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Measuring the Impact of Agricultural Production Shocks on International Trade Flows

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Abstract

The purpose of this study is to measure the sensitivity of traded quantities and trade unit values to agricultural production shocks. We develop a general equilibrium model of trade in which production shocks in exporting countries affect both traded quantities and trade unit values. The model includes per-unit trade costs and develops a methodology to quantify their size exploiting the trade unit value data. Using bilateral trade flow data for a large sample of countries and agricultural commodities we find that the intensive margin of trade is relatively inelastic to production shocks, with a 1 percent increase in production leading to a 0.5 percent increase in exports. We also find that per-unit trade costs are large, comprising 15 to 20 percent of import unit values on average. Overall, our results suggest that there is room for improving trade as a mechanism for coping with food production volatility.

JEL Classification Codes: F14, F18, Q11, Q17, Q18 .

Keywords: Food production volatility, Trade costs, Agricultural trade, Gravity model.

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The recent volatility in food prices has brought issues of food security to the forefront of the policy debate (Anderson et al., 2014). On the supply side, agricultural production is sensitive to growing conditions and it is negatively affected by extreme weather events. As climate change progresses, many types of extreme weather events such as heat waves, droughts and floods are expected to become more frequent (IPCC, 2013) which may contribute to food-price volatility in the years to come.[1]

International trade in food is one potential way to mitigate the effects of production volatility.[2] Unexpected and unintended variations in production can be compensated for by adjusting trade flows. With this in mind, we will here consider how the effects of agricultural production shocks are propagated between countries through trade via their impact on quantities traded and the prices at which they trade, commonly referred to as "trade unit values".

In order to guide our empirical analysis we develop a general equilibrium model of trade in which production shocks in exporting countries affect both traded quantities and trade unit values. The model yields regression equations similar to standard gravity models.[3] In the model, production affects the quantity of trade, which in turn affects prices. This approach is well-suited to modeling short-run changes in agricultural production, and differs from standard general equilibrium trade models, which assume a perfectly inelastic supply.

Using data on bilateral trade of agricultural commodities, our goal is to estimate the sensitivity of trade volumes and trade values to fluctuations in production. In our baseline approach we exploit year-to-year changes in production, using yield per acre as our instrument for production. While yields can be influenced by prices in the medium- to long-term (Miao et al., 2016), Roberts and Schlenker (2013) find that detrended yield shocks appear to stem mainly from random weather shocks, with little risk that short-run yield fluctuations are endogenously determined by prices. We exploit the year-to-year variation in production between crops in the

[1]The connection between climate change and food production is a well researched topic within crop science. For example, Schlenker and Roberts (2009) find that temperatures above a certain threshold are very harmful to corn, soybean and cotton yields. IPCC (2014) provide an overview of the main results and a more detailed synthesis can be found in the full IPCC report. The importance of the connection from an economics perspective has also been long recognized. There are a number of studies investigating the role of trade as a means of adaption (see, e.g., Reilly and Hohmann, 1993; Rosenzweig and Parry, 1994; Tsigas et al., 1997; Randhir and Hertel, 2000).

[2]At least with well-functioning markets. See Gars and Spiro (2018) for an example of how trade may exacerbate shocks if production relies on renewable resources with imperfect property rights.

[3]Gravity models have been used extensively to estimate the impacts of agricultural trade policy on trade flows (Disdier et al., 2008; Emlinger et al., 2008; Clever, 2012; Dal Bianco et al., 2016).

same country, which allows us to disentangle the effect of production on trade from other factors that vary by country and year, such as macroeconomic shocks.

Our regression results reveal that the intensive margin elasticity of traded quantities with respect to production is around 0.5, while the effects on unit values are an order of magnitude smaller. Given that trade in agricultural commodities is small compared to total production, the result for traded quantities suggests that trade is relatively unresponsive to production shocks, and that there is room for improving trade as a mechanism for coping with food-production volatility. This finding suggests that alternative coping strategies such as storage or substitution with alternative foods may diminish the role of trade. Comparing the effects of production shocks on traded quantities and the unit values of the trade flows allows us to back out estimates of the elasticity of substitution. The estimates indicate the presence of product differentiation by country of origin for the agricultural commodities we study, although the estimates imply a high degree of substitutability. An analysis of the extensive margin of trade suggests that this might account for at least part of the discrepancy between the empirically observed effects of production shocks on trade quantities and those predicted by the model.

Our framework also allows us to infer the magnitude of per-unit trade costs from the trade data. Per-unit trade costs have been found to be quantitatively large in international trade of manufacturing goods (Irarrazabal et al., 2015), and given the bulky nature of agricultural commodities, with relatively low value per weight unit, we expect that per-unit trade costs are a prominent feature of international agricultural trade. The difference in the point estimates for the CIF and FOB unit value regressions allows us to calculate the average size of per-unit trade costs in the data, and the point estimates indicate per-unit trade costs that are about 15-20% of import unit values.

Our use of production shocks and trade unit values to quantify per-unit trade costs is new, and builds on earlier literature that highlights the impact of per-unit trade costs on the pattern of trade. Hummels and Skiba (2004) show that the presence of per-unit trade costs encourages firms to export high-value-goods, which lended empirical support to the Alchian and Allen (1964) conjecture. Our work focuses on the importance of per-unit costs for understanding the pass-through of production shocks, and complements work by Chen and Juvenal (2016) who find that real exchange rate shocks in the presence of destination-country per-unit trade costs leads to more pricing-to-market for high quality goods, using evidence from international trade in wine.

Our gravity model of trade with inelastic supply contributes to a recent theoretical literature that relaxes the assumption of perfectly elastic supply (Vannoorenberghe, 2012; Soderbery, 2014, 2015).[4] We estimate substitution elasticities by directly exploiting data on observed production shocks, which departs from the standard approach in the international trade literature pioneered by Feenstra (1994), where supply shocks enter the error term.[5]

Our study is also related to a growing literature on food-price volatility, particularly those studies that focus on transmission of productivity shocks via international trade. These studies have measured the pass-though of world prices to domestic prices (Mundlak and Larson, 1992; Baffes and Gardner, 2003; Dawe, 2008; Ferrucci et al., 2012; Imai et al., 2008; Yang et al., 2015), whereas we focus on the impact of production shocks on the unit values at which trade occurs.

The study most related to our work is Reimer and Li (2009), who adapt the Eaton and Kortum (2002) model of Ricardian trade to estimate the effect of higher yield volatility on trade and welfare. They find that increased yield volatility would lead to increased trade, and that the welfare losses from increased volatility are amplified by trade costs. Their study uses one year of cross-section data on trade and production to calibrate the model and then explores various counterfactual scenarios to make inferences on the pattern of trade and production. Another related study by Reimer and Li (2010) estimate and simulate a Ricardian-based model of the world crop market. They find that trade in crops is significantly lower than what it would be in a frictionless world. They also find that distance limits the extent by which changes in one country are transmitted to others. Our finding that trade responds inelastically to short-term fluctuations in produced quantities is complementary to their findings. While we arrive at similar conclusions, our approach is fundamentally distinct in several respects to Reimer and Li (2009, 2010). First, our theoretical model is based on love-for-variety, while Reimer and Li (2009, 2010) and others are based on Ricardian models of trade. Second, we use historical panel data, while Reimer and Li (2009, 2010) use data from a single year (2001) to conduct their analysis. Third, we measure the sensitivity of of trade to adapt to short term (year-to-year) production variations, while production volatility is a

[4]Inelastic supply has been posited as an explanation for understanding low cost-price pass-through in the literature, in addition to the mechanisms of price rigidities and vertical restraints (Bonnet et al., 2013).

[5]Feenstra's (1994) methodology has been used in several studies, including Broda and Weinstein (2006), Broda et al. (2008), Chen and Novy (2011), Imbs and Mejean (2015) and von Cramon-Taubadel et al. (2016).

parameter that is calibrated from data in one year and used to extrapolate trade flows under various counterfactual scenarios in Reimer and Li (2009, 2010). Finally, Reimer and Li (2009, 2010) infer iceberg trade costs from trade flow data in the Ricardian framework, while we infer per-unit trade costs from the trade unit value data.

Our work is also complementary to studies that emphasize the role of production in other countries and trade as a response to production shocks. Lybbert et al. (2014), for example, analyze whether the staggered growing seasons for wheat and soybeans in the southern and northern hemispheres helps to deal with production shocks. In particular, since the growing seasons are displaced by about a half year between the northern and southern hemisphere, the farmers on one of the hemispheres have time to react to production shocks on the other hemisphere and partially smooth global production. Dingle et al. (2017) analyze the importance of spatial correlation in endowments and its influence on the dispersion of welfare, induced by trade. Their empirical analysis uses agricultural trade and the El Niño-Southern Oscillation. Jones and Olken (2010) investigate the effects of weather on exports, and find that in poor countries, higher temperature is associated with lower exports, especially for agriculture and light manufacturing. Costinot et al. (2016) find that adapting to future climate scenarios through changes in growing patterns is more important than changing the trade patterns. Gouel and Laborde (2018) find that adaptation to climate change through international trade is welfare-enhancing.

