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Nutrition and Climate Policies in the European Union: Friends or Enemies?

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Abstract

The Farm to Fork Strategy of the European Union (EU) Green Deal aims to promote sustainable food systems to reach EU climate-neutrality by 2050. In the framework of the Paris Agreement (2015), the EU countries have agreed in 2020 to increase the ambition of their climate policies by committing to cut EU carbon emissions by at least 55% by 2030. This paper asks the following questions. Does a climate agreement with mitigation targets provides the right incentives to EU countries to implement sustainable diets through nutritional policies? Should EU countries seek agreements on both mitigation and nutrition targets? To address these questions, this paper develops a game-theoretic model where each country implements a nutrition and climate policy. Dietary changes induced by a nutrition policy lead to health benefits at the national level, and can affect the focal country's GHG emissions with related externalities for other countries. In terms of total emissions, our theoretical results show that it is always better to cooperate over both climate mitigation and nutrition policies, whatever dietary changes increase or decrease a country's emissions. The latter property plays however a crucial role on the ambition of nutritional policies chosen by countries within alternative international climate architectures.

Keywords: climate mitigation, nutrition policy, healthy diets, cooperation, agreement.

JEL codes: C71, C72, D62, H41, I18.

1 Introduction

The European Union (EU) adopted recently Green Deal which includes an ambitous package of measures to promote environmental sustainability and to attain climate-neutrality by 2050. This Deal includes a number of actions including climate mitigation, climate adaptation, biodiversity, circular economy and Farm to Fork Strategy. This Strategy which is at the heart of the Green Deal addresses the challenges of sustainable food systems by recognising the close links between healthy people, healthy societies and a healthy planet (European Commission, 2020).[1] While food production and food consumption are vulnerable to the effects of climate change, both food systems and diets are significant contributors to global greenhouse gas (GHG) emissions. Worldwide, GHG emissions from the agri-food sector account for about 19 to 29% of global GHG emissions (UNSCN, 2017)[2] which is similar to industry and is greater than the amount contributed by transport. Livestock supply chains which represent 14.5% of GHG emissions are an important contributor to global warming (Gerber et al., 2013). The transition to sustainable food sytems will clearly require a shift in people's diets, given that European diets are not in line with national dietary recommendations (European Commission, 2020).

In order to honour the commitment all countries made to strengthen national climate plans (NDCs) every five years in the Paris Agreement (2015), the EU countries have adopted in 2020 more ambitious climate targets, with a pledge to make them legally binding. Under the first European Climate Law, the EU commits to cut carbon emissions by at least 55% by 2030, compared with 1990 levels.[3] This is a significant increase compared to the previous target of at least a 40% reduction by 2030. On July 14, 2021, the European Commission published its 'Fit for 55' legislative package to attain the 55% reduction objective.

Taking stock ot these two recent developments in EU policy agenda, this paper investigates

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[1] This Strategy foresees in the future the implementation of several instruments: harmonised mandatory front-of-pack nutrition labelling, a sustainable labelling framework that covers the nutritional, climate, environmental and social aspects of food products, and tax incentives such as differentiated VAT rates to support for instance organic fruit and vegetables (European Commission, 2020).

[2] Food production and consumption are responsible for 60% of terrestrial biodiversity loss and 70% of freshwater use (UNSCN, 2017).

[3] https://ec.europa.eu/clima/policies/eu-climate-action_en#:~:text=First%20climate%20action%20initiatives%20under%20the%20G

theoretically whether the EU policies on sustainable food diets and on climate change mitigation are compatible in the context of international externalities from greenhouse gas (GHG) emissions. We ask the following questions. Does a climate agreement with mitigation targets (climate agreement) provides the right incentives to EU countries to implement sustainable diets through nutritional policies? Should EU countries seek agreements on both mitigation and nutrition targets (full agreement)? To address these questions, this paper develops a game-theoretic model to analyze theoretically the impact of the architecture of international climate agreements on the ambition of nutritional policies chosen by countries. In the model, each country implements a nutrition and climate policy. Dietary changes induced by a nutrition policy lead to health benefits at the national level, and can increase or decrease the focal country's GHG emissions with related externalities for other countries.

In this context, evaluations of the effects of changes to diets in particular reduced consumption of meat and dairy products, on GHG emissions have increased in recent years. A review by Aleksandrowicz et al. (2016) compares the impact of 210 scenarios in 63 studies and shows that a change from a typical Western diet to an alternative dietary pattern (e.g., mediterranean, vegetarian, vegan) could produce a 70% reduction in food-related GHG emissions with a median reduction of between $20\% - 30\%$. Aleksandrowicz et al. (2016) highlight that the different results from different scenarios make clear the complexity involved in assessing the environmental sustainability of certain diets, and the context- and region-specific nature of these assessments. In a region-specific global study which takes no account of substitution effects between food products, Springmann et al. (2016) estimate that the transition from a meat-based diet to a plant-based diet could reduce food-related GHG emissions by between 29% and 70% with the baseline scenario of 2050 and with large differences between regions. In an economic assessment which takes account of substitution effects, Irz et al. (2019) find large disparities in GHG emissions between France, Denmark, and Finland in the adjustment to similar nutrition recommendations. They show that imposing dietary constraints results in reduced GHG emissions ranging from 0.2% to 5%. However, they show that in the case of France, reducing consumption of all animal products would increase GHG emissions by 0.9% due to the higher carbon content of substitute products. Thus, implementation of dietary recommendations does not always decrease GHG emissions considerably, and the differences among countries could be substantial.

An unhealthy diet is a key risk factor for major chronic, non-communicable diseases (NCDs) including obesity, heart attack, stroke, diabetes, and some types of cancers.[4] It is estimated that in 2015 in Europe, diet-related NCDs accounted directly for 29.3% of NCD-related deaths and 16.4% of NCD-related disability-adjusted life years (Melaku et al., 2018).[5] The adverse impacts of an unhealthy diet on health and health care budgets[6] have led most high-income countries to implement nutrition policies and provide information (e.g. information campaigns, labeling rules) and market intervention measures (e.g. taxes, subsidies, food standards). Springmann et al. (2016) estimate that the transition from a meat-based diet to a plant-based diet could reduce global mortality by $6\% - 10\%$ with the baseline scenario of 2050 and with large differences between regions.

In our model, we assume that each country which is signatory to a climate agreement imposing mitigation targets also implements a national nutrition policy. A nutrition policy can take the form of a standard or a tax aimed at reducing consumption of animal products (such as red meat), or equivalently, at increasing relative consumption (over animal products) of vegetal products. It is worth noting that healthier diet (related to a nutrition policy) and climate change mitigation (related to a climate policy) are two different goods. At the country level, a healthier diet is a private good while climate mitigation is a pure public good. The benefits of nutrition policies depend only on national-level measures related to NCDs whereas the benefits of climate policies depend on both own but also other countries' policies. Furthermore, dietary changes induced by nutrition policies lead on the one hand to health benefits at the national level, and on the other hand to either an increase or a decrease in national GHG emissions. Since GHG emissions are a pure public "bad", these additional or reduced emissions produce negative or positive externalities for other countries. Thus, a nutrition policy seen as a private good can become an impure public good (Cornes and

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[4] The rise of NCDs has been driven primarily by 4 major risk factors: tobacco use, physical inactivity, harmful use of alcohol, and unhealthy diets.

[5] In 2014, NCDs represented the major share of the disease burden in Europe and were responsible for 86% of all deaths (European Commission, 2014).

[6] The growing burden of NCDs represents a major challenge for health systems: $70\% - 80\%$ of health care budgets are spent on NCDs in the European Union (European Commission, 2014).

Sandler, 1984; Cornes and Sandler, 1994). In case the nutrition policy decreases a country's GHG emissions, governments have two options to reduce their emissions: the nutrition policy (impure public good) and the climate mitigation policy (pure public good). In our game-theoretic model with emissions externalities, we characterize and study successively the partial cooperation over climate mitigation policy ("climate agreement") and full cooperation over climate mitigation and nutrition policies ("full agreement").

The paper is related to two different literature strands. First, our work adds to the stream of studies on transboundary pollution problems and international environmental cooperation with game-theoretic modeling (Barrett, 2003; Finus, 2008). In the case of the climate change problem, some studies have analyzed the gap, in terms of emissions and welfare between the non-cooperative solution and alternative cooperative solutions (partial and full cooperation) considering only mitigation strategies (Barrett, 2003), considering simultaneously mitigation and climate-friendly R&D strategies (Golombek and Hoel, 2011), or considering simultaneously mitigation and adaptation strategies (Zehaie, 2009**;** Ebert and Welsch, 2012; Breton and Sbragia, 2017). All these studies focus on the effects of climate policies on climate cooperation. However, to our knowledge, there are no published studies on the strategic link between nutrition and climate policies.

