1.1 & 0.1 & 0.3 \\ 0.0 & 0.8 & 0.2 \\ 0.4 & 0.3 & 0.9 \end{bmatrix} \end{array} \quad \mathbf{S} = \begin{array}{c} \\ A.1 \\ A.2 \\ A.3 \\ B.1 \\ B.2 \\ B.3 \\ U.1 \\ U.2 \\ U.3 \\ E.1 \\ E.2 \\ E.3 \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 1.4 & -0.4 & 0.3 \\ -0.2 & 2.1 & 0.2 \\ 0.2 & 0.3 & 1.7 \\ 2.4 & 0.5 & 0.2 \\ 0.7 & 1.6 & 0.3 \\ 0.1 & 0.5 & 1.8 \\ 1.9 & -0.1 & 0.5 \\ -0.1 & 2.8 & 0.4 \\ 0.6 & 0.5 & 2.1 \\ 0.6 & -0.1 & 0.2 \\ -0.1 & 1.1 & 0.5 \\ 0.3 & 0.3 & 0.5 \end{bmatrix} \end{array}.$$

Matrix of accounting (observed) transaction costs:

$$\mathbf{T} = \begin{array}{c} \\ A.A \\ A.B \\ A.U \\ A.E \\ B.A \\ B.B \\ B.U \\ B.E \\ U.A \\ U.B \\ U.U \\ U.E \\ E.A \\ E.B \\ E.U \\ E.E \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} 0.5 & 0.5 & 0.5 \\ 1.5 & 1.5 & 1.5 \\ 1.0 & 1.0 & 1.0 \\ 3.0 & 3.0 & 3.0 \\ 1.5 & 1.5 & 1.5 \\ 0.5 & 0.5 & 0.5 \\ 2.2 & 2.2 & 2.2 \\ 4.0 & 4.0 & 4.0 \\ 1.0 & 1.0 & 1.0 \\ 2.2 & 2.2 & 2.2 \\ 0.5 & 0.5 & 0.5 \\ 3.7 & 3.7 & 3.7 \\ 3.0 & 3.0 & 3.0 \\ 4.0 & 4.0 & 4.0 \\ 3.7 & 3.7 & 3.7 \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \end{array}.$$

[1] GAMS includes solvers specifically designed for "mixed complementarity problems", i.e. problems which incorporates "mixtures of equations and inequalities" (Rutheford, 1995 p. 1300).

The optimal solution obtained without calibrating the model is shown below:
Equilibrium trade flow matrix:

$$\mathbf{X}^* = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A.A & 3.910 & 1.740 & 4.637 \\ A.B & 2.834 & 2.887 & \\ A.U & 3.684 & & \\ B.A & & & 4.835 \\ B.B & 5.356 & 3.037 & \\ U.A & & 2.704 & 2.037 \\ U.U & 7.618 & & 0.837 \\ E.A & 9.809 & & 0.450 \\ E.E & 12.909 & 12.124 & 0.158 \end{array}.$$

Equilibrium total supply and demand quantities:

$$\mathbf{X}^{S*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 10.429 & 4.627 & 4.637 \\ B & 5.356 & 3.037 & 4.835 \\ U & 7.618 & 2.704 & 2.873 \\ E & 22.718 & 12.124 & 0.608 \end{array} \quad \mathbf{X}^{D*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 13.719 & 4.445 & 11.958 \\ B & 8.190 & 5.924 & \\ U & 11.302 & & 0.837 \\ E & 12.909 & 12.124 & 0.158 \end{array}.$$

Corresponding equilibrium supply and demand prices:

$$\mathbf{p}^{S*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 14.540 & 8.659 & 12.057 \\ B & 15.540 & 9.659 & 11.057 \\ U & 15.040 & 8.159 & 11.557 \\ E & 12.040 & 9.769 & 9.557 \end{array} \quad \mathbf{p}^{D*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 15.040 & 9.159 & 12.557 \\ B & 16.040 & 10.159 & 10.766 \\ U & 15.540 & 8.659 & 12.057 \\ E & 12.540 & 10.269 & 10.057 \end{array}.$$

Notice that supply prices differ from demand prices in each country by the amount of the domestic (internal to each country) transaction cost, that was specified in the amount of 0.5, for all commodities, in the **T** matrix. This implies that in this example demand functions may be measured at retail level while supply functions may be measured at farm or some other intermediate level.

Let us now consider the following matrix of realized (observed) trade flows:

$$\bar{\mathbf{X}} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A.A & 3.000 & 2.000 & 3.000 \\ A.B & 2.500 & 2.500 & \\ A.U & 2.000 & & \\ B.A & 0.500 & & 4.000 \\ B.B & 5.000 & 2.000 & \\ U.A & 1.000 & 1.000 & 1.000 \\ U.U & 6.000 & & \\ E.A & 10.000 & & \\ E.E & 12.000 & 10.000 & \end{array}$$

and the corresponding values of realized (observed) produced and consumed quantities of the three products in the four countries:

$$\bar{\mathbf{x}}^S = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 7.500 & 4.500 & 3.000 \\ B & 5.500 & 2.000 & 4.000 \\ U & 7.000 & 1.000 & 1.000 \\ E & 22.000 & 10.000 & \end{array} \quad \bar{\mathbf{x}}^D = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 14.500 & 3.000 & 8.000 \\ B & 7.500 & 4.500 & \\ U & 8.000 & & \\ E & 12.000 & 10.000 & \end{array}$$

and the corresponding values of realized (observed) prices of the three products in the four countries:

$$\bar{\mathbf{p}}^S = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 10.000 & 8.650 & 8.650 \\ B & 15.200 & 7.850 & 9.050 \\ U & 13.100 & 2.700 & 6.400 \\ E & 11.700 & 7.200 & 8.400 \end{array} \quad \bar{\mathbf{p}}^D = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 13.600 & 12.750 & 15.550 \\ B & 16.450 & 12.300 & 11.400 \\ U & 18.600 & 7.600 & 14.800 \\ E & 13.800 & 12.000 & 11.200 \end{array}.$$

When the calibrating constraints (37) (phase I) are included in the model, the matrices of dual variables $\mathbf{\Lambda}^*$ (adjustment to accounting costs) and effective transaction costs $\mathbf{T} + \mathbf{\Lambda}^*$ obtained are given below.