1 Conceptual Framework

1.1 Basic Setting

We set up a gravity model of trade based on CES utility with consumer preference assumptions that follows the seminal work of Anderson (1979). Consider a trade economy where there is a set $\bar{J}$ of different countries. The income in country j is Y_j. There is a set $\bar{G}$ of different goods (e.g. different crops). For each good, different varieties are distinguished by country of origin, following Armington (1969). Let the produced quantity of good $g \in \bar{G}$ in country $i \in \bar{J}$ be X_{gi}. Let q_{gij} denote consumption in country j of good g produced in country i and let the price of this good, in country j, be p_{gij}. We assume a nested structure for the preferences over consumption of the different goods. In particular, the utility of the representative household in country j from consuming the basket $(q_{gij})_{g\in\bar{G},i\in\bar{J}}$ is

$$U\left((q_{gij})_{g,i}\right) = \prod_{g\in\bar{G}} Q_{gj}^{\alpha_g},$$

where

$$\sum_{g\in\bar{G}} \alpha_g = 1 \tag{1}$$

and

$$Q_{gj} \equiv \left[\sum_{i\in\bar{J}} q_{gij}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}. \tag{2}$$

Hence, different varieties of good g are aggregated into total consumption of good g using a CES function with elasticity of substitution σ and consumption of different goods is aggregated into total consumption using a Cobb-Douglas function.

The utility-maximization problem facing the representative household in country j is

$$\max_{(q_{gij})_{g,i}} U\left((q_{gij})_{g,i}\right) \text{ s.t. } \sum_{i\in\bar{J},\, g\in\bar{G}} p_{gij}q_{gij} \leq Y_j. \tag{3}$$

Solving this problem yields that the share of income spent on good g is $\alpha_g Y_j$.[6] This implies that, as long as we disregard potential changes in overall income Y_j, we can treat the different goods (denoted by g) separately and we drop the subscript g from the notation. The demand in country j for the variety from country i, q_{ij}, is given by

$$q_{ij} = \frac{\alpha Y_j p_{ij}^{-\sigma}}{P_j^{1-\sigma}}, \tag{4}$$

where

$$P_j \equiv \left[\sum_{i\in\bar{J}} p_{ij}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{5}$$

is the price index in country j (for varieties of the considered good g).

There are two types of trade costs: proportional (iceberg) τ_{ij} and per unit t_{ij}. The internal trade cost in country i is normalized by setting $t_{ii} = 0$ and $\tau_{ii} = 1$. The price in country j is then

$$p_{ij} = \tau_{ij}p_{ii} + t_{ij} \tag{6}$$

[6] See Appendix A for the derivations.

and the price index (5) becomes

$$P_j = \left[\sum_{i \in \bar{J}} (\tau_{ij} p_{ii} + t_{ij})^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{7}$$

We now turn to the supply-side of the model. Much of the international trade literature imposes constant marginal costs and markup pricing (Helpman and Krugman, 1985) based on equation (4). In such models, prices are determined by a markup over the marginal cost of production. The produced quantities then adjust to the demand for the different varieties implied by the markup pricing rule. Although the constant marginal cost assumption is relevant in many contexts, we argue that it does not capture the nature of short-run supply of agricultural commodities. Our framework differs by assuming a perfectly inelastic supply function. As discussed above, this is intended to capture that short-run fluctuations in yield give rise to exogenous variation of produced quantities. We thus treat short-run supply variations as exogenously given by variations in yield rather than treating variations in yields as variations in marginal production costs.

Let X_i denote the produced amount of the good in exporter country i. The market-clearing condition for that good is then obtained by summing the quantities of that good demanded by all countries (taking the iceberg trade costs into account): $X_i = \sum_{j \in \bar{J}} \tau_{ij} q_{ij}$. Using (4) yields:[7]

$$X_i = \sum_{j \in \bar{J}} \frac{\alpha Y_j \tau_{ij} p_{ij}^{-\sigma}}{P_j^{1-\sigma}}. \tag{8}$$

This yields a system with one equation per country producing the good in the prices p_{ii} (also one per country producing the good). The incomes, Y_j, and the trade costs τ_{ij} and t_{ij} are constant parameters. We are interested in seeing how changes in the produced quantities X_i affect the equilibrium. We can do this by assuming exogenous changes in the produced quantities and derive the endogenous responses of prices and traded quantities. In general this is difficult and we will first consider a special case.

[7] Note that we assume that iceberg trade costs entail physical losses of the shipped good (which is the conventional way of treating them). For the per-unit costs, we do not assume any physical losses. This seems more reasonable since to the extent that there are physical losses, the value of those losses should be proportional to the per-unit value of the goods.

1.2 Equilibrium Without Trade Costs

Without trade costs, $\tau_{ij} = 1$ and $t_{ij} = 0$ for all i, j, and the price index (7) is independent of j so that we can write $P_j = P$ for all i. Furthermore, the price of variety i is the same in all countries j so that $p_{ij} = p_{ii}$ for all j. The market-clearing conditions (8) then imply

$$X_i = \sum_{j \in \bar{J}} \frac{\alpha Y_j p_{ii}^{-\sigma}}{P^{1-\sigma}} = \frac{\alpha p_{ii}^{-\sigma} \sum_{j \in \bar{J}} Y_j}{P^{1-\sigma}}. \tag{9}$$

Solving for the price p_{ii} relative to the price index P gives

$$\frac{p_{ii}}{P} = \left(\frac{\alpha \sum_{j \in \bar{J}} Y_j}{P X_i} \right)^{\frac{1}{\sigma}}. \tag{10}$$

Equation (9) can also be solved for $p_{ii}^{-\sigma}/P^{1-\sigma}$. Substituting the resulting expression in (4) yields a reduced-form expression for trade as a function of income and production:

$$q_{ij} = \frac{Y_j}{\sum_{j' \in \bar{J}} Y_{j'}} X_i. \tag{11}$$

The representative household in each country thus consumes its income share of the total endowment of each variety.

Logging equations (10) and (11) yields the following equations for the model without trade costs:

$$\log(q_{ij}) = \log(Y_j) - \log\left(\sum_{j' \in \bar{J}} Y_{j'} \right) + \log(X_i) \tag{12}$$

$$\log(p_{ij}) = \frac{1}{\sigma}\log(\alpha) + \frac{1}{\sigma}\log\left(\sum_{j' \in \bar{J}} Y_{j'} \right) + \frac{\sigma - 1}{\sigma}\log(P) - \frac{1}{\sigma}\log(X_i). \tag{13}$$

Equations (12) and (13) illustrate that traded quantities and trade unit values are driven by the standard gravity terms such as price indices and importer income. The additional good-specific exporter production term, $\log(X_i)$, is the novel contribution of our theory. The price index and importer income terms can be subsumed by including importer-product-year fixed effects. Without trade costs, the theory thus predicts that a regression of the left hand sides of (12) and (13) on $\log(X_i)$ should yield coefficients that are equal to 1 for traded quantities and $-1/\sigma$ for trade unit values.

1.3 Adding Trade Costs

In this section we consider the case with (proportional and per-unit) trade costs. Solving analytically for the case with inelastic supply is then no longer possible. We can, however, derive some testable predictions. In particular, we can derive the expected relation between the coefficients in the quantity and price regressions and predictions that allow us to test for the presence of per-unit trade costs.

Logging the demand function (4) gives

$$\log(q_{ij}) = \log(\alpha) + \log(Y_j) - (1-\sigma)\log(P_j) - \sigma\log(p_{ij}). \tag{14}$$

Equation (14) implies that for a change (in, e.g., production) that affects quantities and prices, the relationship between the effects on prices and quantities should be the same as in (12) and (13). That is, the effect on the log of the price should be $-1/\sigma$ times the effect on the log of the quantity.[8]

The price p_{ij} is the price paid in the importing country (including trade costs) and thus correspond to the CIF unit values in the data. We also have data on the FOB unit values, and the differences between the two unit value measures are the trade costs. In particular, the CIF price for the trade flow from country i to country j is p_{ij} while the FOB price is p_{ii}. Consider now the effect of a change in some production X on the prices. The difference between the effect on the logs of CIF and FOB prices is

$$\frac{d}{dX}\log(p_{ij}) = \frac{1}{p_{ij}}\frac{dp_{ij}}{dX} = \{(6)\} = \frac{\tau_{ij}p_{ii}}{\tau_{ij}p_{ii}+t_{ij}}\frac{1}{p_{ii}}\frac{dp_{ii}}{dX} = \frac{\tau_{ij}p_{ii}}{\tau_{ij}p_{ii}+t_{ij}}\frac{d}{dX}\log\left(p_{ii}\right). \tag{15}$$

If there are no per-unit trade costs ($t_{ij}=0$), then the effects on CIF and FOB prices should be the same (since the ratio in front of the derivative is then equal to one). With strictly positive per-unit trade costs, we expect the effects on CIF unit values to be smaller than the effects on FOB prices (since the per-unit trade costs dampen the effects of price changes in percentage terms). The (relative) difference between the coefficients then measures the size of the per-unit trade costs.

To sum up, based on our model we can interpret coefficient estimates in terms of model parameters. The relative sizes of the effects of production on traded quan-

[8]In Appendix B we consider the case of symmetric countries. We show that if trade costs are only proportional in nature then the predicted coefficient on changes in produced quantities for traded quantities is larger than one. However, if only per-unit trade costs are present then the predicted coefficient could be larger or smaller than one, with smaller than one being the more likely case. In both cases, however, the predicted coefficients are relatively close to one.

tities and prices provide a measure of substitutability between different varieties (distinguished by country of origin). The relative sizes of the effects of production on CIF and FOB prices provides a measure of per-unit trade costs.