Second, this paper is related to the body of work on impure public goods (Cornes and Sandler, 1984; Cornes and Sandler, 1994). Impure public goods generate a joint private and public good. For example, in the case of consumption of environmentally-friendly (green) products, Kotchen (2005) and Kotchen (2006) consider an impure public good whose (private and public) characteristics are available separately in the form of a private good and a pure public good. Kotchen (2006) shows that the introduction of a green market (e.g. electric vehicles) can increase or decrease private provision of the environmental public good and can increase or decrease social welfare depending on the substitutability/complementarity between the private and public good. In contrast to Kotchen (2005) and Kotchen (2006) who focus on consumer choice, our model considers the decisions of individual countries as in the model of climate coalitions of Finus and Rübbelke (2013). Finus and Rübbelke (2013) consider a climate mitigation policy which is a public good and becomes an impure public good because it generates private ancillary benefits for the home country (e.g. reduced air pollution). Counterintuitively, these ancillary benefits do not help alleviating the free-rider incentives for climate mitigation. The rationale behind this result is that with ancillary benefits countries undertake more abatement in cooperation but also in the non-cooperative case. Thus, ancillary benefits provide not only an additional incentive to cooperate but also an additional incentive to leave the agreement. In our model, differently from Finus and Rübbelke (2013) we consider two separate policies, a climate mitigation policy (a pure public good) and a nutritional policy (impure public good). In this context, we investigate the effects of the architecture of climate agreements (climate versus full agreement) on the ambition of the national nutritional policies, by accounting for the countries' free-rider incentives at the international level.

Our paper contributes to the literature in several ways. We propose a novel theoretical framework highlighting the role of the architecture of climate treaties on countries' incentives to implement sustainable diets through nutritional policies. This game-theoretic framework allows us to investigate also the level of provision of the global public good which is climate mitigation. Finally, we run systematic numerical simulations to assess the welfare implications of alternative international climate architectures.

The paper is organized as follows. Section 2 presents the model framework; sections 3 and 4 describe different institutional arrangements and compare their results. Section 5 proposes some numerical simulations to evaluate their welfare consequences and section 6 concludes with a summary of the main results.

2 Model

We consider n countries indexed by $i = 1, 2, \ldots, n$. In each country, there are two sectors. The activity of sector 1 leads to GHG emissions $e_i \in [0, \bar{e}_i]$. Sector 1 could be thought as an aggregate of all polluting sectors of a country subject to climate regulations, including the industry, agriculture, energy and transport sectors. Each country i chooses its mitigation policy inducing a level of emissions $e_i < \bar{e}_i$ with $\bar{e}_i$ the maximal emissions assumed to be sufficiently large.

The GHG emissions in sector 2, $\widetilde{e_i}$ come from the nutrition policy of a country $f_i \in \left[0, \bar{f_i}\right]$

with $\bar{f}_i$ sufficiently large, leading to changes in diets. We consider that the nutrition policy is well chosen and implemented to increase the relative consumption of vegetal products (over animal products) and to improve national public health. For simplicity of presentation, here f_i represents both the nutrition policy and the implied changes in diets (or a healthier diet). We consider the following relationship:

$$\widetilde{e_i} = \alpha_i f_i, \text{ with } \alpha_i >< 0$$

The term $\widetilde{e_i} = \alpha_i f_i$ represents the additional (or reduced) emissions generated by country i from the dietary changes triggered by country i's nutrition policy f_i. Total GHG emissions emitted by country i can be written as:

$$e_i + \widetilde{e_i} = e_i + \alpha_i f_i$$

where $e_i > 0$ could be thought as *direct* emissions generated by country's aggregate polluting sector, and $\widetilde{e_i} >< 0$ as *indirect* net (of absorption) emissions generated by country's nutrition policy.

Country i's GHG emissions could be increased or decreased by the nutrition policy. We focus on two cases:

- Case 1: $\alpha_i < 0$
- Case 2: $\alpha_i > 0$

Case 1 (*resp.* Case 2) depicts the situation where the nutrition policy aimed at increasing relative consumption of vegetal products decreases (*resp.* increases) the GHG emissions generated by country i. In line with the discussion in the introduction and the related literature, we note that Case 1 is more likely than Case 2. That is, the transition from a meat-based to a plant-based diet usually decreases food-related GHG emissions by up to 70% (Aleksandrowicz et al., 2016, Springmann et al., 2016), thanks to the reduction in the consumption of dairy products which are relatively more carbon intensive. Although Case 2 is less likely, it can apply to some diet scenarios and some country contexts. In Vieux et al. (2012), meat reduction supplemented isocalorically by fruit and vegetables induces an increase in GHG emissions, since some fruits or vegetables generate higher GHG emissions per calorie than dairy and non-ruminant meats. In Irz et al. (2019), the recommendation of a 5% decrease in the consumption of animal products raises GHG emissions in France (but not Denmark or Finland) by 0.9% due to the higher carbon content of the substitute products. For completeness, we study both Cases 1 and 2 in detail. As the impact of a nutrition policy on emissions is additional to emissions from the aggregate polluting sector, we assume that $|\alpha_i f_i| < e_i$ which ensures that $(e_i + \alpha_i f_i) > 0$, i.e., the total emissions generated by country i are positive. The case $\alpha_i = 0$ corresponds to the standard model in the literature on international environmental agreements without emissions induced by the nutrition policy.

It is worth recalling that if the nutrition policy is beneficial for the environment ($\alpha_i < 0$), governments have at their disposal two climate mitigation channels: climate policy and nutrition policy.

Global GHG emissions $ET = \sum_{i=1}^{n} (e_i + \alpha_i f_i)$ induce damage for n countries. The payoff of country i is given by:

$$U_i(e_i, f_i) = V(e_i, f_i) - C(f_i) - D(ET) = [\gamma_i A(f_i) + B(e_i)] - C(f_i) - D\left(ET\right). \tag{1}$$

The payoff comprises the utility of the representative consumer $V(e_i, f_i)$ from the mitigation and nutrition policy, the costs of the nutritional policy for the consumer $C(f_i)$, and damage costs $D(ET)$ which depend on global emissions ET.

The consumer utility could be decomposed into two parts: $A(f_i)$ induced by the nutrition policy f_i, and $B(e_i)$ from (direct) emissions e_i (production or consumption equivalently). $A(f_i)$ includes the benefits from the consumption of products related to healthier diets and the associated health benefits. The larger the parameter $\gamma_i > 0$, the more the consumer prefers the nutritional policy. $C(f_i)$ represents the costs of the nutritional policy for the consumer, including changes in taste and increasing cooking time of meals due to changes in diets, or the payment of taxes if healthier diets are incentivized through taxes on animal products.[7]

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[7] Between 2009 and 2014, several countries motivated by nutritional objectives have introduced food taxes: Denmark with an excise tax on sugar-sweetened beverages (SSB) and juices with sugar content higher than 0.5g/100 ml, France with an excise tax on SSBs, Chile with an excise tax on SSBs with sugar content higher than 6.25g/100 ml, Mexico with an excise tax on nonalcoholic beverages with added sugar and taxes on calorie-dense unhealthy food, and Hungary with excise taxes targeting a wide range of beverage and food products with high fat, sugar, or salt content

As the paper is motivated by the EU context, we assume that countries have similar benefit and cost functions, similar relative nutrition policy preference $\gamma_i = \gamma_j = \gamma > 0$ and similar effects of nutrition policies on GHG emissions $\alpha_i = \alpha_j = \alpha$, with $\alpha < 0$ or $\alpha > 0$. We are aware that the EU countries do not have the same technology and preferences, but we believe that the heterogeneity among EU countries is less strong than that among the developed and developing economies. Our objective is to study the differential effects of considering nutrition policies which are beneficial for or harmful to the environment ($\alpha < 0$ or $\alpha > 0$), and of considering consumers biaised in favor of nutrition policies rather than climate policies ($\gamma > 0$).

Note that all functions including their first and second derivatives, are continuous in their variable(s). Also, we make the following assumptions regarding the components of the payoff functions where the subscripts denote derivatives, $A_f = \frac{\partial A}{\partial f}$ and $A_{ff} = \frac{\partial^2 A}{\partial f^2}$, and $D_E = \frac{\partial D}{\partial ET}$ and $D_{EE} = \frac{\partial^2 D}{\partial ET^2}$.

Assumptions

a) $B(0) = 0$, $B_e > 0$, $B_{ee} \leq 0$, $D(0) = 0$, $D_E > 0$, $D_{EE} > 0$.

b) $A(0) = 0$, $A_f > 0$, $A_{ff} \leq 0$, $C(0) = 0$, $C_f > 0$, $C_{ff} \geq 0$.