$$\mathbf{\Lambda}^* = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A.A & 3.100 & 3.600 & 6.400 \\ A.B & 4.950 & 2.150 & 1.250 \\ A.U & 7.600 & -2.050 & 5.150 \\ A.E & 0.800 & 0.350 & -0.450 \\ B.A & -3.100 & 3.400 & 5.000 \\ B.B & 0.750 & 3.950 & 1.850 \\ B.U & 1.200 & -2.450 & 3.550 \\ B.E & -5.400 & 0.150 & -1.850 \\ U.A & -0.500 & 9.050 & 8.150 \\ U.B & 1.150 & 7.400 & 2.800 \\ U.U & 5.000 & 4.400 & 7.900 \\ U.E & -3.000 & 5.600 & 1.100 \\ E.A & -1.100 & 2.550 & 4.150 \\ E.B & 0.750 & 1.100 & -1.000 \\ E.U & 3.200 & -3.300 & 2.700 \\ E.E & 1.600 & 4.300 & 2.300 \end{array} \quad \mathbf{T} + \mathbf{\Lambda}^* = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A.A & 3.600 & 4.100 & 6.900 \\ A.B & 5.450 & 3.650 & 2.750 \\ A.U & 8.600 & -1.050 & 6.150 \\ A.E & 3.800 & 3.350 & 2.550 \\ B.A & -1.600 & 4.900 & 6.500 \\ B.B & 1.250 & 4.450 & 2.350 \\ B.U & 3.400 & -0.250 & 5.750 \\ B.E & -1.400 & 4.150 & 2.150 \\ U.A & 0.500 & 10.050 & 9.150 \\ U.B & 3.350 & 9.600 & 5.000 \\ U.U & 5.500 & 4.900 & 8.400 \\ U.E & 0.700 & 9.300 & 4.800 \\ E.A & 1.900 & 5.550 & 7.150 \\ E.B & 4.750 & 5.100 & 3.000 \\ E.U & 6.900 & 0.400 & 6.400 \\ E.E & 2.100 & 4.800 & 2.800 \end{array}.$$

Several elements of $\mathbf{\Lambda}^*$ are negative and the same is true for four of the effective transaction costs in the $\mathbf{T} + \mathbf{\Lambda}^*$ matrix above. In general, a meaningful effective transaction cost will be nonnegative. However, when trade policies are not explicitly modeled, effective transaction costs will include the effects of missing policy instruments; for example, when export subsidies are larger than the sum of other transaction costs, the overall effective transaction cost between two countries may be negative, as is the case in the example.

Using the calibrating model, phase II equilibrium matrices of supply and demand quantities are given as:

$$\mathbf{x}^{S*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 7.500 & 4.500 & 3.000 \\ B & 5.500 & 2.000 & 4.000 \\ U & 7.000 & 1.000 & 1.000 \\ E & 22.000 & 10.000 & \end{array} \quad \mathbf{x}^{D*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 14.500 & 3.000 & 8.000 \\ B & 7.500 & 4.500 & \\ U & 8.000 & & \\ E & 12.000 & 10.000 & \end{array}.$$

These matrices match precisely the corresponding realized (observed) matrices of total demand and supply quantities.

Phase II equilibrium matrices of supply and demand prices:

$$\mathbf{p}^{S*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 10.000 & 8.650 & 8.650 \\ B & 15.200 & 7.850 & 9.050 \\ U & 13.100 & 2.700 & 6.400 \\ E & 11.700 & 7.200 & 8.400 \end{array} \quad \mathbf{p}^{D*} = \begin{array}{c|ccc|} & 1 & 2 & 3 \\ \hline A & 13.600 & 12.750 & 15.550 \\ B & 16.450 & 12.300 & 11.400 \\ U & 18.600 & 7.600 & 14.800 \\ E & 13.800 & 12.000 & 11.200 \end{array}.$$

These supply and demand prices differ, in each country, by the domestic effective transaction costs exhibited in the $(\mathbf{T} + \mathbf{\Lambda}^*)$ matrix. The phase II equilibrium model calibrates exactly observed production and consumption and prices of the three commodities in each country. It calibrates as well the realized (observed) trade flows as long as all the available information is used to guide the solver in its search of an equilibrium solution, i.e. as long as the realized (observed) trade flows and the corresponding quantities of supply and demand, and demand and supply prices are used as initial values.

As discussed in previous sections, the spatial equilibrium model in phase II admits multiple optimal solutions of the trade flow matrix. We present two such matrices. The first matrix – obtained using the realized (observed) trade flows as initial values for the optimization routine by the solver – calibrates exactly the observed trade flows. The second matrix is obtained using alternative initial values, $\mathbf{x}_{ij} = 10$; in this case the model calibrates observed prices and quantities produced and consumed in each country, but not observed trade flows.

Matrix of equilibrium trade flows N. 1:

$$\mathbf{X}_1^* = \begin{array}{r} \\ A.A \\ A.B \\ A.U \\ B.A \\ B.B \\ U.A \\ U.U \\ E.A \\ E.E \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \left[\begin{array}{ccc} 3.000 & 2.000 & 3.000 \\ 2.500 & 2.500 & \\ 2.000 & & \\ 0.500 & & 4.000 \\ 5.000 & 2.000 & \\ 1.000 & 1.000 & 1.000 \\ 6.000 & & \\ 10.000 & & \\ 12.000 & 10.000 & \end{array}\right] \end{array}.$$

Matrix of equilibrium trade flows N. 2:

$$\mathbf{X}_2^* = \begin{array}{r} \\ A.A \\ A.E \\ B.A \\ B.E \\ U.A \\ U.B \\ E.A \\ E.B \\ E.U \\ E.E \end{array} \begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \left[\begin{array}{ccc} 7.500 & & 3.000 \\ & 4.500 & \\ 5.500 & & 4.000 \\ & 2.000 & \\ 1.500 & 1.000 & 1.000 \\ 5.500 & & \\ & 2.000 & \\ 2.000 & 4.500 & \\ 8.000 & & \\ 12.000 & 3.500 & \end{array}\right] \end{array}.$$

The value of total transaction costs is the same in both cases and is equal to 267.400.

5. Conclusions

The use of spatial models for evaluating policies of interest to international trade – or any type of trade – must deal with the traditional discrepancy between realized (observed) trade flow patterns and the optimal (equilibrium) solutions obtained from the mathematical programming models at hand. The extension of the PMP methodology to this type of analysis allows for the specification of models that calibrate perfectly total demand and total supply of the commodities considered in each country as well as the realized trade flow pattern. Given the theoretical occurrence of multiple optimal (equilibrium) solutions in trade models, this last statement is achieved empirically when all the available information is used – in the form of initial values – for the guidance of the solver.