2 Data, Descriptive Statistics and Empirical Specification

2.1 Data and Descriptive Statistics

For our empirical analysis we combine country-level data on food production and yields with data on bilateral trade flows. The country-level data on food production and yields is taken from the FAOSTAT database, which uses the FAOSTAT Commodity List (FCL) classification. Production data is reported in tonnes, while yield data is reported in tonnes per hectare. Figure 1 illustrates the average yield over time for soybeans, bananas, tomatoes and coffee, which are the most traded commodities in the grain, fruit, vegetable and miscellaneous product groups. Figure 2 illustrates yields over time for U.S. wheat. These figures suggest that the yield data exhibits significant variation over time.

The aggregate bilateral trade data on trade quantities, trade values and trade unit values is taken from UN COMTRADE data and are available at the 6-digit HS product level. The database reports unit value data in terms of exporter-reported "Free On Board" (FOB) and importer-reported "Cost Insurance Freight" (CIF). FOB unit values reflect the price when the good leaves the exporting country, while CIF unit values reflect the price when it arrives at its destination. The trade unit value data is based on current prices. We adjust the trade data to remove re-exports, and we winsorize the traded quantity, trade value and trade unit value data at the top and bottom 1 percent of the distribution in order to remove extreme values.

We match trade flows with exporter and importer production and yield data using FAOSTAT's concordance between its own FCL classification and 6-digit HS2007. In some cases a single FCL code matches to more than one HS code. We thus restrict the analysis to importer-exporter-year-commodity trade flows for which we have a one-to-one match. We control for population and GDP per capita in regression specifications without the full set of fixed effects, with the data taken from the Penn World Tables.

We are interested in studying primary agricultural production and thus focus our analysis on grains, vegetables, fruits and miscellaneous products such as coffee and nuts. We do not use processed food production data in this analysis since the link between production of processed food and domestic yields is potentially weak, partly because imported agricultural commodities may be used as inputs. We also disregard animal-based commodities since it is difficult to interpret year-to-year variations in animal production in the same way as crop production. A complete list of products included in the analysis is provided in Appendix D. In addition, we remove trade flows where the exporting country does not produce the commodity according to FAOSTAT. There are many instances where country-pairs do not trade certain goods, which we do not include in the main analysis, but consider in a robustness check. After all of these restrictions we are left with a maximum of 540,453 observations for the CIF unit value analysis covering 76 FAO products, 182 exporting countries and 183 importing countries for the years 1993 to 2014. Descriptive statistics are given in Table 1.

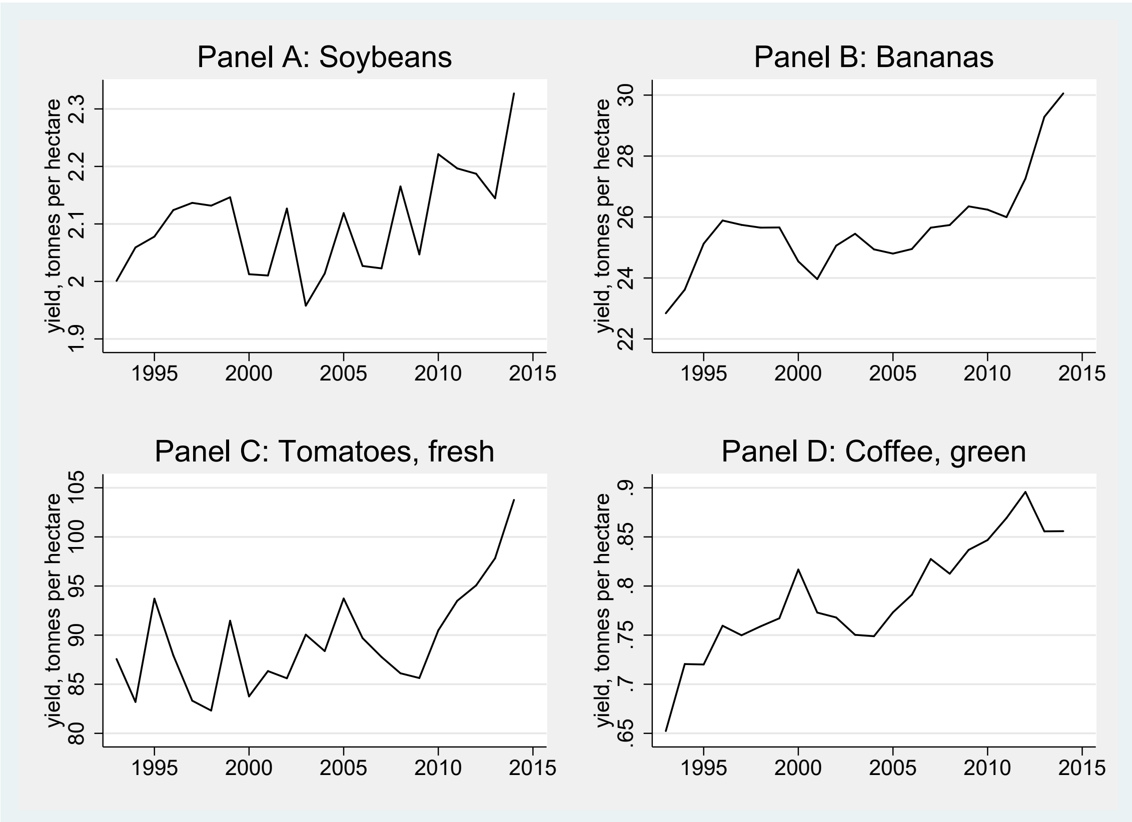

Figure 1: Average yields for soybeans, bananas, tomatoes and coffee, 1993-2014. Source: FAOSTAT

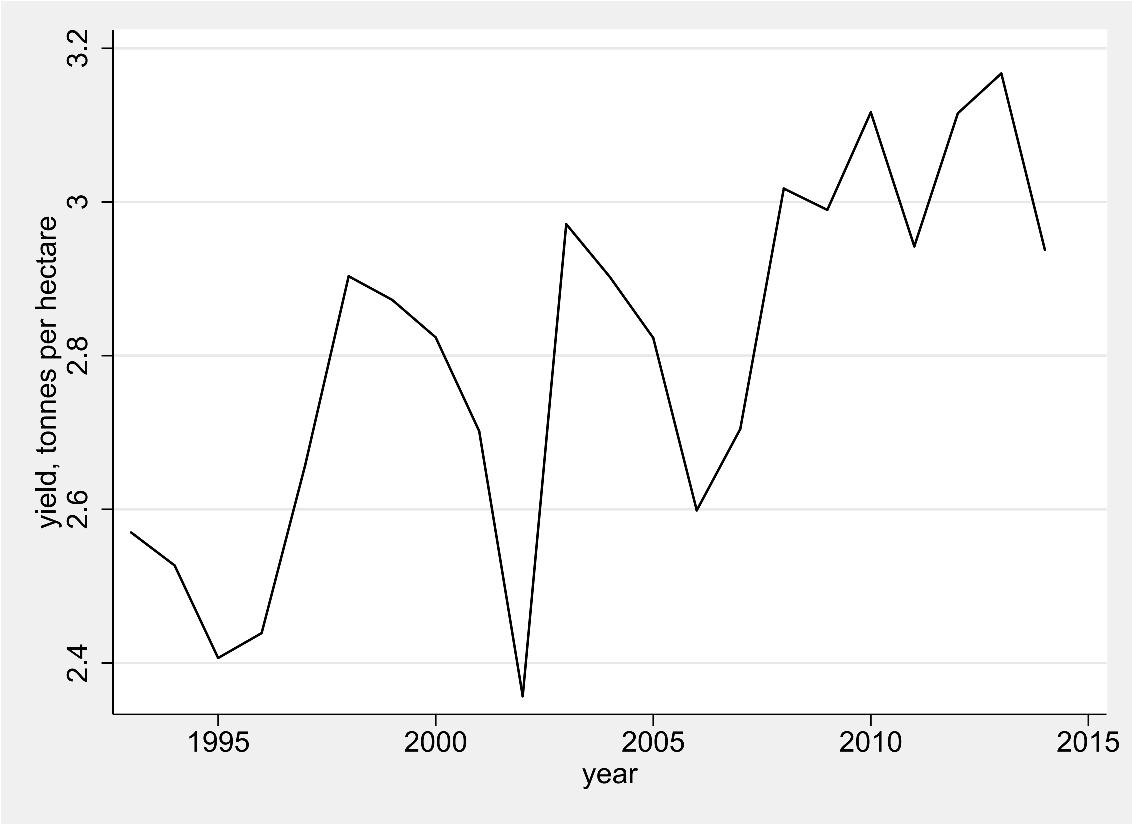

Figure 2: U.S. wheat yields, 1993-2014. Source: FAOSTAT

2.2 Empirical Specification

We estimate regressions based on equations (12) and (13). Since we use panel data we denote the calendar year with subscript t. We perform our estimation using a Two Stage Least Squares (TSLS) estimation, where we instrument contemporaneous and lagged exporter production with contemporaneous and lagged exporter country yield. We first-difference our data along the time dimension since our production variables are not trend stationary.[9] First-differencing the data subsumes the panel fixed effects and thus controls for all time-constant variation along the country-pair-product dimension. The regression specification for traded quantities takes the following form:

$$\begin{aligned} \Delta \ln(q_{gijt}) &= \beta_{0,q} + \beta_{1,q}\Delta \ln(X_{git}) + \beta_{2,q}\Delta \ln(X_{gi,t-1}) \\ &\quad + \alpha_{gjt} + \alpha_{it} + \epsilon_{gijt}, \end{aligned} \tag{16}$$

[9]The Hadri LM test statistics for exporter production ($\Delta \ln(X_{git})$) is 120, which rejects the null hypothesis that all panels are stationary. We perform the test on 3019 time series for which there are no missing year observations.