Assumptions $a)$ and $b)$ are the standard concave benefit and convex cost and damage function assumptions. Assumption $a)$ indicates that emissions are a pure public "bad" i.e. the marginal damage from emissions depends on the sum of all (and not individual) emissions levels. In contrast, assumption $b)$ indicates that the nutrition policy is a private good i.e. the marginal benefit depends on country's nutrition policy (and not to those of other countries). While the nutrition policy is a private good, it becomes an impure public good via its effect on global GHG emissions.

3 Non-cooperative and cooperative equilibria

We focus on two situations: a climate agreement with partial cooperation over climate mitigation policy (thus direct emissions e_i), and a full agreement with full cooperation over climate mitigation

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(Etilé, 2019, p. 4-5).

and nutrition policies (thus direct emissions e_i and indirect emissions $\widetilde{e_i}$ through f_i). In the full agreement, the regulator takes account not only of the negative externalities from direct emissions but also the externalities from indirect emissions due to nutrition policies. In order to characterize the free-rider incentives of the countries, we also study the non-cooperative solution represented by a Nash equilibrium below.

3.1 Non-cooperation

Here, we investigate the non-cooperative solution given by a Nash equilibrium denoted "N".

3.1.1 Nash equilibrium

Country i maximizes its payoff with respect to e_i and f_i taking the total emissions of the other countries $ET_{-i} = E_{-i} + \alpha F_{-i} = ET - (e_i + \alpha f_i)$ as given:

$$\max_{e_i, f_i} U_i(e_i, f_i) = \gamma A(f_i) + B(e_i) - C(f_i) - D\left((e_i + \alpha f_i) + E_{-i} + \alpha F_{-i}\right) \tag{2}$$

The first-order condition (FOC) with respect to e_i is:

$$\frac{\partial U_i}{\partial e_i} = 0 \Leftrightarrow B_e(e_i) - D_E(ET)\frac{\partial ET}{\partial e_i} = 0 \Leftrightarrow B_e(e_i) = D_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \tag{3}$$

From this FOC, it is clear that each country chooses the same emission level $e_i^N = e_j^N = e^N$.

The FOC with respect to f_i is:

$$\frac{\partial U_i}{\partial f_i} = 0 \Leftrightarrow \gamma A_f(f_i) - C_f(f_i) - D_E(ET)\frac{\partial ET}{\partial f_i} = 0 \Leftrightarrow \gamma A_f(f_i) - C_f(f_i) = \alpha D_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \tag{4}$$

This FOC implies that each country chooses the same nutrition policy, hence the same implied changes to diets $f_i^N = f_j^N = f^N$.

These conditions indicate that each country chooses the same levels of direct emissions and changes to diets at the equilibrium. Then the FOCs[8] can be written as follows:

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[8] For the second-order conditions, see appendix A.

$$\begin{aligned} B_e(e^N) &= D_E\left(n(e^N + \alpha f^N)\right) & (5) \\ \gamma A_f(f^N) - C_f(f^N) &= \alpha D_E\left(n(e^N + \alpha f^N)\right) & (6) \end{aligned}$$

The first condition shows that the marginal benefits from individual direct emissions are equal to the marginal damage costs from direct emissions to this country only, neglecting the internalization of externalities from direct emissions to other countries. The second condition indicates that the marginal net benefits from changes to diets are equal to the marginal damage costs from those changes. Again, as for direct emissions, negative externalities from indirect emissions to other countries are not accounted for in the non-cooperative situation.

3.1.2 Reaction functions

We next analyze the links between strategic variables, given that global GHG emissions are equal to $ET = (e_i + \alpha f_i) + E_{-i} + \alpha F_{-i}$.

Proposition 1 (Slopes of Reaction Functions for Emissions)**.** *The slope of the reaction function in*

(i). direct emissions space $e_i = g_i(ET_{-i})$ *is given by*

$$g_i^{'}(ET_{-i}) = \frac{de_i}{dET_{-i}} = \frac{(\gamma A_{ff} - C_{ff})D_{EE}}{Det(H^{NS})} < 0.$$

(ii). indirect emissions space $\widetilde{e_i} = k_i(ET_{-i})$ *are given by*

$$k_i^{'}(ET_{-i}) = \frac{d\widetilde{e_i}}{dET_{-i}} = \frac{\alpha^2 B_{ee} D_{EE}}{Det(H^{NS})} < 0.$$

Proof. See appendix B. □

The first statement highlights whether emission levels are strategic substitutes or complements. In this game, they are always substitutes if we exclude $D_{EE} = 0$ in which case the reaction functions are orthogonal corresponding to dominant strategies. In the case of convex damage functions, a country always reacts to a reduction of total emissions by other countries (ET_{-i}) by an increase in its direct emissions ("leakage" effect).

The second statement stresses that whatever the sign of parameter α, the country reacts to a reduction in total emissions by other countries (ET_{-i}) by increasing its indirect emissions through changes to diets. This can be viewed as an additional "leakage" effect, i.e. a leakage effect through the nutrition policy. The existence of this novel additional leakage effect renders the collective action problem more challenging, because countries' free-rider incentives are stronger than in the standard model without nutrition policy and related GHG emissions.

In order to explain the sign of the slope of the reactions functions, we can write the FOCs in the following way:

$$\begin{aligned} B_e(e^N) &= D_E\left(n(e^N + \alpha f^N)\right) \\ \gamma A_f(f^N) &= C_f(f^N) + \alpha D_E\left(n(e^N + \alpha f^N)\right) \end{aligned}$$

The ratio of these equations is written as: $\dfrac{B_e(e^N)}{\gamma A_f(f^N)} = \dfrac{D_E\left(n(e^N + \alpha f^N)\right)}{C_f(f^N) + \alpha D_E\left(n(e^N + \alpha f^N)\right)}$. This ratio can be interpreted as the equality of the marginal rate of substitution with the ratio of marginal costs. If the total emissions of other countries ET_{-i} decrease, the marginal damage D_E decreases, leading to the increase of the ratio of marginal costs. This increase in the ratio causes substitution effects between the consumption of good 1 which leads to direct emissions e_i and the consumption of good 2, i.e. the nutritional policy f_i: since good 1 is less costly, its consumption increases, inducing an increase in direct emissions e_i. This is the leakage effect from the climate policy: if the total emissions of other countries decrease, direct emissions of country i increases.

What is the effect of the reduction of total emissions by other countries on nutrition policy? This effect depends on the sign of α, but the emissions associated with the nutritional policy are unambiguous: the indirect emissions $\widetilde{e_i}$ increase regardless of the sign of α. On the one hand, if α is positive, the marginal benefit of the nutritional policy $\gamma A_f(f^N)$ is higher than $C_f(f^N)$ because the term αD_E is positive. In this case, the nutritional policy behaves like the standard good 1: it increases when the ratio of the marginal costs increases (its relative cost decreases). In turn, the indirect emissions $\widetilde{e_i}$ increase. On the other hand, if α is negative, the marginal benefit of the nutritional policy $\gamma A_f(f^N)$ is lower than $C_f(f^N)$ because the term αD_E is now negative. In this case, the nutritional policy decreases but the indirect emissions increase. This is the leakage effect from the nutrition policy: if the total emissions of other countries decrease, indirect emissions of country i increases.

Proposition 2 (Effect of Parameter γ on the Slopes of the Reaction Functions). *The effect of parameter γ on the slopes of the reaction functions can be summarized as follows:*

(i). The larger the consumer's preference for nutrition policies rather than climate policies, the larger is the leakage effect from the climate policy.

(ii). The larger the consumer's preference for nutrition policies rather than climate policies, the lower is the leakage effect from the nutrition policy.

Proof. See appendix C. □

This proposition highlights the effect of consumer's preference for a nutrition policy rather than a climate policy on the free-rider incentives to reduce the GHG emissions either directly or indirectly. The first statement shows that if consumer puts more weight on nutrition policies (larger γ), the leakage effect from the climate policy (direct emissions) is stronger: when other countries make efforts to reduce their emissions, country i has less incentives to increase its mitigation level through the climate policy.

In contrast, the second statement shows that if consumer puts more weight on nutrition policies (larger γ), the leakage effect from the nutrition policy (indirect emissions) is lower: when other countries make efforts to reduce their emissions, country i has less incentives to decrease its mitigation level through a nutrition policy. Thus, the consumer bias in relation to policies leads to two constrasting effects on free-rider incentives.

We obtain these results because parameter γ appears in the denominator of the ratio $\dfrac{B_e(e^N)}{\gamma A_f(f^N)}$. Thus, an increase in γ decreases the marginal rate of substitution enhancing the nutritional policy. From the explanations of Proposition 1, we know that a reduction of total emissions by other countries ET_{-i} decrease the marginal damage D_E, leading to the increase of the ratio of marginal costs. A larger consumer preference for nutrition policies therefore amplifies the effect of an increase in the marginal cost ratio on good 1 (with related emissions e_i) and dampens the effect on nutrition policy (with related emissions $\tilde{e_i}$).