The calibration methodology developed in this paper deals with the adjustment of unit transaction costs in the form of differential quantities to be either added or subtracted from the level of the given accounting costs. When demand and supply functions in each country too are measured with imprecision at the same market level, a least-squares methodology was presented to estimate deviations from the intercepts and slopes of the demand and supply functions that allows for the calibration of the model as well as the equality between demand and supply prices in each country, as required by theory. When three or more commodities are involved in the analysis and the matrices of demand (or supply) slopes are not symmetric – the most frequent event – a structure called the Equilibrium Problem was proposed for handling such a case. All these calibrated mathematical programming structures, augmented by the appropriate specification of domestic and trade policy instruments (such as consumption taxes, export subsidies, and import tariffs) can be used to evaluate the effects of policy changes on participants in domestic and international markets.[2]

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[2] Anania (2010) uses the procedure developed in this paper to calibrate a single commodity spatial mathematical programming model to assess the effects of recent changes in the European Union import regime for bananas; Anania and Scoppola (2010) propose the use of the procedure introduced in this paper as a tool to assess the feasibility of imperfectly competitive market structures in international trading.

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Calibration of incomplete demand systems in quantitative analysis

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An easily implemented and flexible calibration technique for partial demand systems is introduced, combining recent developments in incomplete demand systems and a set of restrictions conditioned on the available elasticity estimates. The technique accommodates various degrees of knowledge on cross-price elasticities, satisfies curvature restrictions, and allows the recovery of an exact welfare measure for policy analysis. The technique is illustrated with a partial demand system for food consumption in Korea for different states of knowledge on cross-price effects. The consumer welfare impact of food and agricultural trade liberalization is measured.

I. INTRODUCTION

This study is a methodological contribution to policy analysis and more particularly to the calibration of partial demand systems involving a subset of disaggregated goods. The paper provides a feasible and suitable answer to the following generic problem. To quantify the impact of changing market conditions (e.g. policy shock, brand structure) on a subset of markets and consumer welfare, economic analysis often requires the calibration of disaggregated but partial demand systems and recovery of welfare measure associated with multiple price changes affecting these demands. Policy analysis is obviously in mind, but the approach applies to modelling other exogenous changes in markets (see Baltas for a business application).

An easily implemented and flexible calibration technique is introduced for partial demand systems combining recent developments in incomplete demand systems (LaFrance, 1998) and a set of restrictions conditioned on the available elasticity estimates. The proposed technique accommodates various degrees of knowledge on cross-price elasticities, satisfies curvature restrictions, and allows the recovery of an exact welfare measure for economic analysis. The calibration technique is illustrated with an incomplete demand system for agricultural and food consumption in Korea and for different states of knowledge on cross-price responses. Then, the consumer welfare impact of a policy shock and the trade liberalization of agricultural and food markets is measured, and the sensitivity of the welfare measure to the inclusion/deletion of cross-price effects assessed.

Calibration rather than econometric estimation is the rule in quantitative policy analysis for several reasons. First, quantitative policy analysis typically occurs when data are not available to estimate a demand system (partial or full), or when the data are too old to make the analysis current and reflect current market conditions. In addition, to palliate the data availability problem, the econometric estimation of partial systems often relies on restricting assumptions on separability precluding welfare analysis because the recovery of an exact welfare measure is difficult or impossible (Moschini, 2001).

Other considerations also matter. Typically, a small subset of markets is relevant for the analysis in mind (e.g. food markets). However, these few markets have to be sufficiently disaggregated for the analysis to be meaningful and

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useful (e.g. dairy, livestock, grains, oilseeds, as opposed to aggregate agriculture and food). This disaggregation requirement exacerbates the data availability problem. Timeliness is another important consideration. For example, congressional requests to the US General Accounting Office, or policy outfits impose a tight schedule on the policy analyst. These tight deadlines exclude the collection of recent data and careful econometric estimation.

Calibration has its own drawbacks. It requires 'finding' a large set of elasticities,[1] which may come from various sources or may not exist. Most often the set of elasticities is incomplete and ad hoc restrictions are added to palliate the lack of available estimates (e.g. OECD, 2000). Particularly acute is the problem of unknown cross-price responses. Many applied researchers restrict unknown cross-price elasticities to zero (Roningen *et al.*, 1991; OECD, 2000). From this ad hoc, incomplete demand system, one cannot recover an exact welfare measure. This shortcoming plagues well-known applied partial equilibrium models. Other researchers force cross-price responses for all goods concerned to be positive, identical, or proportional to expenditure shares (Keller, 1984; Moschini, 1999; Selvanathan, 1985). The latter approaches lead to an exact welfare measure for the representative consumer but impose too much structure on key parameters (cross-price effects).

To summarize the problem at hand: could the calibration of the partial demand model generate calibrated estimates of missing cross-price responses, based on the few existing estimates of elasticities available to the analyst (typically, the own-price and income elasticities)? Further, could it lead to exact welfare measures, such as Equivalent Variation (EV) or compensating variation (CV)? Finally, could the calibration procedure be adaptable, as new econometric estimates become available for the missing cross-price elasticities?

The calibration method proposed provides a unified satisfactory answer to these three questions. The approach is flexible in the sense that it does not impose restrictions on available individual income response or cross-price effects. For example, complementarity between any two goods is easily accommodated. Finally, the approach satisfies curvature restrictions (concavity).[2]

The paper is organized as follows. First, we introduce incomplete demand systems and follow with the presentation of the calibration method and the procedure to accommodate various cross-price effects. Sufficient conditions for concavity to be satisfied are provided, and are defined over available elasticity estimates. Then the Korean illustration follows with the welfare measurement of consumer price changes.

II. INCOMPLETE DEMAND SYSTEMS

LaFrance (1985), LaFrance and Hanemann (1989), and LaFrance *et al.* (2002), proposed a methodology of identification and recovery of the structure of preferences for incomplete demand systems. They obviously had econometric applications in mind but as is shown in the next section, their approach provides fruitful grounds for calibration exercises. The most recent development in incomplete demand systems is the Linquad system, which is quadratic in price and linear in income (LaFrance, 1998). Linquad preserves the theoretical consistency of the previous incomplete demand systems but allows for more flexibility to reflect preferences underlying the demand system by including quadratic price terms in its specification.

Integrability conditions establish the connection between a system of demands and a well-behaved expenditure function. These conditions insure that the demands are consistent with well-behaved consumer preferences. Utility maximization subject to a budget constraint results in a complete set of demand functions with certain properties. If a subset of demands from this complete demand system is considered separately, its properties only change slightly. The key insight in this body of work is the development of a duality theory of incomplete systems, as explained next.