Table 1: Descriptive statistics

Variable	Obs.	Mean	St. dev.	Min	Max
CIF unit values, USD/tonne, $p_{gijt,CIF}$	540453	2280.4	3506.9	95.6	29333.3
Annual change, $\Delta \ln (p_{gijt,CIF})$	540453	0.034	0.59	-5.73	5.73
Quantity traded, th. tonnes, q_{gijt}	540453	3.17	11.5	0.0000030	78.5
Annual change, $\Delta \ln (q_{gijt})$	540453	0.050	1.66	-16.7	16.8
Value traded, th. USD, v_{gijt}	540453	2351.6	7826.6	0.014	50764.8
Annual change, $\Delta \ln (v_{gijt})$	540453	0.084	1.49	-14.3	14.7
Exporter production, million tonnes, X_{git}	540453	3.37	18.6	0.0000010	361.1
Annual change, $\Delta \ln (X_{git})$	540453	0.014	0.27	-5.40	5.16
Exporter yield, tonnes/Ha, ψ_{git}	540453	21.9	117.9	0.0056	4651.5
Annual change, $\Delta \ln (\psi_{git})$	540453	0.011	0.20	-7.53	3.67
Exporter population, millions, pop_{it}	224652	129.3	295.1	0.0046	1369.4
Exporter GDP per capita, th. USD, $gdppc_{it}$	224652	24.2	15.2	0.45	164.1
Importer population, millions, pop_{jt}	224652	63.0	174.5	0.0048	1369.4
Importer GDP per capita, th. USD,	224652	25.8	17.1	0.45	151.8

Notes: Based on observations from columns (1) and (3) of Table 4.

where q_{gijt} is the quantity traded from exporter country i to importer country j of good g in year t. $\Delta \ln(X_{git})$ and $\Delta \ln(X_{gi,t-1})$ are the percent changes in production in exporter country i of good g in year t and $t-1$ respectively. Exporter-year and importer-product-year fixed effects subsume the income and price index terms, and are denoted by α_{it} and α_{gjt}. Country-year fixed effects control for any unobserved country-year variation that can explain trade flows or prices, including inflation in trade unit values.

We include lagged production terms since many commodities are storable and experience long time lags due to transportation, implying that production the previous year can affect current trade patterns. This is especially important in the Northern Hemisphere, where many crops are harvested in the fall and then exported the next calendar year. The combination of first-differencing and using lags requires that a country-pair must produce and trade a particular good for at least three years in a row in order to be included in the regression. In the baseline analysis we thus explore the product-country intensive margin of trade in this study. Towards the end of the analysis, we discuss the potential importance of also considering the extensive margin.

For our unit value regressions we use the following specification:

$$\begin{aligned} \Delta \ln (p_{gijt}) \quad = \quad & \beta_{0,p} + \beta_{1,p} \Delta \ln (X_{git}) + \beta_{2,p} \Delta \ln (X_{gi,t-1}) \\ & + \alpha_{gjt} + \alpha_{it} + \upsilon_{gijt}, \end{aligned} \tag{17}$$

where p_{gijt} is the trade unit value from exporter country i to importer country j in good g in year t. The combination of exporter-year and importer-product-year fixed effects also controls for the effect of exchange rates on trade and prices and for any changes in trade costs over time that are country-year-specific. This combination of fixed effects controls for a wide array of factors that can affect the price of traded food products, including GDP and GDP per capita, but also tariffs (Curzi et al., 2015) and quality standards (Rau and van Tongeren, 2007; Ramos et al., 2009).

The coefficients from these regressions reflect the impact of production shocks on changes in the import price from country i. As discussed in the conceptual framework, higher production in exporting country i should increase q_{gijt} and decrease p_{gijt}. For the model with trade costs, equation (14) shows that the difference in the coefficients from the quantity and price regressions can be used to back out the elasticity of substitution, σ. Estimating the elasticity of substitution allows us to infer the extent to which food commodities are differentiated by country of origin.

3 Main Results

We now present the TSLS regression results for traded quantities and trade unit values. We cluster by exporter country in all specifications, which provides the most conservative standard errors.[10]

3.1 First Stage

We instrument for contemporaneous and lagged production using yield data in order to remove any endogeneity of trade on seeded acreage. According to Roberts and Schlenker (2013), year-to-year variation in yields is mainly caused by short term fluctuations in growing conditions. Moreover, Choi and Helmberger (1993) find that yields are insensitive to commodity price changes.[11]

[10] The results are also robust to clustering by exporter*year, which provides smaller standard errors in Tables 2 and 4.

[11] An alternative to using yield as instrument would be to try to capture the underlying weather conditions that drive the yield variations. However, the specific aspects of weather outcomes that drive yields are difficult to capture. Especially for many crops in many countries. Examples of specific relevant aspects are temperature minima or precipitation above or below some threshold. These outcomes often also matter particularly during specific growth phases of the crops. While much data on weather, what crops are grown where and crop calendars (planting and harvesting times) exist, it is not obvious that the data would allow for constructing strong instruments. We therefore treat yield as a sufficient statistic that captures the effects of weather, disease and any other factors that affect production.

The first-stage results are reported in Table D.2 in the Appendix. The results in column (1) suggest that a one percent increase in yield leads to a 0.78 percent contemporaneous increase in production, with a very high t-statistic. The results in column (2) indicate that a one percent increase in lagged yield increase lagged production by 0.78 percent, with a very high t-statistic as well. We include the one-year lag and lead of exporter yield in columns (1) and (2) respectively because they are also included in the first stage. The lagged yield term in column (1) is statistically significant in column (1), with a negative sign and a relatively small point estimate (-0.02). The one year lead yield term in column (2) is also statistically significant, also with a negative sign and small point estimate (-0.06). The negative point estimates in the lag and lead terms is likely caused by reversion to the mean, which we find in Figures 1 and 2. In sum, our treatment of yields as giving exogenous variations in production predicts coefficients close to one. Given that any measurement error in yields would bias our estimates towards zero, we find our point estimates slightly below one to be reasonable. As mentioned earlier, the alternative treatment of yields as variations in marginal costs would (with a high degree of substitutability) predict much larger effects of yields on produced quantities. The point estimates from the first-stage thus support our approach to modelling supply as perfectly inelastic.

3.2 Production Shocks and Traded Quantities

We first investigate the effect of production shocks on traded quantities and the results are presented in Table 2. In column (1) of Table 2 we present the results using first-differenced data but without any additional fixed effects. In each successive column we add more fixed effects until we arrive at our preferred specification. Importer-product-year fixed effects are added in column (2), which controls for the price index, aggregate income terms, and changes in import tariffs and regulations in the importing country (Disdier et al., 2008). In column (3) we add exporter-year fixed effects, which control for exporter-specific variation over time that affects trade. Country-level macroeconomic shocks in the exporting countries would be captured by the exporter-year fixed effects, as would any weather event that affected exports of all crops. The fixed effects used in column (3) thus allow us to exploit the variation in production between crops in the same country. The combination of first-differencing and country-year fixed effects follows the work of Baier and Bergstrand (2007) in a gravity equation context. The R-squared statistics do not include the variation subsumed by first-differencing the data, making them appear low. The individual

F-statistics suggest that the yield instruments are strong. The point estimates in column (3) of Table 2 suggest that a one percent increase in exporter production leads to a 0.30 percent increase in relative trade quantities the same year and a further 0.18 percent increase the following year.

We also estimate the effect of production shocks on traded quantities by product group and country characteristics. In Table 3 we present the subsample results separately for grains, vegetables and fruits. The point estimates suggest that production shocks in exporter countries affect trade in grains, vegetables and fruits, although the time profiles are quite different. For grains, lagged production shocks are most important, while in the case of vegetables and fruits the contemporaneous shocks are more important. This difference is consistent with grains being significantly more storable than vegetables and fruits.[12] In Table D.3 we present the subsample results distinguishing between OECD and non-OECD member countries, which we use as a proxy of their level of development. Our main result holds regardless of whether the importing and/or exporting country is an advanced economy.

