Foreign Demand, Soy Exports, and Deforestation

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November 2023

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Abstract

The current paper aims to assess the credibility of demand-side policies to curb deforestation. We tackle this question focusing on the Brazilian soy sector, as conversion from forests to soy-producing areas is a major driver of deforestation. We estimate a firm-level gravity model relating soy exports to destination-specific soy demand. First, we estimate a positive elasticity of soy exports to foreign demand, which confirms the credibility of demand-side policies. Second, we document that the average response hides significant heterogeneities across exporters and across municipalities. Combining export elasticities with soy expansion possibilities, demand-side policies could hence avoid aggregate deforestation, particularly in regions proximate to the Amazon.

Keywords: Agriculture, Trade, Firms, Deforestation.

JEL Codes: F18, Q17, Q23

*Acknowledgments: We would like to thank Philippe Delacote, Christophe Gouel, Valentin Guye, Derya Keles, Julie Lochard, Anouch Missirian and Raphaël Soubeyran as well as colleagues for their comments and discussions on this paper. Thanks to seminar participants in PSAE, Orléans (LEO), Montpellier (CEEM), Créteil (ERUDITE), Bordeaux (BSE), Climate Economics Chair, and to the audience of LAGV 2023 and FAERE 2023. The usual disclaimer applies.
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1 Introduction

Tackling deforestation is among the top priorities of policymakers in light of climate change issues. Existing policies include soy moratorium, blacklisting of particular municipalities and firms, implementation of protected areas, monitoring, and changes in access to credit, among others. The common characteristic of these policies is that they are supply-side policies. Indeed, these policies target producers and intend to affect deforestation through producers' behavior. Whereas these policies can be effective (Heilmayr et al., 2020; Assunção et al., 2020), policymakers have recently considered complementary actions. The AR6 report of the IPCC underscores the potential impact on mitigation of demand-side and material substitution measures for the agriculture, forestry, and other land use sector. These measures could contribute to reducing emissions by 2.1 [1.1–3.6] GtCO2-eq per year (IPCC, 2022). There are many international and national initiatives to implement demand-side policies to curb deforestation. For instance, the European Green Deal includes measures to favor sustainable supply chains. In France, a strategy to fight against "imported deforestation" has been set up, and actions include the relocation of plant protein production on the national territory, i.e. relying on locally available proteins instead of on imported proteins.[1] All in all, reducing the import demand of forest-risk commodities is envisaged by policymakers.

The general objective of the current paper is to assess the credibility and the potential effects of these demand-side policies. To provide some insights on this important issue, we tackle this question focusing on the soy sector. Indeed, conversion from forests to soy-producing areas (potentially indirectly through conversion into pastures first) is a major driver of deforestation (Song et al., 2021; Pendrill et al., 2019). Lowering demand for soy could thus curb land conversion and deforestation rates. Whereas soy supply is responsible for deforestation, the quantitative role of foreign demand for soy remains an open question.

To answer this question, we use data covering the universe of soy exports from Brazil and estimate the elasticity of exports to soy foreign demand. Most of the soy produced in Brazil is for exports (75% in our dataset), leading exports and production patterns to be very close. As a result, changes in soy production could plausibly be driven by changes in foreign demand. Our analysis combines location and firm-specific soy export data with aggregate trade data informing on soy demand (imports) by destinations. In this context, we estimate a firm-level gravity model relating firm-municipality-destination export flows to destination-specific soy demand and to standard firm-level trade determinants. Combined with demanding fixed effects, identification relies on the exogeneity of demand from abroad faced by soy exporters.

Our analysis delivers the following conclusions. First, we estimate an average micro-level elasticity of soy exports to foreign demand of around 0.2. On average, exporting firms increase their exports by 0.2% for a 1% increase in foreign demand. This result is robust to including a wide array of potentially omitted

[1] https://www.deforestationimportee.ecologie.gouv.fr/en/sndi/article/sndi

variables, alternative estimations, and measurement issues. This positive average elasticity confirms the credibility of demand-side policies, even though the magnitude of the effect remains small.

Second, we document that the average response hides significant heterogeneities across exporters and across municipalities in Brazil. If changes in demand affect soy exports, the response varies across places and across exporting firms. In particular, our analysis highlights (i) that the largest exporters are more sensitive to soy demand shocks, (ii) that higher past deforestation patterns reduces the response, and (iii) that the number of competitors in the same municipality also dampens the impact of demand. Changes in demand, hence, mainly affect large exporters and municipalities with less competition and low soy expansion possibilities. We also document no heterogeneity across the origin of the import demand. Taking these results at face value, demand-side policies – regardless of their origin– could effectively curb soy production but would imply reallocations of soy production across places and firms. These reallocations are important as they would redistribute exports and production in favor of the smallest exporters but not necessarily into deforestation-prone places.

Third, we assess the potential benefits of the envisaged demand-side policies. The main metric of interest is the avoided deforestation. In our case, it measures the amount of deforestation that would have occurred to produce the avoided exports. This metric combines the avoided exports and expansion possibilities at the municipality level. In empirical terms, it combines (i) observed soy expansion possibilities with (ii) the estimated elasticities of exports from the gravity model and using observed firm size, competition, and recent deforestation patterns as determinants. In the cross-section of municipalities, avoided exports and soy expansion possibilities are positively correlated: places with high export response to demand are also places with a lot of remaining forests. This underlines both the risks generated by the current global increase in demand and the potential effectiveness of policies to reduce deforestation, on the side of consumer countries. Many municipalities have a high potential for avoided deforestation. These are mainly located in the Amazon region. However, in certain localities, such as southern Mato Grosso or Matopiba, which still have significant forest cover, the weak response to exports suggests that the effects of a demand-driven policy would be lower.

Related Literature This paper builds upon and contributes to three strands of the literature. Firstly, it adds to the growing body of research on the link between trade and deforestation. While previous studies have identified several channels through which trade openness may affect deforestation, including agricultural market prices (Berman et al., 2023), land-use value, imported agricultural input costs, and productivity (Abman and Lundberg, 2019), empirical evidence of the effect of trade on deforestation has been limited (Balboni et al., 2023). However, recent studies have provided new insights into this relationship. (Abman and Lundberg, 2019) shows that deforestation increases following RTAs and that this effect is mediated by agricultural trade. Tracking the deforestation in trade flows, (Pendrill et al., 2019) shows that a large part of tropical deforestation can be attributed to foreign consumer countries, especially soybean. Also, the recent microdata of the supply chains documents the involvement of transnational firms in this process (West et al., 2018). This paper builds on this literature by quantifying the heterogeneous effects of changes in foreign demand on supply and deforestation, considering geographic and firm-level characteristics. We also build on the international economics literature that considers the importance of firm heterogeneity in shaping the patterns of international trade (Melitz, 2003; Bernard et al., 2012). Here, we empirically show how the heterogeneity in firms in the soybean markets affects the elasticity of supply to foreign demand and how this heterogeneity matters for the effect of demand-side policies on deforestation. Finally, this paper adds to the growing body of literature on policies to slow the rate of deforestation. Recent research has considered trade policies as instruments to encourage conservation in countries that may otherwise deforest their territories (Balboni et al., 2023). While some studies have proposed import tariffs as a means of reducing deforestation (Harstad, 2022; Domínguez-Iino, 2022) and others have examined the efficiency of bans (Busch et al., 2022; Villoria et al., 2022), the effectiveness of these policies remains controversial. This paper contributes to this literature by examining how changes in foreign demand can be transmitted heterogeneously to deforestation through firms and how changes in foreign demand could translate into a decrease in deforestation. Our results on demand-side policies suggest that, although acting on foreign demands would not transmit homogeneously across the market, the adaptation of the supply to the changes in demand could indeed slow down the deforestation process in producing countries.