Consider a system of Marshallian demands

$$\mathbf{x} = \mathbf{x}^M(\mathbf{q}, \mathbf{q}_z, R) \tag{1}$$

where $\mathbf{x} = [x_1, \ldots, x_n]'$ is the vector of consumption levels for the commodities of interest to the modeller, $\mathbf{q} = [q_1, \ldots, q_n]'$ is the corresponding price vector, $\mathbf{q}_z = [q_{z1}, \ldots, q_{zm}]'$ is the corresponding price vector for the vector of consumption levels of all other commodities denoted by variable $\mathbf{z} = [z_1, \ldots, z_m]$ with $m \geq 2$, and R is income. The selection of commodities to be included in $\mathbf{x}$ is done on a case-by-case basis depending on the policy problem to quantify.

Maximizing an increasing, quasi-concave utility function, $u(\mathbf{x}, \mathbf{z})$, with respect to consumption, under the budget constraint, $\mathbf{q}'\mathbf{x} + \mathbf{q}_z{}'\mathbf{z} \leq R$, results in demands for the goods of interest with four properties: (a) the demands are positive valued, $\mathbf{x} = \mathbf{x}^M(\mathbf{q}, \mathbf{q}_z, R) > \mathbf{0}$; (b) the demands are zero degree homogeneous in all prices and income, $\mathbf{x}^M(\mathbf{q}, \mathbf{q}_z,$

[1] For n goods, the number of price elasticities to estimate is equal to $\{n(n+1)/2\}$, assuming symmetry is imposed in a calibration using deflated prices; n income elasticities have to be found as well.

[2] Concavity (quasi-concavity) of utility is defined with the condition that the Slutsky matrix of compensated price responses of the demand system is negative definite (negative semi-definite).

$R) = x^M(tq, tq_z, tR)$ for all $t \infty 0$; (c) the $n \times n$ matrix of compensated substitution effects for x, or Slutsky matrix $S = \partial x^M/\partial q' + \partial x^M/\partial R x^{M'}$, is symmetric, negative semi-definite; and (d) total expenditure on the subset of the goods of interest consumed is strictly smaller than income, $q' x^M\ (q, q_z, R) < R$.

Complete and incomplete demand systems share the first three properties. The last property is specific to incomplete systems. A composite commodity including all other final goods establishes the link between complete and incomplete systems. The expenditure on this composite good is defined as $s = q_z' z = R - q' x$. With a properly defined utility function and the price of s innocuously normalized to one, duality applies to the incomplete system just as if it were a complete system (LaFrance *et al.*, 2002). The four properties of the incomplete demand system and new budget identity are equivalent to the existence of an expenditure function,

$$e(q, q_z, u) = q' x[q, q_z, e(q, q_z, u)] + s[q, q_z, e(q, q_z, u)] \quad (2)$$

By applying integrability conditions, the Linquad demand system is generated from the following quasi-expenditure function

$$e(q, q_z, \theta) = q'\varepsilon + \tfrac{1}{2} q' V q + \delta(q_z) + \theta(q_z, u) e^{\chi' q}, \quad (3)$$

where q is the vector of prices, $\delta(q_z)$ is an arbitrary real valued function of q_z, $\theta(q_z, u)$ is the constant of integration increasing in u, and χ, ε, and V are the vectors and matrix of parameters to be recovered in the calibration.

Hicksian demands, x, are obtained applying Shepherd's lemma to Equation 3:

$$x = \varepsilon + Vq + \chi\left[(q_z, u) e^{\chi' q}\right] \quad (4)$$

The integrating factor, $e^{\chi' p}$, makes the demand system an exact system of partial differential equations. The Linquad expenditure function (Equation 3) provides a complete solution class to this system of differentials and represents the exhaustive class of expenditure functions generating demands for x that are linear in total income and linear and quadratic in prices for x.

Solving the quasi-expenditure function (3) for $\theta(q_z, u) e^{\chi' p}$, and replacing expenditure with R for income yields the Linquad Marshallian demands:

$$x^M = \varepsilon + Vq + \chi(R - \varepsilon' q - \tfrac{1}{2} q' V q - \delta(q_z)) \quad (5)$$

The uncompensated own and cross-price elasticities are

$$\eta_{ii} = \left[v_{ii} - \chi_i \left(\varepsilon_i + \sum_j v_{ij} q_j \right) \right] q_i / x_i \quad (6a)$$

and

$$\eta_{ij} = \left[v_{ij} - \chi_i \left(\varepsilon_j + \sum_k v_{jk} q_k \right) \right] q_{ij} / x_i \quad (6b)$$

The corresponding Hicksian price elasticities are obtained from the Slutsky matrix $S = V + (R - \varepsilon' q - 0.5 q' V q - \delta(q_z))\chi\chi'$ which lead to own and cross-price compensated elasticities,

$$\eta_{ii}^h = \left[v_{ii} + \chi_i^2 \left(R - \varepsilon' q - 0.5 q' V q - \delta(q_z) \right) \right] q_i / x_i \quad (7a)$$

and

$$\eta_{ij}^h = \left[v_{ii} + \chi_i \chi_j \left(R - \varepsilon' q - 0.5 q' V q - \delta(q_z) \right) \right] q_j / x_i \quad (7b)$$

The duality theory of incomplete demand systems allows exact welfare measures to be obtained from the quasi-indirect utility function. To derive the EV associated with the Linquad demand system (Equation 5), the quasi-expenditure equation (Equation 3) is inverted with respect to θ after being set equal to income, R, or $\theta(q, u, z) = [R - q'\varepsilon - \frac{1}{2} q' V q - \delta(q_z)] e^{-\chi' q}$. The EV identity becomes

$$\begin{aligned} &\left[R + EV - q^{0'} \varepsilon - \tfrac{1}{2} q^{0'} V q^0 - \delta(q_z) \right] e^{-\chi' q^0} \\ &\quad = \left[R - q^{1'} \varepsilon - \tfrac{1}{2} q^{1'} V q^1 - \delta(q_z) \right] e^{-\chi' q^1}, \end{aligned} \quad (8)$$

where q^0 and q^1 is a vector of prices of $\mathbf{x}$ before and after the policy chock inducing the price changes, respectively. The EV is:

$$\begin{aligned} EV = &\left[R - q^{1'} \varepsilon - \tfrac{1}{2} q^{1'} V q^1 - \delta(q_z) \right] e^{\chi'(q^0 - q^1)} \\ &- \left[R - q^{0'} \varepsilon - \tfrac{1}{2} q^{0'} V q^0 - \delta(q_z) \right]. \end{aligned} \quad (9)$$

The CV measure can be obtained following similar steps.

III. CALIBRATION

The calibration approach builds on the Linquad structure explained in the previous section as the foundation for the partial demand system. Then, it imposes a set of restrictions on the system conditioned on the available information and integrability to recover taste parameters. From the latter we generate values for missing elasticities and an exact welfare measure consistent with the initial price and income responses on hand. The necessary information set for the calibration is as follows: income and own-price elasticity estimates, levels of Marshallian demands x_i^M, level of income R, prices q_i or alternatively expenditure $(x_i q_i)$,[3] and optionally, some cross-price elasticity estimates for good i and $j = 1, \ldots, n$.