The model without trade costs, equation (12), predicts coefficients on production equal to one. The fact that the coefficients in Table 2 are smaller than one (summed over the two years, they are about 0.5) thus suggests that the relationship between exporter production and traded quantities along the intensive margin is relatively inelastic, although we cannot rule out that attenuation bias may explain at least part of the deviation between the model's prediction and the empirical results. Based on the analysis in Appendix B, proportional trade costs would imply coefficients larger than one while per-unit trade costs would imply coefficients smaller than one. Coefficients smaller than one are thus consistent with trade costs being primarily of the per-unit type, but quantitatively per-unit trade costs do not seem to be a sufficient explanation for the coefficients being this much smaller than one. Further inspection of the data suggests that total exports are small relative to domestic production, which would imply a trade elasticity in excess of unity. We illustrate the fact that exports are relatively small relative to production in Figure D.1 in the Appendix, which ranks exporter-product-year observations by export intensity, defined as the ratio of total exports to domestic production for each good and year. This illustrates that exports are small relative to domestic production in the majority of cases in the data. Given that exports tend to be small relative

[12]Note, however that carryover stocks are relatively small compared to production even for storable commodities. In the case of wheat, for example, world ending stocks were approximately one quarter of total world production during the 1997-2016 period. (USDA, 2017)

Table 2: Productivity shocks and import quantities, country-level

	(1)	(2)	(3)
Exporter production: $\Delta\ln(X_{git})$	0.293***	0.310***	0.297***
	(0.0448)	(0.0400)	(0.0360)
Lagged exporter prod.: $\Delta\ln(X_{gi,t-1})$	0.153***	0.225***	0.184***
	(0.0474)	(0.0416)	(0.0356)
$\Delta\ln(pop_{it})$	0.106	-0.234	
	(0.412)	(0.563)	
$\Delta\ln(gdppc_{it})$	0.0295	-0.0938	
	(0.128)	(0.112)	
$\Delta\ln(pop_{jt})$	-0.115		
	(0.400)		
$\Delta\ln(gdppc_{jt})$	0.836***		
	(0.0977)		
Fixed Effects		gjt	gjt, it
Kleibergen-Paap LM stat:	46	48	46
Kleibergen-Paap Wald F stat:	142	231	337
Observations	224,652	417,342	540,453
R-squared	0.002	0.202	0.220

Notes: Dependent variable is first-differenced log quantity exported from country i to country j, using importer-reported values.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter country.

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

Table 3: Production shocks and import quantities by product group

	(1) grain	(2) vegetables	(3) fruit
Exporter production: $\Delta \ln(X_{git})$	0.149**	0.208***	0.459***
	(0.0570)	(0.0773)	(0.0652)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	0.263***	0.0454	0.0850**
	(0.0620)	(0.0767)	(0.0354)
Kleibergen-Paap LM stat:	22	30	41
Kleibergen-Paap Wald F stat:	249	18	282
Observations	138,117	111,030	217,613
R-squared	0.260	0.230	0.198

Notes: Dependent variable is first-differenced log quantity exported from country i to country j, using importer-reported values.
Exporter*year och importer*product*year fixed effects included in all specifications.
A constant term is included, but not reported, in all specifications
Robust standard errors in parenthesis, clustered by exporter country.
*** p<0.01, ** p<0.05, * p<0.1

to domestic production, our results more closely match our proposed theoretical framework compared to a partial equilibrium model of trade with homogeneous products, since small percentage changes in production in such an alternative model would lead to large percentage changes in exports. In sum, these results suggest that other factors such as storage, trade frictions or consumers' ability to substitute with other commodities or processed goods diminishes the role of international trade to smooth out the year-to-year volatility in production caused by weather and other factors.

3.3 Production Shocks and Trade Unit Values

In our unit value regressions, we first consider CIF unit values derived from the COMTRADE data. In Equation (14), the prices on the right-hand side include trade costs and thus correspond to CIF unit values. Hence, using CIF unit values allows us to back out the elasticity of substitution parameter σ by comparing the coefficients of the quantity and price regressions. In the next section we consider the differences between coefficients from regressions using CIF and FOB unit values.

The results describing the impact of production shocks on CIF unit values are

Table 4: Productivity shocks and (CIF) unit values, country-level

	(1)	(2)	(3)
Exporter production: $\Delta \ln(X_{git})$	-0.0489***	-0.0507***	-0.0521***
	(0.0115)	(0.00969)	(0.00856)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.0774***	-0.0472***	-0.0340***
	(0.0148)	(0.00960)	(0.00936)
$\Delta \ln(pop_{it})$	0.0292	0.0510	
	(0.249)	(0.124)	
$\Delta \ln(gdppc_{it})$	0.341***	0.0750***	
	(0.0634)	(0.0267)	
$\Delta \ln(pop_{jt})$	-0.313***		
	(0.0848)		
$\Delta \ln(gdppc_{jt})$	0.258***		
	(0.0345)		
Fixed Effects		gjt	gjt, it
Kleibergen-Paap LM stat:	46	48	46
Kleibergen-Paap Wald F stat:	142	231	337
Observations	224,652	417,342	540,453
R-squared	0.002	0.275	0.295

Notes: Dependent variable is first-differenced log unit values for exports from country i to country j, using importer-reported (CIF) values.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter country.

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

given in Table 4. The dependent variable is first-differenced log of unit values for exports from country i to country j, using importer-reported (CIF) values.

The results indicate that changes in production among exporters influence unit values, with point estimates that are statistically significant at the 1 percent level for both contemporaneous and lagged production in the exporter country i. All production coefficients are statistically different from zero at the 1 percent level and have the expected signs. Coefficients significantly different from zero indicate imperfect substitutability since for perfect substitutes changes in supply of the variety from one country should not affect the world-market price. The point estimates in column (4) of Table 4 suggest that a one percent increase in production in country i decreases the price by 0.052 percent in the same year and by 0.034 percent for the lag. These point estimates are an order of magnitude smaller compared to the quantity regressions.

Table 5: Production shocks and CIF unit values by product group

	(1) grain	(2) vegetables	(3) fruit
Exporter production: $\Delta \ln(X_{git})$	-0.0175	-0.0654**	-0.0908***
	(0.0147)	(0.0311)	(0.0126)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.0537***	-0.00717	-0.00567
	(0.0161)	(0.0263)	(0.00963)
Kleibergen-Paap LM stat:	22	30	41
Kleibergen-Paap Wald F stat:	249	18	282
Observations	138,117	111,030	217,613
R-squared	0.331	0.278	0.269

Notes: Dependent variable is first-differenced log unit values for exports from country i to country j, using importer-reported (CIF) values.
Robust standard errors in parenthesis, clustered by exporter country.
Exporter*year och importer*product*year fixed effects included in all specifications.
A constant term is included, but not reported, in all specifications
*** p<0.01, ** p<0.05, * p<0.1

Equation (14) from the theory implies that the elasticity of substitution can be calculated by taking the ratio between the effects in the CIF unit value and quantity regressions. By summing the contemporaneous and lagged coefficients from Table 2 and Table 4 and computing the ratio, we find that these imply an elasticity of substitution of about 5.6. Taking the ratio for the contemporaneous and lagged effects separately gives elasticities of substitution 5.7 and 5.4 respectively. This is higher than estimates by Broda and Weinstein (2006), but lower than estimates by Caliendo and Parro (2015).

We also estimate the effect of production shocks on CIF unit values by product group and country characteristics. In Table 5 we present the subsample results for grains, vegetables and fruits. Exporter production negatively affects the trade unit values of grains, vegetables and fruits with a similar time profile as the traded quantity regressions. Lagged production shocks are most important for grains, while contemporaneous shocks are more important in the case of vegetables and fruits. As a further robustness check we present the subsample results distinguishing between OECD and non-OECD member countries in Table D.4 in the Appendix. The point estimates are significant in all columns, which suggests that the Armington assumption holds regardless of the level of development of the importing or exporting country.

3.4 Further Robustness

As a first robustness check we use an alternative source of trade unit value data, which is taken from CEPII's Trade Unit Values (TUV) Database (Berthou and Emlinger, 2011). The CEPII data are based on the same tariff line database used to construct COMTRADE data and are available for the years 2000-2014 at the 6-digit HS product level. CEPII's TUV Database improves upon the raw trade unit value available through COMTRADE by harmonizing quantity units in order to allow cross-country comparison and also removing extreme unit values. Berthou and Emlinger (2011) show that this strategy improves the reliability of the unit value data compared to using raw COMTRADE data. The trade unit value data shares approximately 270000 common observations with our trade quantity and trade unit value data from COMTRADE, so it allows us to check the stability of our estimates. The regression results using the CEPII trade unit value data are reported in Appendix Table D.5. The point estimates for the contemporaneous and lagged exporter production terms are slightly smaller in the CEPII data but remain statistically significant.

Another potential concern is that our estimates using trade unit values are biased due to errors of measurement that are compounded when constructing trade unit values (Kemp, 1962). In order to deal with this concern we estimate the impact of production shocks on the value of trade, with the regression results reported in the Appendix. Combining equations (12) and (13) yields the model's prediction for the value of trade:

$$\log\left(p_{ij}q_{ij}\right) = \frac{1}{\sigma}\log(\alpha) + \frac{1-\sigma}{\sigma}\log\left(\sum_{j'\in\bar{J}} Y_{j'}\right) + \frac{\sigma-1}{\sigma}\log(P) + \frac{\sigma-1}{\sigma}\log(X_i). \quad (18)$$

Denote the coefficients for $\Delta\log(X_i)$ in equations (12), (13) and (18) by β_q, β_p and β_v respectively. Comparing these expressions reveals that the impact of exporter production on trade unit values can be indirectly recovered from the point estimates of the traded quantity and trade value regressions:

$$\beta_p = -\frac{1}{\sigma}\beta_q \text{ and } \beta_v = \left(1 - \frac{1}{\sigma}\right)\beta_q \Rightarrow \beta_v - \beta_q = \beta_p.$$

Hence, by subtracting the point estimates for contemporaneous and lagged exporter production in Table 2 from the corresponding estimates in Table D.6 we can obtain indirect estimates of the effect on trade unit values that are not subject to measurement error stemming from the use of constructed variables. Looking at columns (3) from the different tables and considering the sum of the effect of contemporaneous and lagged production, the effect is almost identical. Considering the effects separately, the implied coefficients from Tables 2 and D.6 are $0.242 - 0.297 = -0.055$ and $0.153 - 0.184 = -0.031$ for the contemporaneous and lagged terms respectively (to be compared to -0.052 and -0.034 from Table 4). We thus conclude that measurement error stemming from directly estimating the impact of production shocks on trade unit values has negligible effects on our results.