The rest of the article is organized as follows. The next section details the data sources and presents the main variables used in the empirical analysis. Section 3 provides an overview of the empirical methodologies employed. Section 4 describes the main results of the analysis. Section 5 presents the implications of our results for deforestation patterns. The final section concludes and discusses the results.

2 Data and context

2.1 Data Sources

We use data covering the universe of soy exports, soy production, and foreign demand from 2004 to 2017.

Soy firm-level exports To identify soy export flows, we rely on the TRASE database (Godar, 2018). This database is constructed from customs records and maps trade flows (in physical quantities and port of export FOB values) from source cities to destination markets and the agribusiness firms intermediating the transactions. The unit of observation in our analysis is at the exporter group ×

municipality (production) × final destination country × year level.

Firms characteristics The TRASE database allows us to identify exporters' characteristics. Namely, we can measure total firm exports, the number of destinations each firm serves, as well as the number of source municipalities. The TRASE dataset also allows us to characterize the market structure of soy exports in Brazil. Indeed, TRASE provides consistent information about traders, source cities, and destination markets. We can measure many aggregates informing on the market structure and which may be driving forces behind the main elasticity. We compute by municipality, the number of exporters (sourcing from this specific municipality, eventually serving a specific destination), the average exports of these firms, the rank of each firm in the hierarchy and other aggregates.

Soy demands measures We measure the soy demands arising in importing countries using the BACI Database. BACI is an international trade database stemming from the harmonization of the COMTRADE database, in which the trade flows reported by exporting and important countries sometimes differ (Gaulier and Zignago, 2010). We select the bilateral trade flows of the six-digit Harmonized System products associated with soybeans (HS6 120100, Soya beans; whether or not broken) and aggregate by destination d and year t the total soy demand: $SoyDemand_{dt} = \sum_o X_{odt}^{soy}$. In benchmark estimations, we exclude human consumption uses of soybean (in HS 120810, 150710, 150790, 230400 – vegetable oils, flours, and meals), representing around 15% of total use of soy worldwide, then used for robustness. As Brazil represents around 40% of soy exports worldwide, excluding export flows from Brazil for the computation would amount to introduce a bias in the foreign demands.

Municipality characteristics We also collected some municipality-specific time-varying variables, which can be determinants of firm-specific and aggregate trade. Among others, we use data on municipality GDP, population, distance to the main port, and other variables from the Brazilian National Institute of Geography and Statistics (IBGE).

Deforestation Patterns To measure deforestation, we rely on the MapBiomas database (Souza et al., 2020), aggregated at the municipality-year level. Because most of the soy expansion takes place in the Cerrado (an ecosystem of tropical savanna not included in the forest definition), we extend the analysis beyond deforestation and consider more broadly the effects of the changes in demand on the changes in natural vegetation. This ecosystem, with low legal protection compared to the Brazilian Amazon, is currently experiencing high conversion rates (five times as high as deforestation rates in the Amazon before the Soy Moratorium) in which soy plays a direct and significant role (Rausch et al., 2019).

2.2 Stylized facts

Fact 1: Increasing soy demands.

Figure 1 underscores a consistent pattern of growth in international demand for soy, illustrating how the world demand for soybean increased dramatically during the sample period. Soy exports worldwide tripled during 2005-2015, in line with an increasing global import demand. In this context, Brazil is a major exporter of soybeans: around 35% of total soy exports are from Brazil origin. Brazilian soy exports follow the same increasing trend.

Fact 2: China and the EU are the top destinations.

Figure 2 plots the main destinations of Brazilian soy, from TRASE dataset. The figure provides the average share of each destination in the sample. The distribution of exports is skewed across destinations. China is the main importing country of soybeans, and the EU is second. These two destinations account for 80% of total flows.

Exporters and municipalities typically serve multiple destinations. Over our period (2004 to 2017), municipalities served on average 18 countries and exporter groups 6 countries, although this number varies widely across exporters. Exporters and municipalities therefore face multiple demand shocks from various importing countries.

Fact 3: Exporters distribution is highly skewed.

Our main estimation sample contains 327 distinct exporters. However, a few firms dominate the market. Figure 3 shows the average share of the top 25 firms. In line with anecdotal evidence, exporter distribution is highly skewed as well. There are a few but very large trading firms. In particular, existing literature highlights the major role played by the ABDC traders: ADM, Bunge, Cargill, and Louis Dreyfus (Clapp, 2015, 2014). These four firms alone control more than half of the soybean export market in Brazil, and this figure does not vary over time. On average, they source from many municipalities and present a high market share in their sourcing municipalities compared to smaller firms. This particular market structure implies that there may be some strategic interactions between these firms. These firms are so large that their presence should impact other firms' export behavior. We account for this feature by computing an index of competition, which is the number of top-4 firms by municipality-destination-year.

3 Empirical models

3.1 Average elasticity

Our main estimation strategy of the micro-level elasticity is based on regressions of soybean exports per firm – municipality - destination on the soybean demand from a destination country. We choose this level of analysis to estimate the reaction of a firm sourcing from a municipality to a demand shock from a destination country. In formal terms, the regressions follow equation:

$$\text{Exports}_{fmdt} = \lambda_{fmd} + \lambda_{fmt} + \alpha \text{Soy Demand}_{dt} + \beta \text{Controls}_{dt} \varepsilon_{fmdt} \tag{1}$$

where Exports_{fmdt} is the value of the soy exports of firm f from municipality m to destination country d in year t, Soy Demand_{dt} is the total soy imports by destination d from anywhere in the world, including Brazil, from BACI.

Controls_{dt} is a vector of time-varying destination-specific trade determinants such as destination observables: foreign GDP and population, both to measure market size. We include a small set of control variables, to avoid over-fitting and bad controls problems. Besides, given the demanding fixed effects structure, most of the variance should be controlled.

Our specification also includes a set of fixed effects. The main results are obtained using firm-municipality-destination fixed effects (λ_{fmd}) and firm-municipality-year fixed effects (λ_{fmt}). The former set of fixed effects absorbs variance across individuals. Coefficients are thus identified from variation across years for a given individual (i.e. an exporter-source municipality-destination country group). These fixed effects absorb the effect of many time-invariant determinants of trade, such as the distance with destination country (as all exporters are located in Brazil) and the pre-existence of a relationship between a firm and a destination country. It also absorbs trade determinants that do not vary in our sample period, such as the existence of a regional trade agreement between Brazil and a destination (as Brazil did not sign any new agreement between 2004 and 2017 with soy exports destinations). We also include a firm-municipality-year set of fixed effects that control for time-varying heterogeneity across cities (such as GDP per capita, the share of agriculture in local GDP, ...) as well as across firms (such as total firm exports, number of destinations, number of sources, etc.). Note that fixed effects also exclude the potential non-random selection of sourcing cities at the firm level: estimations are performed within a given firm network of sourcing and destination at the firm level. All the adjustments must therefore take place within a given network. Crucially, the firm-municipality-year fixed effects also control for changes in both the international and local prices of soy. As a result, we focus on the residual effect of demand, after accounting for price changes.