3.2 Full agreement

We next investigate the full cooperative solution or the full agreement, denoted "C".

The social planner maximizes the total payoff of the n countries with respect to e_i and f_i for all i:

$$\max_{e_1,\ldots,e_n,f_1,\ldots,f_n} W = \sum_{i=1}^{n} U_i(e_i, f_i) = \sum_{i=1}^{n} [\gamma A(f_i) + B(e_i) - C(f_i)] - nD\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \quad (7)$$

The FOC condition with respect to e_i is written as $B_e(e_i) = nD_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \ \forall i.$

The FOC condition with respect to f_i is written as $\gamma A_f(f_i) - C_f(f_i) = \alpha n D_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \ \forall i.$

These conditions indicate that the social planner chooses the same direct emissions levels and dietary changes for all countries. Then the FOCs[9] can be written as follows:

$$B_e(e^C) = nD_E(n(e^C + \alpha f^C)) \quad (8)$$

$$\gamma A_f(f^C) - C_f(f^C) = \alpha n D_E(n(e^C + \alpha f^C)) \quad (9)$$

The first condition shows that the marginal benefits from individual direct emissions are equal to the sum of the marginal damage costs of the direct emissions for all countries. Here, the social planner takes into account the negative externalities from the direct emissions across countries.

The second condition indicates that the marginal net benefits from the changes to diets are equal to the sum of the marginal damage costs of the changes to diets. Here, the social planner takes into account the negative or positive externalities of the emissions associated with the dietary changes.

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[9] For the second-order conditions, see appendix A.

3.3 Climate agreement

Last, we investigate the climate agreement solution denoted "P". Here, countries cooperate only on climate mitigation policies (thus on direct emissions). Each country continues to choose its nutrition policy unilaterally and non-cooperatively.

The climate agreement program can be written as:

$$\max_{e_1,\ldots,e_n} \sum_{i=1}^{n} U_i(e_i, f_i) = \sum_{i=1}^{n} [\gamma A(f_i) + B(e_i) - C(f_i)] - nD\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right). \tag{10}$$

The n FOCs give that

$$B_e(e_i) = nD_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \;\forall i. \tag{11}$$

The level of the dietary changes is given by FOCs similar to (4), that is,

$$\gamma A_f(f_i) - C_f(f_i) = \alpha D_E\left(\sum_{i=1}^{n}(e_i + \alpha f_i)\right) \;\forall i. \tag{12}$$

From the FOCs[10] (11) and (12) we obtain that $e_i = e_j = e^P$ and $f_i = f_j = f^P$, and obtain the following climate agreement solution:

$$B_e(e^P) = nD_E\left(n(e^P + \alpha f^P)\right) \tag{13}$$

$$\gamma A_f(f^P) - C_f(f^P) = \alpha D_E\left(n(e^P + \alpha f^P)\right) \tag{14}$$

The first condition shows that the marginal benefits from individual direct emissions are equal to the sum of the marginal damage costs of the direct emissions for all countries. Here, the social planner takes into account the negative externalities from the direct emissions across countries.

The second condition indicates that the marginal net benefits from the changes to diets are equal to the marginal damage costs of the changes to diets to this country only. Here, the social planner fails to take into account the negative or positive externalities of the emissions associated with the dietary changes.

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[10] For the second-order conditions, see appendix A.

4 Comparison of policy variables

The objective in this section is to compare the equilibrium levels for direct emissions, changes to diets, and total emissions between different non-cooperative and cooperative institutional arrangements (climate and full agreement).

Proposition 3 (Comparison of Policy Variables)**.** *If national nutrition policies induce similar effects on GHG emissions in all countries ($\alpha_i = \alpha_j = \alpha \lesseqgtr 0$), comparing the outcomes of the Nash equilibrium (N), the climate agreement (P), and the full cooperative solution (C) gives the following results:*

(i). direct emissions generated by each country: $e^P < e^C < e^N \quad \forall\alpha$

(ii). changes in diet in each country, and the related indirect emissions generated by each country:

$$\left.\begin{array}{ll} f^C \geq f^N > f^P & \textit{when } \alpha < 0 \\ f^C \leq f^N < f^P & \textit{when } \alpha > 0 \end{array}\right\} \quad \Leftrightarrow \quad \tilde{e}^C < \tilde{e}^N < \tilde{e}^P \quad \forall\alpha$$

(iii). total level of emissions: $ET^C < ET^P < ET^N \quad \forall\alpha,$

Proof. See appendix E. □

Proposition 3 has interesting implications. Regarding (individual) direct emissions e, the climate agreement always leads to lower levels than the full cooperative solution or the Nash equilibrium regardless of the sign of the parameter α. The climate agreement outperforms the other arrangements in this respect because direct emissions are the unique variable chosen cooperatively in the climate agreement, hence countries make significant efforts to ambition their climate mitigation policy.

Regarding (individual) indirect emissions $\tilde{e}$, their level is lowest for the full cooperative solution, followed by the Nash equilibrium and the climate agreement regardless of the sign of the parameter α. This ranking is related to the level of ambition of the nutritional policy chosen in alternative institutional arrangements that we we discuss below.

In the case of global emissions ET, they are lower under the full agreement followed by the climate agreement and the Nash equilibrium regardless of the sign of the parameter α. The full agreement correctly internalizes global externalities from both the direct and indirect emissions associated to the nutrition policy. The nutrition policy is chosen optimally in a cooperative manner, in contrast to the other two institutional arrangements. In the climate agreement, the large savings on direct emissions countervail the bad performance in terms of indirect emissions, comparatively to the Nash equilibrium.

The strength of these results relies on the fact that they are independent from a) the sign of the parameter α, i.e., whether the nutrition policy decreases or increases the GHG emissions generated by a country, b) the level of the parameter γ, the extent of consumers' preference for nutrition policy, and c) the benefit and cost functions from climate mitigation policy B and D, and d), and the benefit and cost functions from nutrition policy A and C.

As the main objective of the paper, we now discuss the results on the comparison of the levels of nutritional policy in alternative international climate architectures. These comparisons sensibly depend on the sign of the parameter α. Let us focus on the most interesting and realistic case with $\alpha < 0$. In this case, our theoretical findings show that the nutrition policy is more ambitious in the full agreement followed by the Nash equilibrium and the climate agreement. Interestingly, we show that the climate agreement provides less impetus to countries to implement ambitious nutrition policies compared to the non-cooperative solution. In both climate agreement and non-cooperative case, countries choose the nutrition policy non-cooperatively without internalizing the positive externalities from reduced (indirect) emissions. In the climate agreement, cooperation focuses on the climate change mitigation policy, which leads countries to provide significant mitigation efforts to the detriment of nutrition policy.

These findings lead to two key messages. First, in terms of the ambition of nutrition policy, countries with objectives of nutritional quality and climate mitigation are worse off in a climate agreement than at non-cooperation when dietary changes decrease a country's emissions ($\alpha < 0$). Second, countries with objectives of nutritional quality and climate mitigation should seek to cooperate via full agreements including both nutrition and environmental objectives to attain higher nutrition policies and to reduce overall GHG emissions. The full agreements allow them to improve their nutrition-related health and to reduce environmental damages from global climate change.

5 Welfare analysis

To analyze countries' welfare and understand their preference for one or other of the institutional arrangements, we perform systematic numerical simulations for the quadratic benefit and cost functions.

5.1 Quadratic functions

We adopt the following quadratic functional forms:

$B(e_i) = b_1 e_i - \frac{b_2}{2} e_i^2$ with $b_1 > 0$ and $b_2 > 0$.

$D(ET) = \frac{d}{2} ET^2$ with $d > 0$.

$A(f_i) = (a_1 f_i - \frac{a_2}{2} f_i^2)$ with $a_1 > 0$ and $a_2 > 0$.
$C(f_i) = \frac{c}{2} f_i^2$ with $c > 0$.

The payoff function can be written as:
$U_i = \gamma \left(a_1 f_i - \frac{a_2}{2} f_i^2 \right) + \left(b_1 e_i - \frac{b_2}{2} e_i^2 \right) - \frac{c}{2} f_i^2 - \frac{d}{2} ET^2$.

These functional forms should respect the model assumptions:

- $|\alpha_i f_i| < e_i$. When $\alpha > 0$, this condition is equal to $(e_i - \alpha_i f_i) > 0$. When $\alpha < 0$, this condition is equal to $(e_i + \alpha_i f_i) > 0$.

- $D_E = d(ET) > 0$ and $D_{EE} = d > 0$.