Our main empirical analysis only considers the effect of exporter production on trade. Appendix C presents a robustness check that also considers the effect of production in the importing country. In this case we study the subset of trade flows where the exporter and importer both produce the good being traded, which decreases the number of observations. We find that our main results for the impact of exporter country production on traded quantities and trade unit values are robust to controlling for importer country production.

Overall, our results suggest that the intensive margin of trade is inelastic. At the same time, we find that trade in these food commodities exhibits product differentiation by country of origin, although the estimates suggest that importers are particularly sensitive to prices. The fact that we find an inelastic effect on traded quantities at the same time as we find that that product differentiation is relatively weak implies that it is not a reluctance to switch suppliers that causes the inelastic trade result. This result suggests that other factors may be responsible for the inelastic trade result, such as trade frictions or storage, or that consumers substitute with entirely different foods when prices increase. Our finding that international trade does not fully mitigate production volatility agrees with work by Reimer and Li (2009, 2010) and Costinot et al. (2016). We now explore the importance of trade costs in more detail.

4 Estimating Per-Unit Trade Costs

We now exploit the differences in the estimates of effects of production changes on CIF and FOB unit values in the raw COMTRADE data in order to compute the size of per-unit trade costs. Furthermore, this sample of trade flows displays very similar properties in terms of the response of trade unit values to production shocks,

Table 6: CIF versus FOB estimates

	(1) CIF	(2) FOB
Exporter production: $\Delta \ln(X_{git})$	-0.0570***	-0.0765***
	(0.0188)	(0.0246)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.0323*	-0.0331*
	(0.0192)	(0.0193)
Kleibergen-Paap LM stat:	43	43
Kleibergen-Paap Wald F stat:	175	175
Observations	43,579	43,579
R-squared	0.532	0.480

Notes: Dependent variable is first-differenced log unit values for exports from country i to country j, using CIF trade unit values in column (1) and FOB trade unit values in column (2) Robust standard errors in parenthesis, clustered by exporter country. Exporter*year och importer*product*year fixed effects included in all specifications. A constant term is included, but not reported, in all specifications specifications. *** p<0.01, ** p<0.05, * p<0.1

as shown by the robustness check in the previous section. As shown in Equation (15), if the effects were the same for both types of unit costs, this would indicate that per-unit trade costs were insignificant. Table 6 presents the estimates of the sensitivity of trade unit values to production using both CIF and FOB unit values. In the table we have restricted the sample to observations where both types of unit values are available in order to allow for comparison.

Let β_{CIF} and β_{FOB} denote the coefficients from the CIF end FOB regressions respectively. Based on Equation (15), the per-unit trade cost's share of import prices can be inferred from the estimates using the following formula:

$$\frac{\beta_{CIF}}{\beta_{FOB}} = \frac{\tau_{ij} p_{ii}}{\tau_{ij} p_{ii} + t_{ij}} \Rightarrow \frac{t_{ij}}{\tau_{ij} p_{ii} + t_{ij}} = 1 - \frac{\beta_{CIF}}{\beta_{FOB}}.$$

When summing the contemporaneous and lagged effects in Table 6, the implied per-unit trade costs are 18.5% of the CIF unit values.[13] This suggests that per-unit

[13]Alternative estimates of the sensitivity of trade unit values to production using both CIF and FOB unit values from the CEPII database are provided in Table D.7. Using this alternative data we find that the per-unit trade costs in relation to the CIF unit value 15.5% when considering the sum of coefficients.

trade costs here are approximately the same compared to manufacturing, where Irarrazabal et al. (2015) find that per-unit trade barriers are on average 14 percent of the median price. These results also underscores the importance of using CIF unit values to estimate the elasticity of substitution since demand depends on prices including trade costs.

5 The Extensive Margin of Trade

In the analysis so far we have excluded observations where the traded quantities are zero. There are a number of reasons for this. First, while there are methods to deal with observed zero quantities, there is no way to usefully assign trade unit values to such observations. Second, we cannot combine using yield as an instrument and at the same time use more than one dimension of fixed effects in a Poisson estimation due to the incidental parameter problem, which means that we cannot control for the price index and aggregate income terms. Despite these limitations, we will here analyze trade flow zeros in order to consider the importance of the extensive margin of traded quantities, which has been found to be important in studies of agrifood trade (Haq et al., 2013). More precisely, we will include observations of zero trade in a given year if there are non-zero observations for the same country pair and good available at least one other year.

We analyse the extensive margin in two ways. First, we apply a linear probability model using OLS. Second, we run a Poisson regression (Silva and Tenreyro, 2006) including zero trade flows in the sample. The results of the linear probability model regressions are presented in Table 7. The linear probability model permits the use of all required fixed effects, and study the effects of production on the probability of any trade by reducing the trade quantity variable to a binary variable that is one if there is a strictly positive reported quantity and zero otherwise. We estimate the effect of production, instrumented by yield as before, on the probability of this variable being equal to one. Looking at the last column (with the preferred set of fixed effects), we can see that the effect of both contemporaneous and lagged production in the exporter country on the probability of trade is positive and statistically significant at the one percent level. The point estimates suggest that a one percent increase in production increases the probability of trade by about 2.2 percent in the same year and 2.0 percent in the following year.

The results of the Poisson regression are presented in Table D.8.[14] The effect of

[14]We employ Timothy Simcoe's "'xtivpl"' program for implementing an IV and panel fixed

Table 7: Production and the probability of trade using yield IV

	(1)	(2)	(3)
Exporter production: $\ln(X_{git})$	0.0353***	0.0228***	0.0215***
	(0.00723)	(0.00544)	(0.00399)
Lagged exporter prod.: $\ln(X_{gi,t-1})$	0.0253***	0.0235***	0.0196***
	(0.00517)	(0.00430)	(0.00351)
$\ln(pop_{it})$	-0.141**	-0.150**	
	(0.0614)	(0.0609)	
$\ln(gdppc_{it})$	0.0498***	0.0284*	
	(0.0180)	(0.0159)	
$\ln(pop_{jt})$	0.135***		
	(0.0211)		
$\ln(gdppc_{jt})$	0.0853***		
	(0.0141)		
Fixed Effects	gij	gij, gjt	gij, gjt, it
Kleibergen-Paap LM stat:	62	61	61
Kleibergen-Paap Wald F stat:	133	143	218
Observations	790,304	1,456,856	2,140,691
R-squared	0.479	0.606	0.583

Notes: Dependent variable is binary and equal to one if there is a strictly positive observed trade flow from country i to country j and zero otherwise.

Robust standard errors in parenthesis, clustered by exporter.

A constant term is included, but not reported, in all specifications

specifications. *** p<0.01, ** p<0.05, * p<0.1

(instrumented) production is still highly significant. The combined effect of contemporaneous and lagged production now sum to almost one, which is in line with the model prediction. However, since this method does not allow us to use the desired set of fixed effects due to the incidental parameter problem, we cannot definitively conclude that this is the case.

6 Conclusion

The purpose of this study is to measure the sensitivity of international trade to agricultural production shocks in recent decades. We find that the traded quantities and unit values of trade flows vary systematically with production shocks using aggregate data on a large sample of countries and internationally traded agricultural commodities. Furthermore, the responses of traded quantities and trade unit values to production shocks in exporting countries are consistent with product differentiation by country of origin, with a high degree of substitutability. The first-stage results support our treatment of yield shocks as giving exogenous changes in produced quantities and thus our modeling approach of treating short-run changes in production as exogenous.

Our results indicate that the product-country intensive margin of trade is inelastic, with a one percent increase in exporter-country production leading to a 0.5 percent increase in the quantity of trade. Our analysis also suggests that the country-good extensive margin responds to production variability. Nonetheless, the intensive margin estimates are significantly lower than one, which indicates that additional factors, such as storage or substitution between different types of food, have helped to cope with food production shocks and limited the role of trade as a coping mechanism. We thus argue that trade seems to have played a relatively limited role in mitigating the effects of production shocks in recent decades. Our finding that international trade does not fully mitigate production volatility supports work by Reimer and Li (2009, 2010) and Costinot et al. (2016). Further understanding these limitations is important in order to prepare for the future increases in food production variability expected to be caused by climate change, crop disease and other factors.

Our analysis, based on historical data, provide insight on the impact of future production volatility on international trade flows. In particular, our estimates can

effects in a Poisson pseudo maximum likelihood model. The xtivpl estimation does not converge when using the full set of controls or when including year dummies.

be used to predict changes in trade flows when production changes in a given country and crop. Overall, our results suggest that there is room for improving trade as a mechanism for coping with food production volatility. Our results indicate the presence of large per-unit trade costs, and trade frictions may be another contributing factor to our finding that trade responds inelastically to production shocks. Trade frictions come in many forms, such as tariffs, red tape, and a lack of transportation infrastructure, and further research is needed in order to gauge the impact of such frictions on the responsiveness of trade to production shocks.

References

Alchian, A. A. and Allen, W. R. (1964). *University Economics*. Belmont, CA: Wadsworth.

Anderson, J. E. (1979). A theoretical foundation for the gravity equation. *American Economic Review*, 69(1):106–16.

Anderson, K., Ivanic, M., and Martin, W. J. (2014). Food Price Spikes, Price Insulation, and Poverty. In *The Economics of Food Price Volatility*, NBER Chapters, pages 311–339. National Bureau of Economic Research, Inc.