Our coefficient of interest is α, which we expect to be positive as exports and demand should go in the same direction. This coefficient captures the average elasticity of exports to demand. Beyond significance, the value of α will inform the credibility of demand-side policies. Indeed, these policies would have any effect only if α is large enough and to a larger extent as long as the cost of the policy is not too high. Regarding inference, ε_{fmdt} is a random error term. We allow errors to be correlated within groups of destination-year and cluster the standard errors at this level (which is also the level of the demand shocks).

We estimate equation (1) using a PPML estimator, as standard practice regarding trade flows (Santos Silva and Tenreyro, 2006), including zero-trade flows. We will check the sensitivity of results when using alternative estimators (OLS) and specifications.

3.2 Differential effects

After estimating the average export elasticity of firms sourcing from a municipality to a demand shock from a destination country, we investigate the heterogeneous response across firms, municipalities, and destinations. We estimate some interaction models of the following general form:

$$\begin{aligned}\text{Exports}_{fmdt} &= \alpha\text{Soy Demand}_{dt} + \beta\text{Controls}_{dt} + \delta_1(\text{Soy Demand}_{dt} \times \text{Controls}_f) \\ &+ \delta_2(\text{Soy Demand}_{dt} \times \text{Controls}_m) + \delta_3(\text{Soy Demand}_{dt} \times \text{Controls}_{dt}) \\ &+ \mathbf{FE} + \varepsilon_{fmdt}\end{aligned} \tag{2}$$

where the set of δ captures the differential effects of the same soy demand shock across firms, municipalities, and destinations. Regarding interpretation, conditional on a positive α in the previous estimations, a positive δ will mean that the same demand shock will generate increased exports for firms, municipalities, and destinations with bigger controls.

First, to identify which exporters capture the changes in demand, we condition the impact of the demand shocks on observables at the firm level (Controls_f). Variables include the lagged total exports, lagged total number of destinations, and lagged the number of sourcing municipalities per firm. Overall, these variables intend to capture exporter size.

Second, to determine from *where* the additional demand is satisfied, we focus on the interaction between demand shock and municipalities' characteristics (Controls_m). These characteristics include the GDP of the sourcing municipalities, their population, the number of top-4 competitors in the municipality (see previous discussions), as well as its past deforestation levels. All these variables are supposed to capture differences across cities and will inform on the differential pattern of soy exports across municipalities.

Finally, to explore whether the response is shaped by destination characteristics, we interact soy demand with controls at the destination-year level (Controls_d). These controls include country dummies (as for China or the EU) and destination time-varying characteristics, such as GDP and population, to investigate whether foreign market size shapes the elasticity.

In formal terms, we will use a wide array of fixed effects (denoted FE) to use the correct identifying variation and control for many unobserved shocks. For instance, when investigating the variation across firms, we will use (at least) a municipality-destination-year fixed effect to account for observables and unobservables at this level and use the remaining variation across firms only. Note also that the whole set of fixed effects will also absorb most of the unconditional effects of variables of interest. For instance, the unconditional effect of firm size on soy exports will be captured in the firm(-city)-year fixed effect.

Importantly, we will use a destination-year fixed effect: this will absorb the unconditional effect of the demand shock (acting as if all firms faced the same demand shock) but the interaction between demand and observable will remain identifiable.

4 Results

4.1 Effect of foreign demand on soy exports

Benchmark results are displayed in Table 1. Column 1 includes firm-municipality-destination and year fixed effects, whereas columns 2 and others consider a more demanding fixed effects structure, including a firm x municipality x year fixed effect absorbing the major trade determinants at both the firm and the aggregate levels.

The results in columns 1 and 2 point towards a 0.2 average elasticity. The larger the soy demand in a destination, the larger the export flow. Using this 0.2 elasticity, a 10% increase in foreign soy demand increases soy exports (in value) by 2% on average. One standard deviation of soy demand (2.32) is related to a 0.5% increase in exports in our sample. This value is the average effect of changes in demand across firms and municipalities. The positive elasticity is independent of the set of fixed effects included in the estimation and of the subsequent change in samples (excluding singletons in the fixed effect dimensions). Regarding control variables, GDP has a positive impact on soy exports, in line with the gravity literature (Head and Mayer, 2014). We however find no significant and robust pattern regarding the impact of population – capturing the market size – on soy exports.

Table 1 further decomposes the average elasticity of soy exports to demand into an intensive (col. 3) and an extensive (col.4) margin of trade. Indeed, the baseline sample includes both zero trade flows and strictly positive flows. As for the intensive margin, we estimate equation (1) on the sample of positive trade flows. As for the extensive margin, we regress a dummy equal to 1 if the trade flow is positive. Both estimations are run using a PPML estimator (see robustness section for this issue). We estimate that soy demands affect soy exports through both trade margins. In quantitative terms, both trade margins are at play, even though point estimates are larger for the extensive margin of trade. It implies that soy demand changes affect soy exports not only through the level of exports, conditional on presence, but also through changes in the presence of an exporter, i.e. entry and exit of the export market.

4.2 Differential effects across firms, municipalities and destinations

Turning to heterogeneity, we now document the differential effect of the demand shocks across firms, across municipalities, and depending on previous deforestation patterns.

4.2.1 Heterogeneity across firms

Using variation across firms, holding municipality-destination-year observables constant (thanks to the fixed effects, reducing sample size however), Table 2 finds robust differential effects of increased demand across exporters. We differentiate firms along four measures of size: lagged total exports (col.1), lagged number of foreign destinations (col.2), lagged number of sourcing municipalities (col.3), and "being a top-4 firm" dummy (col.4). All those measures are documented to be proxies for firm size (Melitz and Redding, 2014; Bernard et al., 2012). We find that all interactions between soy demand and lagged firm size proxies are positive. When foreign demand increases, larger exporters capture most of this additional demand. In particular, the large differential impact of the top-4 dummy suggests that these top firms capture almost all the additional demand. One additional result is that the firm size premia on exports is not driven by the firm's access to storage and crushing facilities (col.5) as the differential effect of firm size is not affected by this augmented set of interacted controls. Overall, this exporter size premium over demand variations is in line with recent evidence on the topic, relying on heterogeneous elasticities across firms (Bricongne et al., 2022; Chowdhry and Felbermayr, 2021; Melitz and Ottaviano, 2008).

4.2.2 Heterogeneity across municipalities

Next, changes in foreign demand have a different impact across soy-producing municipalities. Table 3 controls for firm-destination-year fixed effects and the identifying variation is hence across cities. Results support strong and robust differential effects of an increase in demand across soy-producing municipalities.