[3] If only expenditures are known, quantity units for each good are redefined such that the associated price is equal to 1 per unit.

More specifically, the calibration involves the recovery of elements of the n-vectors $\boldsymbol{\chi}$ and ε, together with the elements of the $n \times n$ matrix $\boldsymbol{V}$ in Equation 5. The calibration imposes symmetry and negative semi-definiteness of $\boldsymbol{S}$, the Hessian of e. Homogeneity of degree one in prices for e is imposed by deflating prices by a consumer price index serving as a proxy for the price of all other goods. Homogeneity in prices plays no role in the recovery of parameters in the calibration procedure.

The calibration is done sequentially. First, point estimates of derivatives of demand with respect to income are obtained from the known income elasticity estimates. Then, income response parameters $\boldsymbol{\chi}$ are substituted into Equations 5 and 6. Next, price responses are recovered from the point estimates corresponding to the available price elasticities, evaluated at the reference level of the data. Then, all price responses together with restrictions on $\boldsymbol{S}$ from integrability, and the observed demand levels are used to estimate the parameters of the model.

Derivation of income responses $\boldsymbol{\chi}$

From the available income elasticity estimates of demand x_i^M, η_{iI}, we derive the vector of parameters $\boldsymbol{\chi}$, the vector of partial derivatives of the Marshallian demands with respect to income, $\boldsymbol{\chi}_i = x_i^M{}_i \eta_{iI} / R$.

Integrability conditions and derivation of parameters ε *and* $\boldsymbol{V}$

Symmetry of $\boldsymbol{V}$ is sufficient to insure the symmetry of Slutsky matrix $\boldsymbol{S}$. Symmetry of $\boldsymbol{S}$ implies that $v_{ij} = v_{ji}$. This is imposed by choosing a preferred cross-price elasticity η_{ij}, if Marshallian cross-price responses are available, to be substituted in Equation 6b and then identifying a single v_{ij} as explained below. Then the symmetric element v_{ji} is set equal to the identified v_{ij}. If no estimate of η_{ij} is available then $v_{ij} = v_{ji} = 0$ is set in Equation 6b and the unavailable η_{ij} becomes the unknown variable of interest in this case.

Regarding curvature, $\boldsymbol{S}$ should be negative semi-definite to satisfy quasi-concavity of the utility function. Two cases are distinguished. The first case refers to the simple situation in which only own-price and income elasticities are available (i.e. $v_{ij} = v_{ji} = 0$). A sufficient condition for the concavity of the calibrated demand system is derived, which applies to the available elasticity estimates. The condition is based on strict diagonal dominance and the Gerschgorin–Hadamard theorems (Lascaux and Théodor, Theorems 53 and 57, and corollary 63). These theorems, applied to any real symmetric matrix with positive diagonal terms, say that if the absolute value of each diagonal term of such matrix is larger (at least as large) as the sum of the individual absolute values of the off-diagonal terms of the corresponding row or column, then such matrix is positive (semi-)definite. These theorems are applied to $-\boldsymbol{S}$, which should be positive semi-definite for (quasi-)concavity to be satisfied.

The dominance condition for any Slutsky matrix is

$$\left| -v_{ii} - \chi_i^2 \left[R - \boldsymbol{q}^{0'} \varepsilon - \tfrac{1}{2} \boldsymbol{q}^{0'} \boldsymbol{V} \boldsymbol{q}^{\mathbf{0}} - \delta(\boldsymbol{q}_z) \right] \right| \geq \sum_{j \neq i} \left| -v_{ij} - \chi_i \chi_j \left[R - \boldsymbol{q}^{0'} \varepsilon - \tfrac{1}{2} \boldsymbol{q}^{0'} \boldsymbol{V} \boldsymbol{q}^{\mathbf{0}} - \delta(\boldsymbol{q}_z) \right] \right| \quad (10)$$

Recall that in this first calibration case, off-diagonal terms of $\boldsymbol{S}$ are just made off the income effect in the Slutsky decomposition, $\boldsymbol{\chi}_i \boldsymbol{\chi}_j [R - \boldsymbol{q}_{0'} \varepsilon - \frac{1}{2} \boldsymbol{q}_0{}' \boldsymbol{V} \boldsymbol{q}^{\boldsymbol{0}} - \delta(\boldsymbol{q}_z)]$, since $v_{ij} = 0$.

In order to transform inequality (10) in elasticity terms, we momentarily normalize prices $\boldsymbol{q}$ to one by appropriate choice of units and without any loss of generality. Diagonal dominance condition (10) is preserved by adding on both sides the income effect of good i ($\boldsymbol{\chi}_i x_i$).[4] In elasticity form the dominance condition becomes:

$$|-\eta_{ii}| \geq \sum_{j \neq i} \left| -\chi_i \chi_j \left[R - \boldsymbol{q}^{0'} \varepsilon - \tfrac{1}{2} \boldsymbol{q}^{0'} \boldsymbol{V} \boldsymbol{q}^{\mathbf{0}} - \delta(\boldsymbol{q}_z) \right] \Big/ x_i \right| + \chi_i \quad (11)$$

Next, income R is substituted for $[R - \boldsymbol{q}_{0'} \varepsilon - \frac{1}{2} \boldsymbol{q}_0{}' \boldsymbol{V} \boldsymbol{q}^{\boldsymbol{0}} - \delta(\boldsymbol{q}_z)]$ in (11), which reinforces the inequality. It leads to the following sufficient condition for concavity in terms of available information on the Marshallian own-price elasticities, income elasticities, and expenditure shares:

$$|-\eta_{ii}| - \sum_{j \neq i} |-\eta_{iI} \eta_{jI} \alpha_j| - \alpha_i \eta_{iI}, \geq 0 \quad (12)$$

with parameters α_i denoting the total expenditure share of good i. Hence one can check right away if a chosen set of available estimates of elasticities satisfies dominance if it satisfies sufficient condition (12). It is not a necessary condition and it is slightly stronger than the dominance condition (11) since income R is larger than the income term in the demand $[R - \boldsymbol{q}_0{}' \varepsilon - \frac{1}{2} \boldsymbol{q}_0{}' \boldsymbol{V}\ \boldsymbol{q}^{\boldsymbol{0}} - \delta(\boldsymbol{q}_z)]$. If the data on elasticity values do not satisfy either condition (10) or (12) the off-diagonal terms are then scaled down in absolute value by increasing constant $\delta(\boldsymbol{q}_z)$ until diagonal dominance is achieved, insuring the proper curvature. Given that parameters $\boldsymbol{\chi}_i \boldsymbol{\chi}_j$ are typically six to

[4] Giffen goods are ruled out (income term smaller in absolute value to the Hicksian price term in absolute value in the Slutsky decomposition).

eight orders of magnitude smaller than the diagonal terms, concavity is satisfied without having to rescale the off-diagonal terms in most cases we encountered. The intuition of condition (10) is that the aggregate magnitude of substitution (complementarity) effects should not be bigger than the own-price effects such that across-the-board price cuts increase. This condition is illustrated in our Korean food demand application in the application section.