Armington, P. S. (1969). A theory of demand for products distinguished by place of production (une théorie de la demande de produits différenciés d'après leur origine)(una teoría de la demanda de productos distinguiéndolos según el lugar de producción). *Staff Papers-International Monetary Fund*, pages 159–178.

Baffes, J. and Gardner, B. (2003). The transmission of world commodity prices to domestic markets under policy reforms in developing countries. *Journal of Policy Reform*, 6(3):159–180.

Baier, S. L. and Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? *Journal of International Economics*, 71(1):72–95.

Berthou, A. and Emlinger, C. (2011). The trade unit values database. Working Papers 2011-10, CEPII.

Bonnet, C., Dubois, P., Boas, S. B. V., and Klapper, D. (2013). Empirical Evidence on the Role of Nonlinear Wholesale Pricing and Vertical Restraints on Cost Pass-Through. *The Review of Economics and Statistics*, 95(2):500–515.

Broda, C., Limao, N., and Weinstein, D. E. (2008). Optimal Tariffs and Market Power: The Evidence. *American Economic Review*, 98(5):2032–2065.

Broda, C. and Weinstein, D. E. (2006). Globalization and the gains from variety. *The Quarterly Journal of Economics*, 121(2):541–585.

Caliendo, L. and Parro, F. (2015). Estimates of the trade and welfare effects of NAFTA. *The Review of Economic Studies*, 82(1):1–44.

Chen, N. and Juvenal, L. (2016). Quality, trade, and exchange rate pass-through. *Journal of International Economics*, 100(C):61–80.

Chen, N. and Novy, D. (2011). Gravity, trade integration, and heterogeneity across industries. *Journal of International Economics*, 85(2):206–221.

Choi, J.-S. and Helmberger, P. G. (1993). How Sensitive Are Crop Yields To Price Changes And Farm Programs? *Journal of Agricultural and Applied Economics*, 25(01).

Clever, M. (2012). The Trade Impact of European Union Preferential Policies: An Analysis through Gravity Models. *European Review of Agricultural Economics*, 39(3):534–536.

Costinot, A., Donaldson, D., and Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. *Journal of Political Economy*, 124(1):205–248.

Curzi, D., Raimondi, V., and Olper, A. (2015). Quality upgrading, competition and trade policy: evidence from the agri-food sector. *European Review of Agricultural Economics*, 42(2):239–267.

Dal Bianco, A., Boatto, V. L., Caracciolo, F., and Santeramo, F. G. (2016). Tariffs and non-tariff frictions in the world wine trade. *European Review of Agricultural Economics*, 43(1):31–57.

Dawe, D. (2008). Have recent increases in international cereal prices been transmitted to domestic economies? the experience in seven large asian countries. Technical report, FAO-ESA Working Paper 08-03.

Dingle, J. I., Hsiang, S. M., and Meng, K. C. (2017). The spatial structure of endowments, trade and inequality: Evidence from the global climate. Unpublished working paper.

Disdier, A.-C., Fontagne, L., and Mimouni, M. (2008). The Impact of Regulations on Agricultural Trade: Evidence from the SPS and TBT Agreements. *American Journal of Agricultural Economics*, 90(2):336–350.

Eaton, J. and Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, 70(5):1741–1779.

Emlinger, C., Jacquet, F., and Lozza, E. C. (2008). Tariffs and other trade costs: assessing obstacles to Mediterranean countries' access to EU-15 fruit and vegetable markets. *European Review of Agricultural Economics*, 35(4):409–438.

Feenstra, R. C. (1994). New Product Varieties and the Measurement of International Prices. *American Economic Review*, 84(1):157–77.

Ferrucci, G., Jimnez-Rodrguez, R., and Onorantea, L. (2012). Food price pass-through in the euro area: Non-linearities and the role of the common agricultural policy. *International Journal of Central Banking*, 8(1):179–218.

Gars, J. and Spiro, D. (2018). Trade and the risk of renewable-resource collapse. *Journal of the Association of Environmental and Resource Economists*, 5(1):155–206.

Gouel, C. and Laborde, D. (2018). The crucial role of international trade in adaptation to climate change. Unpublished working paper.

Haq, Z. U., Meilke, K., and Cranfield, J. (2013). Selection bias in a gravity model of agrifood trade. *European Review of Agricultural Economics*, 40(2):331–360.

Head, K. and Mayer, T. (2000). Non-Europe: The magnitude and causes of market fragmentation in the EU. *Review of World Economics (Weltwirtschaftliches Archiv)*, 136(2):284–314.

Helpman, E. and Krugman, P. R. (1985). *Market structure and foreign trade: Increasing returns, imperfect competition, and the international economy.* MIT press.

Hummels, D. and Skiba, A. (2004). Shipping the good apples out? an empirical confirmation of the alchian-allen conjecture. *Journal of Political Economy*, 112(6):1384–1402.

Imai, K., Gaiha, R., and Thapa, G. (2008). Transmission of world commodity prices to domestic commodity prices in India and China. Brooks World Poverty Institute Working Paper Series 4508, BWPI, The University of Manchester.

Imbs, J. and Mejean, I. (2015). Elasticity optimism. *American Economic Journal: Macroeconomics*, 7(3):43–83.

IPCC (2013). *Climate change 2013 the physical science basis : summary for policymakers : Working Group I contribution to the IPCC fifth assessment report.* WMO, IPCC Secretariat, Geneva.

IPCC (2014). *Climate change 2014 Impacts, Adaptation, and Vulnerability : summary for policymakers : Working Group II contribution to the IPCC fifth assessment report*. WMO, IPCC Secretariat, Geneva.

Irarrazabal, A., Moxnes, A., and Opromolla, L. D. (2015). The tip of the iceberg: a quantitative framework for estimating trade costs. *Review of Economics and Statistics*, 97(4):777–792.

Jones, B. F. and Olken, B. A. (2010). Climate shocks and exports. *American Economic Review Papers and Proceedings*, 100(2):454–259.

Kemp, M. C. (1962). Errors Of Measurement And Bias In Estimates Of Import Demand Parameters. *The Economic Record*, 38(83):369–372.

Lybbert, T. J., Smith, A., and Sumner, D. A. (2014). Weather shocks and inter-hemispheric supply responses: implications for climate change effects on global food markets. *Climate Change Economics*, 5(04):1450010.

Miao, R., Khanna, M., and Huang, H. (2016). Responsiveness of crop yield and acreage to prices and climate. *American Journal of Agricultural Economics*, 98(1):191–211.

Mundlak, Y. and Larson, D. F. (1992). On the transmission of world agricultural prices. *World Bank Economic Review*, 6(3):399–422.

Ramos, M. P., Bureau, J.-C., and Salvatici, L. (2010). Trade composition effects of the EU tariff structure: beef imports from Mercosur. *European Review of Agricultural Economics*, 37(1):1–26.

Randhir, T. O. and Hertel, T. W. (2000). Trade liberalization as a vehicle for adapting to global warming. *Agricultural and Resource Economics Review*, 29(2).

Rau, M.-L. and van Tongeren, F. (2007). Modeling differentiated quality standards in the agri-food sector: the case of meat trade in the enlarged EU. *Agricultural Economics*, 37(2-3):305–315.

Reilly, J. and Hohmann, N. (1993). Climate change and agriculture: the role of international trade. *The American Economic Review*, pages 306–312.

Reimer, J. J. and Li, M. (2009). Yield variability and agricultural trade. *Agricultural & Resource Economics Review*, 38(2):258.

Reimer, J. J. and Li, M. (2010). Trade costs and the gains from trade in crop agriculture. *American Journal of Agricultural Economics*, 92(4):1024–1039.

Roberts, M. J. and Schlenker, W. (2013). Identifying supply and demand elasticities of agricultural commodities: Implications for the us ethanol mandate. *American Economic Review*, 103(6):2265–95.

Rosenzweig, C. and Parry, M. L. (1994). Potential impact of climate change on world food supply. *Nature*, 367(6459):133–138.

Schlenker, W. and Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to us crop yields under climate change. *Proceedings of the National Academy of sciences*, 106(37):15594–15598.

Silva, J. M. C. S. and Tenreyro, S. (2006). The Log of Gravity. *The Review of Economics and Statistics*, 88(4):641–658.

Soderbery, A. (2014). Market size, structure, and access: Trade with capacity constraints. *European Economic Review*, 70(C):276–298.

Soderbery, A. (2015). Estimating import supply and demand elasticities: Analysis and implications. *Journal of International Economics*, 96(1):1–17.

Tsigas, M. E., Frisvold, G. B., and Kuhn, B. (1997). Global climate change and agriculture. *Global trade analysis: Modeling and applications*, pages 280–304.

USDA (2017). *Wheat Data: Yearbook Tables.* http://www.ers.usda.gov/data-products/wheat-data.aspx. Economic Reserch Service.

Vannoorenberghe, G. (2012). Firm-level volatility and exports. *Journal of International Economics*, 86(1):57–67.

von Cramon-Taubadel, S., Ma, S., and Qu, Y. (2016). Trade costs of heterogeneous agricultural products. Unpublished manuscript.

Yang, F., Bekkers, E., Brockmeier, M., and Francois, J. (2015). Food price pass-through and the role of domestic margin services. *Journal of Agricultural Economics*, 66(3):796–811.