Conclusions are threefold. First, we estimate that, conditional on the soy demand change, the impact is larger in cities with smaller GDP per capita (measured in 2004 to avoid endogeneity) (col. 1). The larger the GDP in 2004, the lower the elasticity to soy demand changes. This effect is almost offset by population: large municipalities capture and absorb more the demand shock. This effect may partly be driven by cities closer to ports (col. 2). Distance to ports could capture within-Brazil trade costs such that the pro-trade effect of increased foreign demand could favor places with lower relative trade costs within the country.[2] Second, competition drives a large part of the differential effect. We measure competition by counting the number of top-4 firms serving the same destination-year from the same municipality. We estimate that, conditional on soy demand changes, the larger effects are observed in municipalities with a low number of top 4 firms that are present in the previous year (col.3). This competition channel appears to be quantitatively an important driver of the differential effect across municipalities, as other determinants are estimated insignificant in column 3 onward. The export response seems to be driven much more by competition than by local economic conditions. This is in line with anecdotal evidence on the importance of these top firms (in an oligopoly setup, with a fringe of small firms) and of their strategic

[2]Recall that distance with the final destination of the good is absorbed in the destination fixed effect.

interactions. Firms sourcing from municipalities with fewer competitors yield higher elasticities. Third, recent deforestation patterns also shape the potential export response. Indeed, we find that the elasticity of exports to demand is larger in places with lower recent deforestation. Most of the action seems to be at play in places with lower recent deforestation patterns. Indeed, low levels of recent deforestation are correlated to potentially large deforestation in the past and thus a path-dependence pattern. Overall, smaller GDP, fewer competitors in the municipality, and lower recent deforestation patterns dampen the impact of demand changes on soy exports.

4.2.3 Heterogeneity across Destinations

Finally, the origin of the demand shock plays no role in the patterns of exports. Table 4 displays models including an interaction term between soy demand and dummies characterizing the origin country. On average, firms do not particularly react to demand originating from China (compared to other countries altogether, in col. 1), nor from the EU (col. 2). More generally, destination GDP per capita and destination population (market size) do not shape the elasticity. This absence of differential effect along the origin of the demand shock is important for the implications of our exercise: it will allow us to remain agnostic on the origin of the shock, and estimated implied exports and deforestation effect will have external validity, independently of the source of the demand shock.

4.3 Robustness checks

Conclusions are robust to many robustness checks detailed in this subsection.

4.3.1 Outcomes: Exports measures

Exports in quantities, and unit values First, we replicated the estimations using firm-level exported quantities. Results are presented in Table A.1. Second, we replicated our main estimation on unit values (defined as the ratio of exports value over exported quantities). Results are presented in Table A.2. The average effects occur regarding quantities, whereas prices (approximated by unit values) are mainly unaffected.

4.3.2 Main determinant: Soy Demands measures

Soy Demand in volume Conclusions are unaffected by our choice of the soy demand measures. Indeed, Table A.3 presents results when using world soy demand in quantities (from BACI) instead of the benchmark export values, without affecting our conclusions.

Soy Demand in for other uses. In benchmark estimations, we excluded human consumption uses of soybean. Table A.4 includes other uses of soy in the analysis. In particular, we account for the demand of soy in HS codes/chapters 120810, 150710, 150790, 230400, i.e. vegetable oils, flours, and meals. These other uses represent around 15% of the total use of soy worldwide. We find much larger estimates, which are less precisely estimated.

4.3.3 Estimation issues

OLS estimation Table A.5 shows results when estimating equation 1 with the log of exports as the dependent variable and using an OLS estimator. Focusing on the universe of positive trade flows only, Table A.5 supports that the main elasticity value is affected by the choice of the estimator and lies on average around 0.1. This is about half the value of the benchmark estimates. One way to interpret this result is: the OLS estimates capture the effect of demand on exports at the intensive margin only, whereas the PPML estimates identify the effects at both the intensive and extensive margins of trade. Hence, it is not surprising to obtain smaller point estimates.

Clustering of standard errors Inference is robust to the use of alternative standard error clustering levels: whereas benchmark results were based on destination-year clustering, inference is confirmed when municipality-year clustered errors (Table A.6) or with two-way municipality-year and destination-year clusters (Table A.7). Table A.8 also shows results when clustering the standard errors at the logistic hub-year level (at the intensive margin of trade only, hence reducing sample size however).

4.3.4 Placebo: other-than-soy exports

Finally, we do not capture a general trend toward Brazilian goods or other trends in import behavior. We first computed the total imports of agricultural goods from Brazil and excluded soy. We then regressed the firm-level soy exports on this demand that is unrelated to soy. In table A.9, plugging this non-soy demand in the estimations provides mainly non-significant coefficients, as expected.

5 Implications for deforestation

So far, we have examined how certain firms and municipalities heterogeneously capture demand variations. Building on this previous result, the final section of this paper discusses the implications of this result for the potential effect of demand-side policies on deforestation.

5.1 Background

Studies of forest conservation policies generally quantify their effectiveness in terms of avoided carbon emissions or avoided deforestation, which is the gap between the observed deforestation and a counterfactual value (Combes Motel et al., 2008; Delacote et al., 2016; Alix-Garcia et al., 2017). To answer our specific research question, we need to examine the amount of forest that would remain intact when implementing a policy that reduces foreign demand for soy, compared to a business-as-usual scenario.

The effects of changes in foreign demand on deforestation can be decomposed into two distinct dimensions. First, the previous section provided an elasticity of exports to demand, that varies across municipalities and firms. Consequently, a demand reduction affects exports differently depending on location and market structure. Second, whether this change in exports will result in deforestation depends on the potential for soybean expansion into forests: how much forest would have been affected in order to produce the (avoided) exports? Obviously, this is also highly location-dependent since some regions have much greater residual forest cover than others. We take both these dimensions into account in our discussion. As a result, avoided deforestation is the combination of avoided exports on the one hand and soy expansion possibilities on the other hand.

5.2 Avoided Exports

To estimate avoided exports, we rely on the previous empirical models and predict the observed export response to a marginal 1% increase in foreign demand. They have been generated from a regression of exports on foreign demands at firm and municipality level, interacted with all firm-specific and municipality-specific variables used in the above analysis (see section on heterogeneity).

Figure 4 illustrates the estimated elasticities at the municipality level. The map displays the weighted average elasticity of exports to demand in each municipality. Dark areas correspond to large elasticities. The larger the elasticity, the larger the soy export response of the municipality. Brighter areas correspond to lower elasticities and imply no change in exports despite a change in soy demand.

A cluster of municipalities whose exports are most responsive to demand seems to emerge towards the east of the Amazon. Other small municipalities located in the south of the country also display relatively high elasticities. Surprisingly, municipalities in Matopiba, a region west of the Cerrado currently being extensively converted to soybean production, exhibit low elasticity.

Two points are worth highlighting. First, we found no significant effect of the origin of the demand shock. We can thus remain agnostic and predict the impact of a change in demand regardless of its origin. It also implies that policies that end up reducing imports (or reducing import growth) will have the same export effect regardless of whether the EU or other countries drive it. Second, avoided exports measure the "costs" of having a 1% increase in demand.