If the sufficient condition for diagonal dominance is met, we set parameter $\delta(\boldsymbol{q_z})$ equal to zero in Equations 5, 7, and 9. This procedure is virtually innocuous because it has little impact on the value of the elasticities derived from the demand system. This normalization of $\delta(\boldsymbol{q_z})$ to zero is used in many econometric investigations of demand because this parameter δ is practically unidentified in many econometric investigations of the AIDS and Linquad demand systems (Deaton *et al.*, 1980). Large variations in its value have little bearing on the values of ε and $\boldsymbol{V}$ and the exact welfare measure.[5] Other values for δ are obviously defensible.

In the second case related to concavity, estimates for some cross-price effects are available. Typically, the degree of knowledge and confidence of the analyst on these cross-price effects is limited. Our approach is to leave income and own-price responses unchanged and to scale down cross-price effects if conditions for concavity are not met. The cross-price effects are scaled in absolute value until the concavity sufficient condition is satisfied either through diagonal dominance (10) or Cholesky factorization (Lau, 1978).[6] In this second case, the scaling affects mostly the cross-slope coefficients v_{ij} and then the intercept terms ε_i, which in turn affect the values of the own-price responses in the Slutsky matrix via feedback on the income term $[R-\boldsymbol{q_0}'\varepsilon-\frac{1}{2}\boldsymbol{q_0}'\boldsymbol{V}\boldsymbol{q^0}-\delta(\boldsymbol{q_z})]$ in Marshallian demands. One could check sequentially if own-price and income elasticities are consistent as a separate set of estimates using the first-case approach, then move to the second case and use the additional estimates of cross-price effects to constrain the whole set of available elasticity estimates.

With $\boldsymbol{\chi}$ being identified in the previous step, its values are then combined with available information on the level of demand (Equation 5) and elasticities (Equation 6), (own-price elasticities, and if available, cross-price elasticity estimates) to recover structural parameters ε_i and v_{ij}. This step leads to a system of $3\times$n equations. The system of equations is linear in unrestricted parameters ε_i, v_{ij}, and unknown cross-price responses $\partial x_i^M/\partial q_j$:

$$\begin{cases} \dfrac{x_i^M-\chi_i R}{\chi_i} = \left(\left(\dfrac{1}{\chi_i}-q_i\right)\right)\varepsilon_i + \left(\left(\dfrac{q_i}{\chi_i}-\frac{1}{2}q_i^2\right)\right)v_{ii} \\ \qquad -\displaystyle\sum_{j\neq i}\varepsilon_j q_j + \sum_{j\neq i}\left((v_{ij}\frac{q_j}{\chi_i}-q_iq_j)\right) \\ \qquad -\frac{1}{2}\displaystyle\sum_{j\neq i}\sum_{k\neq i}v_{jk}q_jq_k \\ \dfrac{\partial x_i^M}{\partial q_j}\dfrac{1}{1+a_{ij}} = v_{ij}-\chi_i\varepsilon_j-\chi_i\displaystyle\sum_{allk}v_{jk}q_k \\ \dfrac{\partial x_i^M}{\partial q_i} = v_{ii}(1-\chi_iq_i)-\chi_i\varepsilon_i-\chi_i\displaystyle\sum_{i\neq j}v_{ij}q_j, \end{cases} \tag{13}$$

In the above system (13), whenever cross-prices effects $\partial x_i^M/\partial q_j$ are unknown, parameter v_{ij} in $\boldsymbol{V}$ is restricted to zero, which implies that $\partial x_i^M/\partial q_j=-\boldsymbol{\chi}_i\ (\varepsilon_j+v_{jj}q_j)$. With scaling parameters a_{ij} set to zero, the system of equations in ε and $\boldsymbol{V}$ is exactly identified. To impose curvature restrictions the scaling parameters a_{ij} are set non-negative and chosen by minimizing the sum of corrections $\sum_i\sum_j a_{ij}$, which satisfy system (13) and condition (10). The non-negative constraint preserves the sign of the estimates of the substitution/complementarity effects.

With the calibrated values of the elements of $\boldsymbol{V}$ and ε, the EV is calibrated and welfare analysis of price changes is possible. GAMS' DNLP solver is used, which handles absolute values.

IV. APPLICATION TO KOREA

The study now turns to our Korean illustration. We look at an incomplete food demand system for a representative Korean agent consuming the following commodities: rice, barley, wheat, corn, soybean, dairy, beef, pork, and poultry. Korea provides a good illustration because consumer prices are distorted and induce large consumer welfare losses. Various income and price elasticity estimates are available, including six cross-price effects between the three cereals and the three meats. The sources are various and detailed in Beghin, Bureau, and Park. Table 1 summarizes the available information on elasticity values, consumption levels and relative prices in 1995 wons.

We start with the first case in which it is assumed only own-price and income elasticities are available to the researcher. These elasticity values and implied expenditure

[5] The sensitivity of EV with respect to $\delta(\boldsymbol{q_z})$ ($\mathrm{d}EV/\mathrm{d}\,\delta(\boldsymbol{q_z})$) is 0.007 (an additional 1 million won in the income argument via $\delta(\boldsymbol{q_z})$ induces 7 million won of variation in EV, which is of the order of 14 trillion won for the price change considered in the illustration).

[6] The Cholesky factorization decomposes minus the Slutsky matrix -$\boldsymbol{S}$ into -$\boldsymbol{S}=\boldsymbol{L_l}\boldsymbol{D}\boldsymbol{L_h}$, where $\boldsymbol{D}$ is a diagonal matrix constrained to have nonnegative elements D_{ii} for quasi-concavity of the utility function, $\boldsymbol{L_l}$ is a unit lower triangular matrix, and $\boldsymbol{L_h}$ is the transpose of $\boldsymbol{L_l}$ (Lau). A similar scaling approach is used for the Cholesky factorization as for the diagonal-dominance approach. Scaling factors are applied to the slope estimates of the Marshallian cross-price effects to satisfy curvature restrictions (D_{ii}) positive.