- $A_f = a_1 - a_2 f_i > 0$ and $A_{ff} = -a_2 < 0$.

- $C_f = cf_i > 0$ and $C_{ff} = c > 0$.

- $B_e = b_1 - b_2 e_i > 0$ and $B_{ee} = -b_2 < 0$.

Appendix F provides the analytical forms for the equilibrium values of the variables in the quadratic model, for all institutional arrangements.

Below, we conduct systematic numerical simulations to assess the welfare implications for countries of the architecture of climate treaties.

5.2 Main simulations

We first consider the parameter constellations[11] $b_1, b_2, a_1, a_2, c, d, \alpha, \gamma$ and n which constitute our total parameter set. We call this set 1 which consists of $267,300$ different combinations. We also consider a subset of set 1 with parameter constellations which satisfy the constraints of the model. We call this set 2; it consists of $20,045$ elements if $\alpha < 0$, and 1878 elements if $\alpha > 0$. For *each simulation run*, we compare the results for the welfare levels achieved in the alternative institutional arrangements.

For the parameter constellations pertaining to $\alpha > 0$, the ranking of institutional arrangements in terms of welfare is as follows $W^N < W^P < W^C$: in these cases, full cooperation is the best arrangement followed by the climate agreement and non-cooperation. If $\alpha < 0$, then as expected, full cooperation is always the best arrangement. In a minority of 59 (out of $20,045$ valid cases) cases (0.3% of valid cases) countries are better off with non-cooperation than the climate agreement which imposes a too low level of direct emissions to the countries (proposition 3). Countries are better off with non-cooperation than with a climate agreement if $\alpha < 0$ but is sufficiently large in absolute value . In these cases, the emissions savings induced by changes in diets are sufficiently large that it becomes penalizing not to use the nutrition policy in climate negotiations. To confirm this intutition, we increase the value of parameter $\alpha < 0$ in absolute value: α moves now from -20 to -1 by 1, instead of from -5 to -1 by 1, keeping the other parameter constellations unchanged.

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[11] Parameters a_1 and b_1 move from 10 to 30 by 10; a_2 moves from 1 to 2 by 1; b_2 moves from 5 to 10 by 1; c moves from 1 to 5 by 1; d moves from 0.01 to 0.09 by 0.01; α moves from -5 to 5 by 1; γ moves from 0.1 to 0.5 by 0.1; n is equal to 10.

In line with our intuition, we find more cases (3% of valid cases) where countries are better off with non-cooperation than the climate agreement.

5.3 Consumer preferences for nutrition policies

Before simulating the effects of consumer's preference for nutrition policies (parameter γ) on welfare, the quadratic model allows us the study its impact on the equilibrium values of the variables. We undertake this analysis for the Nash equilibrium.

Proposition 4 (Effect of Parameter γ on Variables at the Nash Equilibrium). *The effect of parameter γ on the variables at the Nash equilibrium can be summarized as follows:*

(i). The larger the consumer's preference for nutrition policies rather than climate policies, the larger is the ambition of nutrition policies: $\frac{df^N}{d\gamma} > 0 \quad \forall \alpha$.

(ii). The impact of the consumer's preference for nutrition policies on direct emissions depends on the sign of parameter α:

$$\begin{aligned} \tfrac{de^N}{d\gamma} &> 0 \qquad \textit{when } \alpha < 0 \\ \tfrac{de^N}{d\gamma} &< 0 \qquad \textit{when } \alpha > 0 \end{aligned}$$

(iii). The impact of the consumer's preference for nutrition policies on total level of emissions depends on the sign of parameter α:

$$\begin{aligned} \tfrac{dET^N}{d\gamma} &< 0 \qquad \textit{when } \alpha < 0 \\ \tfrac{dET^N}{d\gamma} &> 0 \qquad \textit{when } \alpha > 0 \end{aligned}$$

Proof. See appendix F.1.1. □

Proposition 4 for the Nash equilibrium has interesting implications. First, as expected, an increase in consumer's bias for nutrition policies induces countries to implement more ambitious nutrition policies. Depending on the sign of parameter α, indirect emissions $\tilde{e}$ could go up or down. As it is clear from the form of reactions functions in the quadratic case (see equations F6 in Appendix F.1), for a country, direct and indirect emissions are strategic substitutes. Thus, when $\alpha < 0$ (*resp.* $\alpha > 0$) indirect emissions decrease with γ, but direct emissions e increase (*resp.* decrease). In the case of global emissions ET, the variation of indirect emissions outweighs the variation of direct emissions. Consequently, when $\alpha < 0$ (*resp.* $\alpha > 0$) total emissions decrease with γ (*resp.* increase).

Parameter γ only modifies the first order condition which concerns the nutritional policy. If we consider this condition, we note that an increase in in the parameter γ augments, *ceteris paribus*, the marginal benefit of this policy, which in turn, increases the ambition of nutrition policy chosen by a country no matter the sign of α.

Concerning the impact of the increase of γ on direct emissions e, two cases are to be considered according to the sign of α. To see this, let us consider the ratio $\dfrac{B_e(e^N)}{\gamma A_f(f^N) - C_f(f^N)}$ which is constant and equal to $\dfrac{1}{\alpha}$. As mentioned before, the increase in γ leads to a more ambitous nutrition policy. Thus, if α is positive indirect emissions from the nutritional policy $\tilde{e}$ increase. This increase leads to a reduction in direct emissions e (see the ratio above). This can be explained in the following way. If α is positive the two goods (good 1 and nutritional policy) behave in a usual way: at a “constant” price ratio, a modification of the marginal rate of substitution causes substitution effects: since the nutritional policy increases, the consumption of good 1 decreases. We have the reverse result if α is negative.

Concerning the impact of the parameter γ on total emissions, there are two conflicting effects: when α is negative, indirect emissions decrease with the parameter γ but direct emissions increase. Overall, we find that the total emissions decrease when α is negative, and they increase when α is positive. To sum, when the nutrition policy decreases the GHG emissions generated by a country ($\alpha < 0$), which is more likely than the reverse case as discussed in the paper, a larger consumer preference for nutrition policy is good for the environmental quality: global GHG emissions drop.

We now turn to the welfare anaysis and run different simulations for two different values of parameter γ, 0.3 and 0.5, keeping the other parameter constellations unchanged across the two runs. We consider both cases with $\alpha < 0$ and $\alpha > 0$. The findings highlighted in Table 1 show

Table 1: Consumer's preference for nutrition policies and average welfare

	$\gamma = 0.3$ $\alpha > 0$	$\gamma = 0.5$ $\alpha > 0$
Nash equilibrium	21 457	14 102
Full agreement	35 604	51 540
Partial agreement	22 711	15 283
Welfare gap Full agreement and Nash equilibrium	14 147	37 438
	$\gamma = 0.3$ $\alpha < 0$	$\gamma = 0.5$ $\alpha < 0$
Nash equilibrium	2708	2052
Full agreement	4494	7500
Partial agreement	2867	2224
Welfare gap Full agreement and Nash equilibrium	1786	5448

that on average across the parameter constellations, when γ increases, the welfare gap between non-cooperation and the full agreement increases. For instance, when $\alpha < 0$, if $\gamma = 0.3$ (resp. $\gamma = 0.5$), average total welfare from non-cooperation is equal to 2708 (resp. 2052), and average total welfare from the full agreement agreement is equal to 4494 (resp. 7500). Thus, if consumer preference for a nutrition policy is stronger, this increases the need for full cooperation.

6 Conclusion

The Farm to Fork Strategy which is at the heart of the European Union Green Deal aims to promote sustainable food systems and diets to reach EU climate-neutrality by 2050. In order to align with the objectives of the Paris Agreement, the EU countries have agreed in 2020 to increase the ambition of their climate policies by committing to cut EU carbon emissions by at least 55% by 2030, compared with 1990 levels. This paper investigated whether the EU policies on sustainable food diets and on climate change mitigation are compatible in the context of international externalities from greenhouse gas (GHG) emissions. We asked the following questions. Does a climate agreement with mitigation targets (climate agreement) provides the right incentives to EU countries to implement sustainable diets through nutritional policies? Should EU countries seek agreements on both mitigation and nutrition targets (full agreement)?

To address these questions, we developed a game-theoretic model to analyze theoretically the impact of the architecture of international climate agreements on the ambition of nutritional policies chosen by countries. In the model, each country implements a nutrition and climate policy. A nutrition policy can take the form of a standard or a tax aimed at reducing consumption of animal products (such as red meat) or equivalently at increasing relative consumption of vegetal products (over animal products). In the model, changes to diets induced by a nutrition policy lead to health benefits at the national level. However, they can also increase or decrease the GHG emissions of the country implementing these changes. Since GHG emissions are a public "bad", additional or reduced emissions induce negative or positive externalities for other countries. Thus, a dietary change which is a private good can become an impure public good. We compared different international climate architectures including the non-cooperative situation represented by a Nash equilibrium, a climate agreement (agreement on climate policy), and a full agreement (agreement on both climate and nutrition policies).