5.3 Avoided deforestation

We now combine these elasticities with soy expansion possibilities at the municipality level. We measure soy expansion possibilities by computing the share of remaining forest cover out of the total area per municipality from MapBiomas data. [3]

First, in the cross-section of municipalities, avoided exports and soy expansion possibilities are positively correlated but with a low magnitude: we estimate a pairwise correlation of 0.14. It implies that places with high export response to demand are also places with a lot of remaining forests. This positive correlation supports the direct relationship between foreign demand and deforestation. This also underlines both the risks generated by the increasing trend in global demand and the potential effectiveness of policies to reduce deforestation on the side of consumer countries.

Figure 5 (left) plots the hierarchy of the estimated avoided deforestation. Darker areas represent places with large avoided deforestation. To decompose the total effect into the two components, Figure 5 (right) decomposes this index into the two components (red for exports elasticity and green for soy expansion possibilities). A dark color indicates a high percentage of remaining forest coupled with a high elasticity. This corresponds to areas where demand-side policies result in large avoided deforestation. This map reveals that many municipalities have a high potential for avoided deforestation. These are mainly located in the Amazon region. However, in certain localities, such as southern Mato Grosso or Matopiba, which still have significant forest cover, the weaker response to exports suggests that the effects of a demand-driven policy would be lower.

6 Conclusion and Discussion

The current paper aims to assess the credibility of demand-side policies to curb deforestation. Are changes in consumer demand related to deforestation? To provide some insights on this important issue, we tackle this question focusing on the soy sector. Indeed, conversion from forests to soy-producing areas is a major driver of deforestation. We estimate a firm-level gravity model relating firm-municipality-destination export flows to destination-specific soy demand and to standard firm-level trade determinants.

Our analysis delivers the following conclusions. First, we estimate a positive average micro-level elasticity of soy exports to foreign demand, which confirms the credibility of demand-side policies. Second, we document that the average response hides significant heterogeneities across exporters and across municipalities in Brazil. Our analysis highlights (i) that the largest exporters are more sensitive to soy demand shocks, (ii) that higher past deforestation patterns reduces the response, and (iii) that the number of competitors in the same municipality also dampens the impact of demand. Third, we assess the potential benefits of the envisaged demand-side policies. In the cross-section of municipalities, export elasticities and soy expansion possibilities are positively correlated: places with high export response to demand are also places with a lot of remaining forests. Many municipalities have a high

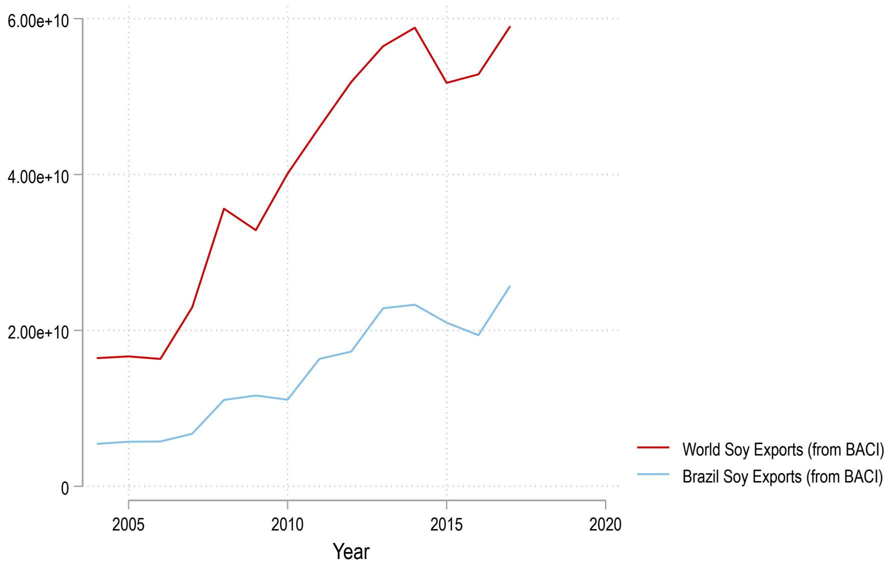
[3] It only includes forest formations and therefore excludes savannah-type vegetation, for example.

potential for avoided deforestation. These are mainly located in the Amazon region. However, in certain localities such as southern Mato Grosso or Matopiba, which still have significant forest cover, the weak response to exports suggests that the effects of a demand-driven policy would be lower. In light of these considerations, one may anticipate that demand-side policies may slow down deforestation in Brazil, particularly in regions proximate to the Amazon.

Estimating the effectiveness of demand-side policies remains challenging and warrants further investigation. The analysis carried out here does not consider general equilibrium effects, and the findings are contingent upon the assumption of symmetry between the impacts of rising and falling foreign demand. These aspects could be explored in future research projects to gain a more nuanced understanding of the dynamics surrounding demand-side policies and their implications for deforestation in tropical countries such as Brazil. Finally, how to reduce import soy demand remains a challenging question. First, increased meat and soy-based product consumption and population growth are fueling growth in soy demand worldwide and trends are not likely to reverse in the short-run. Second, substituting soy with local protein crops is still challenging and the search for alternatives requires attention to avoid creating additional environmental impacts.

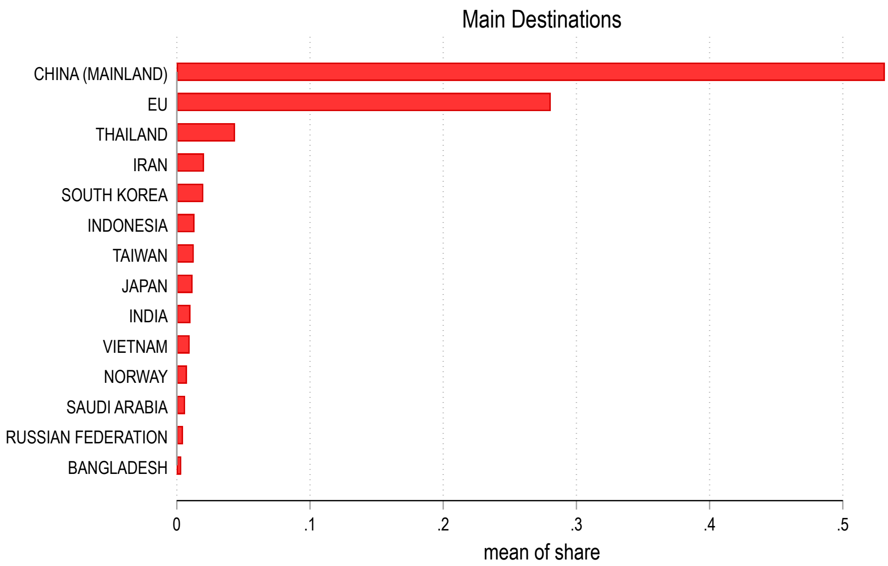
Tables and Figures

Figure 1: Demand from BACI trade flows



Soy Exports: HS6 120100, 'Soya beans; whether or not broken'.

Figure 2: Distribution of export destinations of soybeans



Share of total exports per destination.