Table 1. *Available data for calibration of a partial demand system in Korea (2000 data)*

Goods	Quantities	Domestic prices (q_0)	World price (q_1)	Own-price elasticity η_{ii}	Income elasticities η_{iI}
Rice	5126.00	1657.55	259.88	−0.20	0.12
Barley	467.00	417.08	133.19	−0.60	0.24
Wheat	3173.32	182.42	182.00	−0.40	0.18
Corn	9425.38	153.51	152.68	−0.45	0.43
Soybean	1815.00	358.21	213.58	−0.32	0.32
Milk	2753.00	497.51	131.56	−0.57	0.57
Beef	585.00	6348.26	1914.96	−0.80	0.54
Pork	1012.00	1961.03	1215.87	−0.89	0.73
Poultry	427.00	1692.37	1199.11	−0.70	0.37

Income = 475.830 Trillion won (1995 prices); cross-price elasticities: $\eta_{rice\ wheat} = 0.08$; $\eta_{barley\ wheat} = 0.21$; $\eta_{barley\ corn} = 0.15$; $\eta_{beef\ pork} = 0.22$; $\eta_{beef\ poultry} = 0.04$; $\eta_{pork\ poultry} = 0.04$.

Table 2. *Hicksian price elasticities without information on off-diagonal elasticities*

	Rice	Barley	Wheat	Corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.19786	0.00001	0.00003	0.00015	0.00005	0.00019	0.00049	0.00035	0.00006
Barley	0.0005	−0.5999	0.00005	0.0003	0.0001	0.00038	0.00097	0.0007	0.00013
Wheat	0.00037	0.00002	−0.39978	0.00023	0.00008	0.00028	0.00073	0.00053	0.0001
Corn	0.00089	0.00004	0.00009	−0.44869	0.00018	0.00068	0.00175	0.00126	0.00023
Soybean	0.00066	0.00003	0.00007	0.0004	−0.31956	0.00051	0.0013	0.00094	0.00017
Milk	0.00118	0.00005	0.00012	0.00072	0.00024	−0.56836	0.00231	0.00167	0.00031
Beef	0.00111	0.00005	0.00011	0.00068	0.00023	0.00085	−0.79579	0.00158	0.00029
Pork	0.00151	0.00007	0.00015	0.00092	0.00031	0.00115	0.00296	−0.88696	0.0004
Poultry	0.00076	0.00004	0.00008	0.00047	0.00016	0.00058	0.0015	0.00109	−0.69944

Table 3. *Marshallian elasticities without information on off-diagonal price responses*

	Rice	Barley	Wheat	Corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.2	−0.00004	−0.00012	−0.00021	−0.00011	−0.00016	−0.00045	−0.00015	−0.00012
Barley	−0.00379	−0.6	−0.00024	−0.00043	−0.00023	−0.00031	−0.0009	−0.0003	−0.00023
Wheat	−0.00284	−0.00006	−0.4	−0.00032	−0.00017	−0.00023	−0.00067	−0.00022	−0.00018
Corn	−0.00679	−0.00014	−0.00043	−0.45	−0.00041	−0.00056	−0.00161	−0.00053	−0.00042
Soybean	−0.00505	−0.0001	−0.00032	−0.00057	−0.32	−0.00042	−0.0012	−0.0004	−0.00031
Milk	−0.009	−0.00018	−0.00057	−0.00102	−0.00054	−0.57	−0.00213	−0.00071	−0.00056
Beef	−0.00853	−0.00017	−0.00054	−0.00096	−0.00051	−0.0007	−0.8	−0.00067	−0.00053
Pork	−0.01153	−0.00023	−0.00073	−0.0013	−0.00069	−0.00095	−0.00273	−0.89	−0.00071
Poultry	−0.00584	−0.00012	−0.00037	−0.00066	−0.00035	−0.00048	−0.00139	−0.00046	−0.7

shares satisfy the dominance condition (12) (for rice, 0.19647; barley, 0.59665; wheat, 0.39736; corn, 0.44338; soybean, 0.31533; milk, 0.56150; beef, 0.79068; pork, 0.87920; and poultry, 0.69459). Hence, no correction is required and parameter $\delta(\boldsymbol{q}_z)$ is set equal to zero. Table 2 shows the implied Hicksian price elasticity values implied by the calibration for the diagonal case. The Hicksian cross-price response elasticities generated by the calibration procedure are small but are fully consistent with an integrable demand system and lead to exact welfare measure. They are positive as expected because all goods are normal in this illustration. Indeed, for any v_{ij} restricted to zero, then the sign of the product of the income responses for good i and j, $\boldsymbol{\chi}_i\, \boldsymbol{\chi}_j$, determines the sign of the substitution effect between goods i and j. The implied Marshallian elasticities are shown in Table 3. Marshallian cross-price effects are negative because of the correction for the income effect being larger than the small positive substitution effect.

In the second calibration case all available cross-price elasticities are made use of. The diagonal dominance condition requires to scale down one cross-price effect (wheat–rice) as shown in Table 4.1. The Slutsky price responses are shown in Table 4.2, and the implied Marshallian elasticities in Table 4.3. We also show the corresponding results when the curvature restriction is imposed via Cholesky factorization (Tables 5.1 to 5.3). Results are qualitatively similar between the two approaches to impose curvature. Diagonal dominance induces a slightly larger adjustment

Table 4. *Calibration with information on six off-diagonal elasticities and diagonal dominance*

4.1. *Scaling of estimates (in per cent)*

	Wheat
Rice	26.9%

4.2. *Calibrated Hicksian price elasticity estimates*

	Rice	Barley	Wheat	Corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.19786	0.00001	0.06321	0.00015	0.00005	0.00019	0.00049	0.00035	0.00006
Barley	0.0005	−0.5999	0.21029	0.15073	0.0001	0.00038	0.00097	0.0007	0.00013
Wheat	0.92778	0.07076	−0.39978	0.00023	0.00008	0.00028	0.00073	0.00053	0.0001
Corn	0.00089	0.02029	0.00009	−0.44869	0.00018	0.00068	0.00175	0.00126	0.00023
Soybean	0.00066	0.00003	0.00007	0.0004	−0.31956	0.00051	0.0013	0.00094	0.00017
Milk	0.00118	0.00005	0.00012	0.00072	0.00024	−0.56836	0.00231	0.00167	0.00031
Beef	0.00111	0.00005	0.00011	0.00068	0.00023	0.00085	−0.79579	0.22225	0.04082
Pork	0.00151	0.00007	0.00015	0.00092	0.00031	0.00115	0.4159	−0.88696	0.04111
Poultry	0.00076	0.00004	0.00008	0.00047	0.00016	0.00058	0.20978	0.1129	−0.69944