We obtained several interesting theoretical results. First, in addition to leakage resulting from countries' direct emission strategies, our model highlights an additional leakage channel via nutrition policy. For instance, if the nutrition policy benefits the environment ($\alpha < 0$), the country will react to the reduced total emissions from other countries by reducing its nutrition policy through changes in diet, inducing a lower effort to reduce indirect emissions. Thus, free-rider incentives arise through two channels: direct emissions and indirect emissions via the nutrition policy which reinforces the free-rider problem in the case of public good provision.

In terms of total emissions, our theoretical results show that it is always better to cooperate over both climate mitigation and nutrition policies, whatever dietary changes increase or decrease a country's emissions. The latter property plays however a crucial role on the ambition of nutritional policies chosen by countries within alternative climate agreements. In the most interesting and realistic case with $\alpha < 0$, i.e. when healthier diets decrease a country's emissions, our theoretical findings show that the nutrition policy is more ambitious in the full agreement followed by the Nash equilibrium and the climate agreement. In this case, interestingly, we show that the climate agreement provides less impetus to countries to implement ambitous nutrition policies compared to the non-cooperative solution.

These findings lead to two key messages. First, in terms of the ambition of nutrition policy, when healthier diets decrease a country's emissions ($\alpha < 0$), countries with objectives of nutritional quality and climate mitigation are worse off in a climate agreement than at non-cooperation. As shown in numerical simulations, this also holds for the welfare of countries for some parameter's constellations, especially when the nutrition policy is very powerful for reducing indirect emissions. In this case, the climate agreement prevents the countries to benefit from large health benefits channeled via the nutrition policy. The second message is that countries should seek to cooperate via full agreements including both nutrition and climate mitigation objectives to attain higher nutrition policies, to reduce overall GHG emissions, and improve their welfare. The full agreements allow them to improve their nutrition-related health and to reduce environmental damages from global climate change.

The results obtained in this novel theoretical framework, highlighting strategic links between countries' climate mitigation and nutrition policies, present a rationale for the implementation of the recent European Union New Green Deal and its Farm to Fork Strategy[12] for a fair, healthy, and environmentally-friendly food system. The Farm to Fork Strategy foresees European-wide initiatives which align all European diets to nutrition recommendations and to European Union commitments to biodiversity conservation and climate mitigation. Some of these initiatives include minimum mandatory criteria for sustainable food procurement by 2021, mandatory front-of-pack nutrition labeling by 2022[13], and a sustainable food labeling framework by 2024. Our results are also in line with the recommendations of IPES Food (International Panel of Experts on Sustainble Food Systems) which pushes for a Common Food Policy for the European Union to ensure food and environmental sustainability. As underlined in this report[14], and shown analytically in our model, a common food and climate policy for the EU would allow both a horizontal (across climate and nutrition policy areas) and vertical (across countries) integration by exploiting spillovers and controlling trade-offs between countries' policies, leading to the reduction of costly economic

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[12] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0381&from=EN

[13] Nutrition labelling such as Nutri-Score implemented in France in 2017, and adopted by other countries such Belgium, Spain, Germany, the Netherlands, Switzerland, and Luxembourg is on voluntary basis. Currently, 400 food manufacturers are involved in this label.

[14] http://www.ipes-food.org/_img/upload/files/CFP_FullReport.pdf

inefficiencies in EU policy-making. These results applying mainly to the case of the European Union have also implications for other jurisdictions with multiple food governance structures. For instance, in the United States, at the absence of a single federal food agency, 20 different federal departments shape food policies.[15] The absence of a harmonized national food policy for Canada is also underlined as the root cause of missing horizontal (across sectors) and vertical (between the federal government and the provinces) food policy coherence and coordination (Berger and Lambek, 2018).

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[15] https://foodprint.org/issues/food-policy-101/

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Appendixes

A Second-order conditions

At the Nash equilibrium, the Hessian matrix of the second derivatives of the payoff function is given by:

$$H^{NS} = \begin{pmatrix} \frac{\partial^2 U_i}{\partial e_i^2} & \frac{\partial^2 U_i}{\partial e_i \partial f_i} \\ \frac{\partial^2 U_i}{\partial f_i \partial e_i} & \frac{\partial^2 U_i}{\partial f_i^2} \end{pmatrix} = \begin{pmatrix} B_{ee} - D_{EE} & -\alpha D_{EE} \\ -\alpha D_{EE} & \gamma A_{ff} - C_{ff} - \alpha^2 D_{EE} \end{pmatrix} \tag{A1}$$

The first determinant of H^{NS}, $D_1 = B_{ee} - D_{EE}$, is negative by assumption $a)$ and the second $D_2 = Det(H^{NS}) = B_{ee}\,(\gamma A_{ff} - C_{ff} - \alpha^2 D_{EE}) - D_{EE}(\gamma A_{ff} - C_{ff})$ is positive by assumptions $a)$ and $b)$. Thus H^{NS} is defined as positive and U_i is strictly concave. Then there is a unique solution to the optimization program (2), (e^N, f^N) defined by equations 5 and 6.

At the full agreement, the Hessian matrix of the second derivatives of the welfare function, H^{OS}, is a symmetric matrix of size $2n$ with $\frac{\partial^2 W}{\partial e_i^2} = B_{ee} - nD_{EE}$, $\frac{\partial^2 W}{\partial e_i \partial e_j} = -nD_{EE}$, $\frac{\partial^2 W}{\partial e_i \partial f_j} = n\alpha D_{EE}$, $\frac{\partial^2 W}{\partial f_i^2} = \gamma A_{ff} - C_{ff} - n\alpha^2 D_{EE}$, and $\frac{\partial^2 W}{\partial f_i \partial f_j} = -n\alpha^2 D_{EE} \quad \forall i,\, j$. Assumptions $a)$ and $b)$, ensure that all the eigenvalues of the matrix H^{OS} are negative; therefore, the welfare function is quasi-concave. As a result, there is a unique solution to the optimization program (7), (e^C, f^C) defined by equations 8 and 9.

At the climate agreement, the Hessian matrix of the second derivatives of the welfare function is given by H^{CS}, a symmetric matrix of size n with $\frac{\partial^2 W}{\partial e_i^2} = B_{ee} - nD_{EE}$, $\frac{\partial^2 W}{\partial e_i \partial e_j} = -nD_{EE} \quad \forall i,\, j$. Assumptions $a)$ and $b)$ ensure that all the eigenvalues of the matrix H^{CS} are negative; therefore, the welfare function is quasi-concave. As a result, there is a unique solution to the optimization program (10), (e^P, f^P) defined by equations 13 and 14.

B Proof of Proposition 1

Here, we investigate the reaction functions at the Nash equilibrium.

The total differential of Equation (3) is:

$$(B_{ee} - D_{EE})de_i - \alpha D_{EE} df_i = D_{EE} dET_{-i} \tag{B2}$$

The total differential of Equation (4) is:

$$-\alpha D_{EE} de_i + (\gamma A_{ff} - C_{ff} - \alpha^2 D_{EE})df_i = \alpha D_{EE} dET_{-i} \tag{B3}$$

Equations (B2) and (B3) can be written in matrix form:

$$\begin{pmatrix} B_{ee} - D_{EE} & -\alpha D_{EE} \\ -\alpha D_{EE} & \gamma A_{ff} - C_{ff} - \alpha^2 D_{EE} \end{pmatrix} \times \begin{pmatrix} de_i \\ df_i \end{pmatrix} = \begin{pmatrix} D_{EE} \\ \alpha D_{EE} \end{pmatrix} dET_{-i} \tag{B4}$$

$$\Leftrightarrow \begin{pmatrix} de_i \\ df_i \end{pmatrix} = \frac{1}{Det(H^{NS})} \begin{pmatrix} \gamma A_{ff} - C_{ff} - \alpha^2 D_{EE} & \alpha D_{EE} \\ \alpha D_{EE} & B_{ee} - D_{EE} \end{pmatrix} \times \begin{pmatrix} D_{EE} dET_{-i} \\ \alpha D_{EE} dET_{-i} \end{pmatrix} \tag{B5}$$

(i). Equation (B5) leads to $\frac{de_i}{dET_{-i}} = \frac{(\gamma A_{ff} - C_{ff})D_{EE}}{Det(H^{NS})} < 0$, since $A_{ff} < 0$, $D_{EE} > 0$, and $Det(H^{NS}) > 0$.