Figure 3: Distribution of exporters in sample

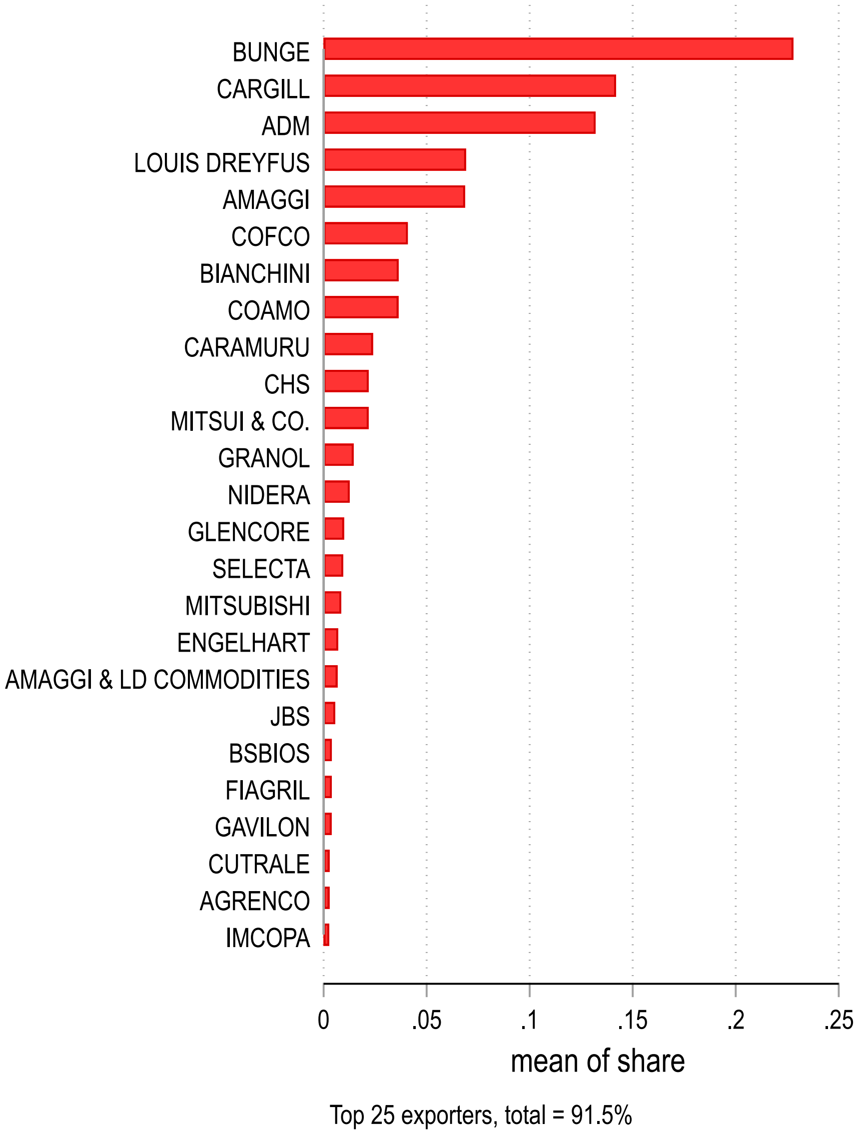


Figure 4: Average elasticities of exports in municipalities

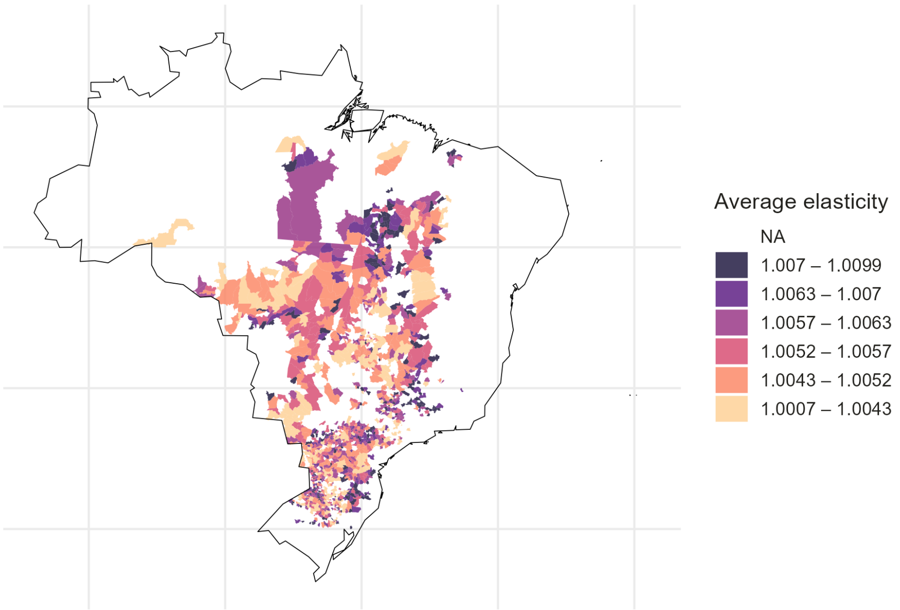


Figure 5: Potential of demand-side policies to avoid deforestation

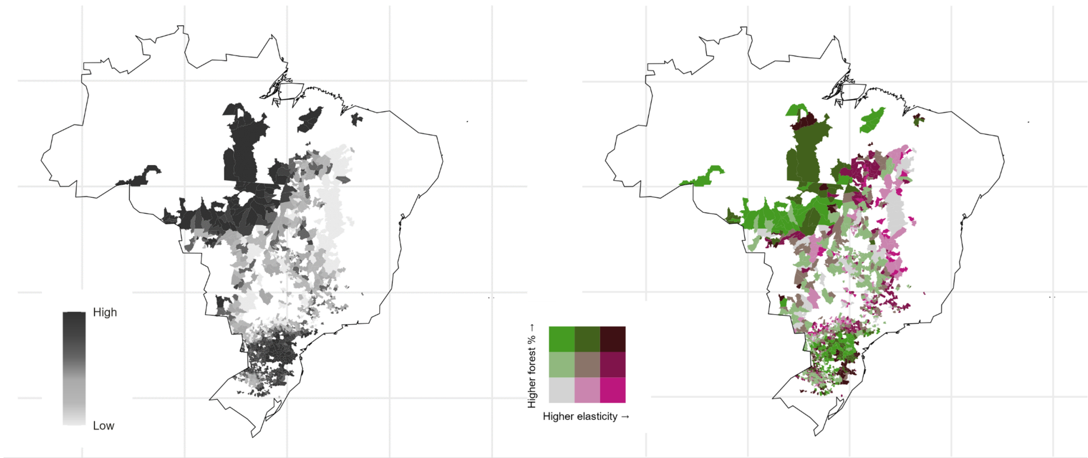


Table 1: Average Effects

Dep. Variable:	Firm-level Exports (X_{fmdt})			$1(X > 0)$
	(1)	(2)	(3)	(4)
Soy Demand dt	0.188***	0.191***	0.085***	0.137***
	(0.036)	(0.033)	(0.027)	(0.019)
Dest GDP pc.	1.788***	2.363***	1.941***	0.628***
	(0.107)	(0.140)	(0.240)	(0.107)
Dest. Pop.	0.482	1.343*	-0.382	1.207**
	(0.738)	(0.725)	(0.680)	(0.494)
Observations	199895	110855	56840	110855
Fixed Effects	fmd t	fmd fmt	fmd fmt	fmd fmt
Cluster Level	dt	dt	dt	dt
Sample	Full	Full	Exports>0	Full