4.3. *Marshallian elasticity estimates*

	Rice	Barley	Wheat	Corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.20000	−0.00004	0.06306	−0.00021	−0.00011	−0.00016	−0.00045	−0.00015	−0.00012
Barley	−0.00379	−0.60000	0.21000	0.15000	−0.00023	−0.00031	−0.00090	−0.00030	−0.00023
Wheat	0.92456	0.07068	−0.40000	−0.00032	−0.00017	−0.00023	−0.00067	−0.00022	−0.00018
Corn	−0.00679	0.02011	−0.00043	−0.45000	−0.00041	−0.00056	−0.00161	−0.00053	−0.00042
Soybean	−0.00505	−0.00010	−0.00032	−0.00057	−0.32000	−0.00042	−0.00120	−0.00040	−0.00031
Milk	−0.00900	−0.00018	−0.00057	−0.00102	−0.00054	−0.57000	−0.00213	−0.00071	−0.00056
Beef	−0.00853	−0.00017	−0.00054	−0.00096	−0.00051	−0.00070	−0.80000	0.22000	0.04000
Pork	−0.01153	−0.00023	−0.00073	−0.00130	−0.00069	−0.00095	0.41020	−0.89000	0.04000
Poultry	−0.00584	−0.00012	−0.00037	−0.00066	−0.00035	−0.00048	0.20689	0.11135	−0.70000

Table 5. *Calibration with information on 6 off-diagonal elasticities and Cholesky factorization*

5.1. *Scaling of estimates (in per cent)*

	Wheat
Rice	12.9%

5.2. *Hicksian elasticity estimates*

	Rice	Barley	Wheat	corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.19786	0.00001	0.07100	0.00015	0.00005	0.00019	0.00049	0.00035	0.00006
Barley	0.00050	−0.59990	0.21029	0.15073	0.00010	0.00038	0.00097	0.00070	0.00013
Wheat	1.04211	0.07076	−0.39978	0.00023	0.00008	0.00028	0.00073	0.00053	0.00010
Corn	0.00089	0.02029	0.00009	−0.44869	0.00018	0.00068	0.00175	0.00126	0.00023
Soybean	0.00066	0.00003	0.00007	0.00040	−0.31956	0.00051	0.00130	0.00094	0.00017
Milk	0.00118	0.00005	0.00012	0.00072	0.00024	−0.56836	0.00231	0.00167	0.00031
Beef	0.00111	0.00005	0.00011	0.00068	0.00023	0.00085	−0.79579	0.22225	0.04082
Pork	0.00151	0.00007	0.00015	0.00092	0.00031	0.00115	0.41590	−0.88696	0.04111
Poultry	0.00076	0.00004	0.00008	0.00047	0.00016	0.00058	0.20978	0.11290	−0.69944

5.3. *Marshallian elasticity estimates*

	Rice	Barley	Wheat	Corn	Soybean	Milk	Beef	Pork	Poultry
Rice	−0.20000	−0.00053	0.07016	−0.00165	−0.00135	−0.00175	−0.00199	−0.00235	−0.00214
Barley	0.00015	−0.60000	0.20990	0.15041	−0.00015	0.00004	0.00055	−0.00003	−0.00026
Wheat	1.04218	0.07074	−0.40000	0.00017	0.00003	0.00023	0.00067	0.00024	0.00003
Corn	−0.00062	0.01989	−0.00090	−0.45000	−0.00084	−0.00073	−0.00003	−0.00110	−0.00138
Soybean	0.00004	−0.00014	−0.00050	−0.00015	−0.32000	−0.00009	0.00056	−0.00023	−0.00051
Milk	−0.00056	−0.00041	−0.00111	−0.00081	−0.00096	−0.57000	0.00025	−0.00116	−0.00157
Beef	−0.00250	−0.00089	−0.00170	−0.00240	−0.00218	−0.00247	−0.80000	0.21724	0.03703
Pork	−0.00023	−0.00040	−0.00125	−0.00062	−0.00090	−0.00050	0.41383	−0.89000	0.03921
Poultry	0.00028	−0.00011	−0.00051	0.00001	−0.00020	0.00010	0.20918	0.11182	−0.70000

Table 6. *Equivalent variation (EV) for the removal of price distortions*

Without information on off-diagonal	13.95086
With information and diagonal dominance	13.70318
With information and Cholesky	13.70355

Units are trillions of won at 1995 prices.

of the estimate of the cross-price response between wheat and rice than Cholesky factorization does. This is expected since the former method is a sufficient but not necessary condition whereas the latter is necessary and sufficient to establish positive semi-definiteness of a symmetric real matrix.

Next, we simulate a large policy shock equivalent to full trade liberalization and measure the EV corresponding to the price changes from domestic prices to border prices. We do so for the two calibration cases (no off-diagonal information, the polar case with information on six cross-price responses and curvature restrictions under both diagonal dominance and Cholesky factorization). Table 6 shows the three EV estimates. As shown in the table, the EV measures do change somewhat but the order of magnitude of the impact of the price shock does not. The three EV measures are between 13.7 and 14 trillion won and income is 476 trillion won. Hence, it is concluded that the EV measure is robust to the inclusion or absence of available estimates of cross-price effects.

V. CONCLUSIONS

This study is a methodological contribution to quantitative economic analysis and more particularly to the calibration of partial systems involving a subset of disaggregated goods. It proposes and illustrates an easily implemented and flexible calibration technique for partial demand systems, combining recent developments in incomplete demand systems and a set of restrictions conditioned on the available elasticity estimates and integrability.

The technique accommodates various degrees of knowledge on cross-price elasticities and allows the recovery of an exact welfare measure. It generates values for missing cross-price elasticities, which are consistent with the available estimates. The approach is illustrated with a partial demand system for food consumption in Korea for different states of knowledge on cross-price effects. The consumer welfare impact of food and agricultural trade liberalization is measured and is shown not to be sensitive to the inclusion or deletion of available estimates of cross-price effects.

Curvature restrictions are imposed using alternative approaches (diagonal dominance and Cholesky factorization). Diagonal dominance provides a sufficient condition for concavity of utility, which can be expressed in terms of available estimates of Marshallian own-price and income elasticities. This condition provides a direct and convenient check of the estimates available to the policy analyst. The drawback of the diagonal dominance approach is that it might impose adjustments in estimates that are larger than is necessary to satisfy curvature. Cholesky factorization does not allow for a ‘quick’ check of available estimates of own-price and income elasticities. However, it does provide minimum adjustments in estimates that are necessary for curvature restrictions to be satisfied. In our calibration illustration, the two methods to impose proper curvature yield very close estimates of preferences parameters and EV measures for the policy changes.

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