(ii). Equation (B5) leads to $\frac{df_i}{dET_{-i}} = \frac{\alpha B_{ee} D_{EE}}{Det(H^{NS})}$ leading to $\frac{d\widetilde{e_i}}{dET_{-i}} = \frac{\alpha^2 B_{ee} D_{EE}}{Det(H^{NS})}$, since $\widetilde{e_i} = \alpha f_i$, and $B_{ee} < 0$, $D_{EE} > 0$, and $Det(H^{NS}) > 0$.

C Proof of Proposition 2

Here, we investigate how parameter γ affects the slopes of reaction functions at the Nash equilibrium.

The effect of parameter γ on the slope of the reaction function of direct emissions is given by:

$$\frac{d\left(\frac{de_i}{dET_{-i}}\right)}{d\gamma} = \frac{-\alpha^2 A_{ff} D_{EE}^2 B_{ee}}{\left(Det(H^{NS})\right)^2} < 0$$

since $A_{ff} < 0$ and $B_{ee} < 0$. Thus, when consumers put more weight on nutrition policies (larger γ), the negative slope (from proposition 1, we have $\frac{de_i}{dET_{-i}} < 0$), becomes larger in absolute value, indicating a stronger direct leakage effect.

The effect of parameter γ on the slope of the reaction function of indirect emissions is given by

$$\frac{d\left(\frac{d\widetilde{e_i}}{dET_{-i}}\right)}{d\gamma} = \frac{-\alpha^2 B_{ee} D_{EE} A_{ff}(B_{ee} - D_{EE})}{\left(Det(H^{NS})\right)^2} > 0$$

since $B_{ee} < 0$, $D_{EE} > 0$, and $A_{ff} < 0$. Thus, when consumers put more weight on nutrition policies (larger γ), the slope (from proposition 1, the sign of $\frac{d\widetilde{e_i}}{dET_{-i}} < 0$), becomes lower in absolute value, indicating a smaller indirect leakage effect.

D Table of results

Equilibria	With emissions from nutrition policy
No agreement	$B_e(e^N) = D_E\left(n(e^N + \alpha f^N)\right)$ $\gamma A_f(f^N) - C_f(f^N) = \alpha D_E\left(n(e^N + \alpha f^N)\right)$
Climate agreement	$B_e(e^P) = nD_E\left(n(e^P + \alpha f^P)\right)$ $\gamma A_f(f^P) - C_f(f^P) = \alpha D_E\left(n(e^P + \alpha f^P)\right)$
Full cooperative	$B_e(e^C) = nD_E(n(e^C + \alpha f^C))$ $\gamma A_f(f^C) - C_f(f^C) = \alpha n D_E(n(e^C + \alpha f^C))$

E Proof of Proposition 3

We will use the method of proof by contradiction to compare the levels of the variables between the full agreement and the non-cooperative solution.

- Suppose that $\alpha > 0$ and $e^N \leq e^C$, this implies that

$$\begin{aligned}
B_e(e^N) \;&\geq\; B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow\; D_E(n(e^N + \alpha f^N)) \geq nD_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (5)} \\
&\Rightarrow\; \alpha D_E(n(e^N + \alpha f^N)) \geq \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow\; G_f(f^N) \geq G_f(f^C) \quad \text{from Eq. (9) and (6) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow\; f^N \leq f^C \;\text{ since } G_{ff}(f) = \gamma A_{ff}(f) - C_{ff}(f) < 0 \\
&\Rightarrow\; n(e^N + \alpha f^N) \leq n(e^C + \alpha f^C) \\
&\Rightarrow\; D_E(n(e^N + \alpha f^N)) \leq nD_E(n(e^C + \alpha f^C)) \text{ which is a contradiction, thus we have } e^N > e^C.
\end{aligned}$$

$$\begin{aligned}
e^N &> e^C \text{ implies } B_e(e^N) < B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) < nD_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (5)} \\
&\Rightarrow \alpha D_E(n(e^N + \alpha f^N)) < \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow G_f(f^N) < G_f(f^C) \quad \text{from Eq. (9) and (6) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow f^N > f^C \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^N + \alpha f^N) > n(e^C + \alpha f^C) \Rightarrow ET^N > ET^C
\end{aligned}$$

- Suppose that $\alpha < 0$ and $e^N \leq e^C$, this implies that

$$\begin{aligned}
B_e(e^N) &\geq B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) \geq nD_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (5)} \\
&\Rightarrow \alpha D_E(n(e^N + \alpha f^N)) \leq \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow G_f(f^N) \leq G_f(f^C) \quad \text{from Eq. (9) and (6) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow f^N \geq f^C \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^N + \alpha f^N) \leq n(e^C + \alpha f^C) \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) \leq D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) \leq nD_E(n(e^C + \alpha f^C)) \text{ which is a contradiction, thus we have } e^N > e^C.
\end{aligned}$$

$$\begin{aligned}
e^N &> e^C \text{ implies } B_e(e^N) < B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) < nD_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (5)} \\
&\Rightarrow \alpha D_E(n(e^N + \alpha f^N)) > \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow G_f(f^N) > G_f(f^C) \quad \text{from Eq. (9) and (6) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow f^N < f^C \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^N + \alpha f^N) > n(e^C + \alpha f^C) \Rightarrow ET^N > ET^C
\end{aligned}$$

We will now use the method of proof by contradiction to compare the levels of the variables between the full agreement and the climate agreement.

- Suppose that $\alpha > 0$ and $e^P \geq e^C$, this implies that

$$\begin{aligned}
B_e(e^P) &\leq B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \leq D_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (13)} \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \leq nD_E(n(e^C + \alpha f^C)) \\
&\Rightarrow \alpha D_E(n(e^P + \alpha f^P)) \leq \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow G_f(f^P) \leq G_f(f^C) \quad \text{from Eq. (9) and (14) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow f^P \geq f^C \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^P + \alpha f^P) \geq n(e^C + \alpha f^C) \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \geq nD_E(n(e^C + \alpha f^C)) \text{ which is a contradiction, thus we have } e^P < e^C.
\end{aligned}$$

$$\begin{aligned}
e^P &< e^C \text{ implies } B_e(e^P) > B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) > D_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (13)} \\
&\Rightarrow n(e^P + \alpha f^P) > n(e^C + \alpha f^C) \\
&\Rightarrow ET^P > ET^C \\
&\Rightarrow f^P > f^C
\end{aligned}$$

- Suppose that $\alpha < 0$ and $e^P \geq e^C$, this implies that

$$\begin{aligned}
B_e(e^P) &\leq B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \leq D_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (13)} \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \leq n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow \alpha D_E(n(e^P + \alpha f^P)) \geq \alpha n D_E(n(e^C + \alpha f^C)) \\
&\Rightarrow G_f(f^P) \geq G_f(f^C) \quad \text{from Eq. (9) and (14) with } G(f) = \gamma A(f) - C(f) \\
&\Rightarrow f^P \leq f^C \ \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^P + \alpha f^P) \geq n(e^C + \alpha f^C) \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) \geq n D_E(n(e^C + \alpha f^C)) \text{ which is a contradiction, thus we have } e^P < e^C.
\end{aligned}$$

$$\begin{aligned}
e^P &< e^C \text{ implies } B_e(e^P) > B_e(e^C) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^P + \alpha f^P)) > D_E(n(e^C + \alpha f^C)) \quad \text{from Eq. (8) and (13)} \\
&\Rightarrow n(e^P + \alpha f^P) > n(e^C + \alpha f^C) \Rightarrow ET^P > ET^C \\
&\Rightarrow f^P < f^C
\end{aligned}$$

We will now use the method of proof by contradiction to compare the levels of the variables between the climate agreement and the non-cooperative solution.