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table 2: Heterogeneity across Firms

	Dep. Variable: Firm-level Exports (X_{fmdt})				
	(1)	(2)	(3)	(4)	(5)
Soy Demand dt × Firm Exports (t-1)	0.053***				0.057***
	(0.008)				(0.008)
Soy Demand dt × Nb Dest. (t-1)		0.100***			
		(0.020)			
Soy Demand dt × Nb Sources (t-1)			0.051***		
			(0.008)		
Dtop4 × Soy Demand dt				0.109***	
				(0.022)	
Storage × Soy Demand dt					-0.467***
					(0.110)
Crushing × Soy Demand dt					-0.340***
					(0.055)
Observations	19942	19942	19942	21847	19942
R^2					
Fixed Effects	mdt fmt	mdt fmt	mdt fmt	mdt fmt	mdt fmt
Cluster Level	dt	dt	dt	dt	dt

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table 3: Heterogeneity across Municipalities

	Dep. Variable: Firm-level Exports (X_{fmdt})			
	(1)	(2)	(3)	(4)
Soy Demand dt × GDP 2004	-0.029***	-0.023**	-0.023	-0.008
	(0.010)	(0.010)	(0.017)	(0.018)
Soy Demand dt × Population (city)	0.029***	0.024**	0.025	0.003
	(0.010)	(0.011)	(0.017)	(0.016)
Soy Demand dt × Distance to Port		-0.025*	-0.013	0.021
		(0.014)	(0.017)	(0.018)
Nb Top 4 firms (t-1)			2.181***	1.972***
			(0.282)	(0.295)
Soy Demand dt × Nb Top 4 firms (t-1)			-0.110***	-0.097***
			(0.018)	(0.019)
Soy Demand dt × Deforestation (t-1) (Mapbiomas)				-0.007***
				(0.001)
Soy Demand dt × Deforestation (t-2) (Mapbiomas)				-0.007***
				(0.002)
Observations	133753	133753	46211	37555
Fixed Effects	fdt mt	fdt mt	fdt mt	fdt mt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table 4: Heterogeneity across Destinations

	Dep. Variable: Firm-level Exports (X_{fmdt})				
	(1)	(2)	(3)	(4)	(5)
Soy Demand dt	0.193***	0.220***	0.220***	0.307	-0.433*
	(0.033)	(0.038)	(0.037)	(0.195)	(0.246)
Dest GDP pc.	2.084***	2.281***	2.025***	2.559***	2.145***
	(0.241)	(0.145)	(0.245)	(0.389)	(0.155)
Dest. Pop.	1.473**	1.145	1.272*	1.304*	0.900
	(0.728)	(0.730)	(0.730)	(0.723)	(0.732)
China=1 × Soy Demand dt	0.147		0.137		
	(0.137)		(0.138)		
EU=1 × Soy Demand dt		-0.118	-0.113		
		(0.072)	(0.072)		
Soy Demand dt × Dest GDP pc.				-0.013	
				(0.022)	
Soy Demand dt × Dest. Pop.					0.035**
					(0.014)
Observations	110855	110855	110855	110855	110855
Fixed Effects	fmd fmt	fmd fmt	fmd fmt	fmd fmt	fmd fmt
Cluster Level	dt	dt	dt	dt	dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

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Appendix for

Foreign Demand, Soy Exports, and Deforestation

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A Robustness: Tables

Table A.1: Firm-level exports in Quantities

	Dep. Variable: Firm-level Exports Volumes Q.			
	(1)	(2)	(3)	(4)
Soy Demand dt	0.197***			0.576**
	(0.039)			(0.229)
GDP pc (Dest.)	2.431***			3.027***
	(0.173)			(0.449)
Dest. Pop.	1.296*			1.224*
	(0.751)			(0.733)
Soy Demand dt × Firm Exports (t-1)		0.048***		
		(0.008)		
Soy Demand dt × 2004-GDP (city)			-0.010	
			(0.017)	
Soy Demand dt × L.Population (city)			-0.002	
			(0.016)	
Soy Demand dt × Distance to Ports			0.020	
			(0.018)	
Nb. Top-4 (t-1)			1.975***	
			(0.323)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.096***	
			(0.021)	
Soy Demand dt × Deforestation (t-1)			-0.006***	
			(0.001)	
Soy Demand dt × Deforestation (t-2)			-0.006***	
			(0.001)	
Soy Demand dt × GDP pc (Dest.)				-0.040
				(0.025)
Observations	110855	21765	37555	110855
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.2: Unit Values

	Dep. Variable: Firm-level: Unit Value			
	(1)	(2)	(3)	(4)
Soy Demand dt	-0.006*			0.025
	(0.004)			(0.021)
GDP pc (Dest.)	-0.020			0.033
	(0.025)			(0.041)
Soy Demand dt × Firm Exports (t-1)		-0.002***		
		(0.001)		
Soy Demand dt × 2004-GDP (city)			-0.001	
			(0.001)	
Soy Demand dt × L.Population (city)			-0.001	
			(0.001)	
Soy Demand dt × Distance to Ports			-0.009***	
			(0.003)	
Nb. Top-4 (t-1)			0.067	
			(0.053)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.004	
			(0.003)	
Soy Demand dt × Deforestation (t-1)			-0.000	
			(0.000)	
Soy Demand dt × Deforestation (t-2)			0.000	
			(0.000)	
Soy Demand dt × GDP pc (Dest.)				-0.003
				(0.002)
Observations	56840	8633	15639	56840
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.3: Soy Demand: Quantities

	Dep. Variable: Firm-level Exports Values			
	(1)	(2)	(3)	(4)
Soy Demand (Q)	0.168***			0.252
	(0.030)			(0.180)
GDP pc (Dest.)	2.394***			2.552***
	(0.138)			(0.382)
Dest. Pop.	1.426*			1.394*
	(0.728)			(0.732)
Soy Demand (Q) × Firm Exports (t-1)		0.052***		
		(0.007)		
Soy Demand (Q) × 2004-GDP (city)			-0.009	
			(0.017)	
Soy Demand (Q) × L.Population (city)			0.003	
			(0.016)	
Soy Demand (Q) × Distance to Ports			0.021	
			(0.017)	
Nb. Top-4 (t-1)			2.021***	
			(0.308)	
Soy Demand (Q) × Nb. Top-4 (t-1)			-0.095***	
			(0.019)	
Soy Demand (Q) × Deforestation (t-1)			-0.007***	
			(0.001)	
Soy Demand (Q) × Deforestation (t-2)			-0.006***	
			(0.002)	
Soy Demand (Q) × GDP pc (Dest.)				-0.009
				(0.020)
Observations	110855	21765	37555	110855
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table A.4: Other Uses of Soy