- Suppose that $\alpha > 0$ and $e^N \leq e^P$, this implies that

$$
\begin{aligned}
B_e(e^N) &\geq B_e(e^P) \quad \text{since } B_{ee} \leq 0 \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) \geq nD_E(n(e^P + \alpha f^P)) \quad \text{from Eq. (13) and (5)} \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) \geq D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow \alpha D_E(n(e^N + \alpha f^N)) \geq \alpha n D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow G_f(f^N) \geq G_f(f^P) \quad \text{from Eq. (14) and (6)} \\
\text{with } G(f) &= \gamma A(f) - C(f) \\
&\Rightarrow f^N \leq f^P \ \text{ since } G_{ff} < 0 \\
&\Rightarrow n(e^N + \alpha f^N) \leq n(e^P + \alpha f^P) \text{ which is a contradiction} \\
\text{with the condition } D_E(n(e^N + \alpha f^N)) &\geq D_E(n(e^P + \alpha f^P)), \\
\text{thus we have } e^N &> e^P.
\end{aligned}
$$

$$
\begin{aligned}
e^N &> e^P \text{ implies } B_e(e^N) < B_e(e^P) \Leftrightarrow \\
D_E(n(e^N + \alpha f^N)) &< nD_E(n(e^P + \alpha f^P)) \\
\text{Let suppose that } n(e^N + \alpha f^N)) &< n(e^P + \alpha f^P) \\
&\Rightarrow f^N < f^P \Leftrightarrow G(f^N) > G(f^P) \Leftrightarrow \\
\alpha D_E(n(e^N + \alpha f^N)) &> \alpha D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow n(e^N + \alpha f^N) > n(e^P + \alpha f^P) \text{ which is a contradiction,} \\
\text{thus we have } n(e^N + \alpha f^N)) &> n(e^P + \alpha f^P) \Leftrightarrow ET^N > ET^P \\
\text{Let suppose that } f^N &> f^P \\
&\Rightarrow G_f(f^N) < G_f(f^P) \Leftrightarrow \alpha D_E(n(e^N + \alpha f^N)) < \alpha D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow n(e^N + \alpha f^N) < n(e^P + \alpha f^P) \text{ which is a contradiction,} \\
\text{thus we have } f^N &< f^P
\end{aligned}
$$

- Suppose that $\alpha < 0$ and $e^N \leq e^P$, this implies that

$$\begin{array}{rcl}
B_e(e^N) & \geq & B_e(e^P) \quad \text{since } B_{ee} \leq 0 \\
& \Rightarrow & D_E(n(e^N + \alpha f^N)) \geq nD_E(n(e^P + \alpha f^P)) \quad \text{from Eq. (13) and (5)} \\
& \Rightarrow & D_E(n(e^N + \alpha f^N)) \geq D_E(n(e^P + \alpha f^P)) \\
& \Rightarrow & \alpha D_E(n(e^N + \alpha f^N)) \leq \alpha n D_E(n(e^P + \alpha f^P)) \\
& \Rightarrow & G_f(f^N) \leq G_f(f^P) \quad \text{from Eq. (14) and (6)} \\
\text{with } G(f) & = & \gamma A(f) - C(f) \\
& \Rightarrow & f^N \geq f^P \; \text{ since } G_{ff} < 0 \\
& \Rightarrow & n(e^N + \alpha f^N) \leq n(e^P + \alpha f^P) \text{ which is a contradiction} \\
\text{with the condition } D_E(n(e^N + \alpha f^N)) & \geq & D_E(n(e^P + \alpha f^P)), \\
\text{thus we have } e^N & > & e^P.
\end{array}$$

$$\begin{array}{rcl}
e^N & > & e^P \text{ implies } B_e(e^N) < B_e(e^P) \\
& \Rightarrow & D_E(n(e^N + \alpha f^N)) < nD_E(n(e^P + \alpha f^P)) \\
\text{Let suppose that } n(e^N + \alpha f^N)) & < & n(e^P + \alpha f^P) \\
& \Rightarrow & D_E(n(e^N + \alpha f^N)) < D_E(n(e^P + \alpha f^P)) \\
& \Rightarrow & \alpha D_E(n(e^N + \alpha f^N)) > \alpha D_E(n(e^P + \alpha f^P)) \\
& \Rightarrow & G_f(f^N) > G_f(f^P) \\
& \Rightarrow & f^N < f^P \\
& \Rightarrow & n(e^N + \alpha f^N) > n(e^P + \alpha f^P) \text{ which is a contradiction,} \\
\text{thus we have } n(e^N + \alpha f^N)) & > & n(e^P + \alpha f^P) \Rightarrow ET^N > ET^P
\end{array}$$

$$
\begin{aligned}
\text{Let suppose that } f^N &< f^P \\
&\Rightarrow G_f(f^N) > G_f(f^P) \Leftrightarrow \alpha D_E(n(e^N + \alpha f^N)) > \alpha D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow D_E(n(e^N + \alpha f^N)) < D_E(n(e^P + \alpha f^P)) \\
&\Rightarrow n(e^N + \alpha f^N) < n(e^P + \alpha f^P) \text{ which is a contradiction,} \\
\text{thus we have } f^N &> f^P
\end{aligned}
$$

F Quadratic Model

F.1 Nash equilibrium

The reactions functions are given by:

$$
\begin{aligned}
e_i &= \frac{b_1 - d(\alpha f_i + E_{-i} + \alpha F_{-i})}{b_2 + d} \\
f_i &= \frac{\gamma a_1 - \alpha d(e_i + E_{-i} + \alpha F_{-i})}{\gamma a_2 + c + \alpha^2 d} \\
f_i &= \frac{\gamma a_1 - \alpha d(ET)}{\gamma a_2 + c}
\end{aligned}
\tag{F6}
$$

The solution is given by:

$$
\begin{aligned}
e^N &= \frac{b_1(\gamma a_2 + c) + \alpha dn(\alpha b_1 - \gamma a_1)}{\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn} \\
f^N &= \frac{\gamma a_1(b_2 + dn) - \alpha b_1 dn}{\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn} \\
ET^N &= \frac{n\left[\gamma(a_1 \alpha b_2 + a_2 b_1) + b_1 c\right]}{\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn}
\end{aligned}
$$

The total payoff function then is given by:

$$
W^N = nU^N = n\left[\gamma\left(a_1 f^N - \frac{a_2}{2} f^{N^2}\right) + \left(b_1 e^N - \frac{b_2}{2} e^{N^2}\right) - \frac{c}{2} f^{N^2} - \frac{d}{2} ET^{N^2}\right]
$$

F.1.1 Proof of Proposition 4

Here, we investigate how parameter γ affects the variables at the Nash equilibrium, defined by the equations F6.

The effect of parameter γ on the ambition of nutrition policies is given by:

$$\frac{df^N}{d\gamma} = \frac{(nd + b_2)\left[nd(\alpha^2 a_1 b_2 + \alpha a_2 b_1 + a_1 c) + a_1 b_2 c\right]}{\left(\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn\right)^2} > 0 \quad \forall \alpha$$

The numerator is positive thanks to the condition $A_f = a_1 - a_2 f^N > 0$ which is given by $[nd(\alpha^2 a_1 b_2 + \alpha a_2 b_1 + a_1 c) + a_1 b_2 c] > 0$.

The effect of parameter γ on direct emissions depens on the sign of parameter α:

$$\frac{de^N}{d\gamma} = \frac{-\alpha nd\left[nd(\alpha^2 a_1 b_2 + \alpha a_2 b_1 + a_1 c) + a_1 b_2 c\right]}{\left(\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn\right)^2}$$

Similarly, the effect of parameter γ on total level of emissions depens on the sign of parameter α:

$$\frac{dE^N}{d\gamma} = \frac{\alpha n b_2\left[nd(\alpha^2 a_1 b_2 + \alpha a_2 b_1 + a_1 c) + a_1 b_2 c\right]}{\left(\gamma a_2(b_2 + dn) + b_2(\alpha^2 dn + c) + cdn\right)^2}$$

F.2 Full cooperative solution

The solution is given by:

$$\begin{aligned} e^C &= \frac{b_1(\gamma a_2 + c) + \alpha dn^2(\alpha b_1 - \gamma a_1)}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn^2 + c) + cdn^2} \\ f^C &= \frac{\gamma a_1(b_2 + dn^2) - \alpha b_1 dn^2}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn^2 + c) + cdn^2} \\ ET^C &= \frac{n\left[\gamma(a_1 \alpha b_2 + a_2 b_1) + b_1 c\right]}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn^2 + c) + cdn^2} \end{aligned}$$

The total payoff function then is given by:

$$W^C = nU^C = n\left[\gamma\left(a_1 f^C - \frac{a_2}{2} f^{C^2}\right) + \left(b_1 e^C - \frac{b_2}{2} e^{C^2}\right) - \frac{c}{2} f^{C^2} - \frac{d}{2} ET^{C^2}\right]$$

F.3 Climate agreement

The solution is given by:

$$
\begin{aligned}
e^P &= \frac{b_1(\gamma a_2 + c) + \alpha dn(\alpha b_1 - \gamma a_1 n)}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn + c) + cdn^2} \\
f^P &= \frac{\gamma a_1(b_2 + dn^2) - \alpha b_1 dn}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn + c) + cdn^2} \\
ET^P &= \frac{n\left[\gamma(a_1 \alpha b_2 + a_2 b_1) + b_1 c\right]}{\gamma a_2(b_2 + dn^2) + b_2(\alpha^2 dn + c) + cdn^2}
\end{aligned}
$$

The total payoff function then is given by:

$$
W^P = nU^P = n\left[\gamma\left(a_1 f^P - \frac{a_2}{2} f^{P^2}\right) + \left(b_1 e^P - \frac{b_2}{2} e^{P^2}\right) - \frac{c}{2} f^{P^2} - \frac{d}{2} ET^{P^2}\right]
$$