	Dep. Variable: Firm-level Exports			
	(1)	(2)	(3)	(4)
Soy Demand (Extended)	0.567***			1.512***
	(0.099)			(0.498)
GDP pc (Dest.)	1.822***			3.412***
	(0.202)			(0.857)
Dest. Pop.	1.165			0.963
	(0.710)			(0.690)
Soy Demand (Extended) × Firm Exports (t-1)		0.069***		
		(0.011)		
Soy Demand (Extended) × 2004-GDP (city)			0.007	
			(0.024)	
Soy Demand (Extended) × L.Population (city)			-0.005	
			(0.021)	
Soy Demand (Extended) × Distance to Ports			0.026	
			(0.025)	
Nb. Top-4 (t-1)			2.621***	
			(0.402)	
Soy Demand (Extended) × Nb. Top-4 (t-1)			-0.129***	
			(0.024)	
Soy Demand (Extended) × Deforestation (t-1)			-0.009***	
			(0.002)	
Soy Demand (Extended) × Deforestation (t-2)			-0.009***	
			(0.002)	
Soy Demand (Extended) × GDP pc (Dest.)				-0.095*
				(0.050)
Observations	110855	21765	37555	110855
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.5: OLS

	Dep. Variable: log Firm-level Exports			
	(1)	(2)	(3)	(4)
Soy Demand dt	0.085***			0.258
	(0.027)			(0.182)
GDP pc (Dest.)	1.941***			2.216***
	(0.240)			(0.381)
Dest. Pop.	-0.382			-0.462
	(0.680)			(0.680)
Soy Demand dt × Firm Exports (t-1)		0.041***		
		(0.007)		
Soy Demand dt × 2004-GDP (city)			0.018	
			(0.015)	
Soy Demand dt × L.Population (city)			-0.018	
			(0.015)	
Soy Demand dt × Distance to Ports			0.004	
			(0.019)	
Nb. Top-4 (t-1)			0.968**	
			(0.402)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.043	
			(0.027)	
Soy Demand dt × Deforestation (t-1)			-0.003**	
			(0.001)	
Soy Demand dt × Deforestation (t-2)			-0.003***	
			(0.001)	
Soy Demand dt × GDP pc (Dest.)				-0.019
				(0.020)
Observations	56840	8633	15639	56840
R^2	0.848	0.794	0.726	0.848
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

OLS estimations. Standard errors in parentheses.

* p<0.1, ** p<0.05, *** p<0.01

Table A.6: Alternative clustering: municipality-year

	Dep. Variable: Firm-level Exports			
	(1)	(2)	(3)	(4)
Soy Demand dt	0.191***			0.307**
	(0.021)			(0.134)
GDP pc (Dest.)	2.363***			2.559***
	(0.111)			(0.249)
Dest. Pop.	1.343***			1.304***
	(0.463)			(0.465)
Soy Demand dt × Firm Exports (t-1)		0.053***		
		(0.007)		
Soy Demand dt × 2004-GDP (city)			-0.008	
			(0.021)	
Soy Demand dt × L.Population (city)			0.003	
			(0.022)	
Soy Demand dt × Distance to Ports			0.021	
			(0.022)	
Nb. Top-4 (t-1)			1.972***	
			(0.426)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.097***	
			(0.028)	
Soy Demand dt × Deforestation (t-1)			-0.007***	
			(0.002)	
Soy Demand dt × Deforestation (t-2)			-0.007***	
			(0.002)	
Soy Demand dt × GDP pc (Dest.)				-0.013
				(0.015)
Observations	110855	21765	37555	110855
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	mt	mt	mt	mt

Standard errors in parentheses, clustered by c-t.

* p<0.1, ** p<0.05, *** p<0.01

Table A.7: Two-way clustering: municipality-year + destination-year

	Dep. Variable: Firm-level Exports Values			
	(1)	(2)	(3)	(4)
Soy Demand dt	0.191***			0.307
	(0.035)			(0.205)
GDP pc (Dest.)	2.363***			2.559***
	(0.157)			(0.399)
Dest. Pop.	1.343*			1.304*
	(0.738)			(0.733)
Soy Demand dt × Firm Exports (t-1)		0.053***		
		(0.009)		
Soy Demand dt × 2004-GDP (city)			-0.008	
			(0.023)	
Soy Demand dt × L.Population (city)			0.003	
			(0.023)	
Soy Demand dt × Distance to Ports			0.021	
			(0.023)	
Nb. Top-4 (t-1)			1.972***	
			(0.387)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.097***	
			(0.026)	
Soy Demand dt × Deforestation (t-1)			-0.007***	
			(0.002)	
Soy Demand dt × Deforestation (t-2)			-0.007***	
			(0.002)	
Soy Demand dt × GDP pc (Dest.)				-0.013
				(0.023)
Observations	110855	21765	37555	110855
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	mt dt	mt dt	mt dt	mt dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.8: Alternative clustering: by logitic hub-year

	Dep. Variable: Firm-level Exports Values			
	(1)	(2)	(3)	(4)
Soy Demand dt	0.095***			0.476***
	(0.026)			(0.137)
GDP pc (Dest.)	1.971***			2.605***
	(0.136)			(0.273)
Soy Demand dt × Firm Exports (t-1)		0.042***		
		(0.007)		
Soy Demand dt × 2004-GDP (city)			0.022	
			(0.018)	
Soy Demand dt × L.Population (city)			0.000	
			(0.020)	
Soy Demand dt × Distance to Ports			0.071***	
			(0.021)	
Nb. Top-4 (t-1)			1.238***	
			(0.369)	
Soy Demand dt × Nb. Top-4 (t-1)			-0.059**	
			(0.025)	
Soy Demand dt × Deforestation (t-1)			-0.004***	
			(0.002)	
Soy Demand dt × Deforestation (t-2)			-0.005***	
			(0.001)	
Soy Demand dt × GDP pc (Dest.)				-0.041***
				(0.015)
Observations	56840	8633	15639	56840
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	ht	ht	ht	ht

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.9: Placebo: other-than-soy exports

	Dep. Variable: Firm-level Exports			
	(1)	(2)	(3)	(4)
Non-Soy Demand	0.071			0.885***
	(0.051)			(0.305)
GDP pc (Dest.)	2.559***			3.939***
	(0.155)			(0.566)
Dest. Pop.	2.349***			2.379***
	(0.743)			(0.732)
Non-Soy Demand × Firm Exports (t-1)		0.016		
		(0.011)		
Non-Soy Demand × 2004-GDP (city)			0.029*	
			(0.017)	
Non-Soy Demand × L.Population (city)			-0.026*	
			(0.015)	
Non-Soy Demand × Distance to Ports			-0.023	
			(0.023)	
Nb. Top-4 (t-1)			1.931***	
			(0.308)	
Non-Soy Demand × Nb. Top-4 (t-1)			-0.097***	
			(0.021)	
Non-Soy Demand × Deforestation (t-1)			-0.005***	
			(0.001)	
Non-Soy Demand × Deforestation (t-2)			-0.005***	
			(0.002)	
Non-Soy Demand × GDP pc (Dest.)				-0.090***
				(0.034)
Observations	110855	21765	37555	110855
R^2				
Fixed Effects	fmd fmt	mdt fmt	fdt mt	fmd fmt
Cluster Level	dt	dt	dt	dt

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01