A Deriving the demand functions

The Lagrangian associated with maximization problem (3) is

$$\mathcal{L} = \prod_{g \in \bar{G}} Q_{gj}^{\alpha_g} + \sum_g \mu_{gj} \left[\left[\sum_{i \in \bar{J}} q_{gij}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} - Q_{gj} \right] + \lambda_j \left[Y_j - \sum_{gi} p_{gij} q_{gij} \right].$$

The first-order conditions are

$$Q_{gj} : \mu_{gj} = \alpha_g \frac{U_j}{Q_{gj}} \tag{19}$$

$$q_{gij} : \lambda_j p_{gij} = \mu_{gj} \left(\frac{Q_{gj}}{q_{gij}} \right)^{\frac{1}{\sigma}} = \{(19)\} = \alpha_g \frac{U_j}{Q_{gj}} \left(\frac{Q_{gj}}{q_{gij}} \right)^{\frac{1}{\sigma}}, \tag{20}$$

where $U_j = U\left(\{q_{gij}\}_{g,i}\right)$. Total spending on good g is

$$\sum_{i \in \bar{J}} p_{gij} q_{gij} = \frac{1}{\lambda_j} \alpha_g \frac{U_j}{Q_{gj}^{\frac{\sigma-1}{\sigma}}} \sum_{i \in \bar{J}} q_{gij}^{\frac{\sigma-1}{\sigma}} = \{(2)\} = \frac{1}{\lambda_j} \alpha_g U_j. \tag{21}$$

Total overall spending is

$$Y_j = \sum_{g \in \bar{G}} \sum_{i \in \bar{J}} p_{gij} q_{gij} = \frac{1}{\lambda_j} U_j \sum_{g \in \bar{G}} \alpha_g = \{(1)\} \frac{1}{\lambda_i} U_j. \tag{22}$$

Substituting this in (21) yields

$$\sum_{i \in \bar{J}} p_{gij} q_{gij} = \alpha_g Y_j. \tag{23}$$

Total spending on good g is thus a given share α_g of total income Y_j. In our empirical analysis we will focus on variations of production of about 10 percent for any given good. The overall effect of this variation on the income of the entire economy should be relatively small and we will assume that it is zero. Equation (23) then implies that we can treat different goods separately. In the continued analysis we drop the subscript g from the notation.

Combining (20) and (22) gives

$$p_{ij} = \frac{\alpha Y_j}{Q_j^{\frac{\sigma-1}{\sigma}} q_{ij}^{\frac{1}{\sigma}}}.$$

This can also be written as

$$q_{ij} = Q_j^{1-\sigma}\left(\frac{\alpha Y}{p_{ij}}\right)^{\sigma}. \tag{24}$$

Using (23), we obtain

$$\alpha Y_j = Q_j^{1-\sigma}\left(\alpha Y_j\right)^{\sigma}\sum_{i\in\bar{J}} p_{ij}^{1-\sigma} \Rightarrow \alpha Y_j = Q_j\left[\sum_{i\in\bar{J}} p_{ij}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}.$$

The last factor is the price index defined in (5) and substituting for this we arrive at

$$\alpha Y_j = P_j Q_j.$$

Solving for Q_j and substituting this in (24) delivers (4).

B The case of symmetric countries

Consider an exogenous change Δ that affects production. Writing the market-clearing condition (8) in the form

$$X_i = \sum_{j\in\mathbb{J}} \tau_{ij} q_{ij} \tag{25}$$

and differentiating with respect to Δ gives

$$\frac{1}{X_i}\frac{dX_i}{d\Delta} = \sum_{j\in\mathbb{J}} \frac{\tau_{ij} q_{ij}}{X_i}\frac{1}{q_{ij}}\frac{dq_{ij}}{d\Delta}. \tag{26}$$

Differentiating (4) and (5) with respect to Δ yields

$$\frac{dq_{ij}}{d\Delta} = -q_{ij}\left[(1-\sigma)\frac{1}{P_j}\frac{dP_j}{d\Delta} + \sigma\frac{1}{p_{ij}}\frac{dp_{ij}}{d\Delta}\right] \text{ and } \frac{1}{P_j}\frac{dP_j}{d\Delta} = \sum_{i\in\mathbb{J}}\left(\frac{p_{ij}}{P_j}\right)^{1-\sigma}\frac{1}{p_{ij}}\frac{dp_{ij}}{d\Delta}. \tag{27}$$

Substituting these in (26) and rewriting we arrive at

$$\begin{aligned}\frac{1}{X_i}\frac{dX_i}{d\Delta} &= -\left[\sum_{j\in\mathbb{J}} \frac{\tau_{ij} q_{ij}}{X_i}\left((1-\sigma)\left(\frac{p_{ij}}{P_j}\right)^{1-\sigma} + \sigma\right)\right]\frac{1}{p_{ij}}\frac{dp_{ij}}{d\Delta} \\ &\quad - \sum_{i'\in\mathbb{J}\setminus\{i\}}\left[\sum_{j\in\mathbb{J}}(1-\sigma)\frac{\tau_{ij} q_{ij}}{X_i}\left(\frac{p_{i'j}}{P_j}\right)^{1-\sigma}\right]\frac{1}{p_{i'j}}\frac{dp_{i'j}}{d\Delta}.\end{aligned}$$

Using that Equation (6) implies

$$\frac{1}{p_{ij}}\frac{dp_{ij}}{d\Delta}=\frac{\tau_{ij}p_{ii}}{\tau_{ij}p_{ii}+t_{ij}}\frac{1}{p_{ii}}\frac{dp_{ii}}{d\Delta}$$

we get

$$\frac{1}{X_i}\frac{dX_i}{d\Delta}=-A_{ii}\frac{1}{p_{ii}}\frac{dp_{ii}}{d\Delta}-\sum_{i'\in\mathbb{J}\setminus\{i\}}A_{ii'}\frac{1}{p_{i'i'}}\frac{dp_{i'i'}}{d\Delta}, \tag{28}$$

where

$$A_{ii'}\equiv\begin{cases}\sum_{j\in\mathbb{J}}\frac{\tau_{ij}q_{ij}}{X_i}\left((1-\sigma)\left(\frac{\tau_{ij}p_{ii}+t_{ij}}{P_i}\right)^{1-\sigma}+\sigma\right)\frac{\tau_{ij}p_{ii}}{\tau_{ij}p_{ii}+t_{ij}} & \text{if } i'=i\\ \sum_{j\in\mathbb{J}}(1-\sigma)\frac{\tau_{ij}q_{ij}}{X_i}\left(\frac{\tau_{i'j}p_{i'i'}+t_{i'j}}{P_j}\right)^{1-\sigma}\frac{\tau_{i'j}p_{i'i'}}{\tau_{i'j}p_{i'i'}+t_{i'j}} & \text{if } i'\neq i\end{cases}. \tag{29}$$

Consider now the case where there are $N+1$ symmetric countries. The first country represents the exporter and the remaining countries potential importers. Since our regression equations consider the effects of production in the exporter country, we here assume that production in all other countries is unaffected by Δ. Hence $\frac{1}{X_i}\frac{dX_i}{d\Delta}=0$ for all $i\geq 2$.

We, furthermore, assume that all countries are symmetric in the following sense:

$$X\equiv X_i\;\forall i,\;Y\equiv Y_j\;\forall j,\tau_{ij}=\begin{cases}1 & \text{if } i=j\\ \tau & \text{if } i\neq j\end{cases}\text{ and } t_{ij}=\begin{cases}0 & \text{if } i=j\\ t & \text{if } i\neq j\end{cases}.$$

This implies that all prices are the same, $p_{ii}=p$ for all i and the price index (5) becomes

$$P_i=P\equiv\left[p^{1-\sigma}+N(\tau p+t)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}.$$

Furthermore, combining (4) and (25) gives

$$q_{ij}=\begin{cases}\frac{p^{-\sigma}}{p^{-\sigma}+N\tau(\tau p+t)^{-\sigma}}X\equiv q & \text{if } i=j\\ \frac{(\tau p+t)^{-\sigma}}{p^{-\sigma}+N\tau(\tau p+t)^{-\sigma}}X\equiv\tilde{q} & \text{if } i\neq j\end{cases}.$$

All this combined implies that

$$\begin{aligned}A_{ii}=A &\equiv \frac{q}{X}\left((1-\sigma)\left(\frac{p}{P}\right)^{1-\sigma}+\sigma\right)+N\frac{\tau\tilde{q}}{X}\left((1-\sigma)\left(\frac{\tau p+t}{P}\right)^{1-\sigma}+\sigma\right)\frac{\tau p}{\tau p+t}\\ A_{ii'}=\tilde{A} &\equiv (1-\sigma)\left[\left((N-1)\frac{\tau\tilde{q}}{X}+\frac{c}{X}\right)\left(\frac{\tau p+t}{P}\right)^{1-\sigma}\frac{\tau p}{\tau p+t}+\frac{\tau\tilde{q}}{X}\left(\frac{p}{P}\right)^{1-\sigma}\right],\end{aligned}$$

for all i and $i' \neq i$.

Under symmetry we furthermore have that

$$\frac{1}{p_{ii}}\frac{dp_{ii}}{d\Delta} = \frac{1}{p_{22}}\frac{dp_{22}}{d\Delta}$$

for all $i \geq 2$. Equation (28) for $i = 1, 2$ becomes (the second equation would be the same for any $i \geq 2$)

$$\begin{aligned}
\frac{1}{X_1}\frac{dX_1}{d\Delta} =& - A\frac{1}{p_{11}}\frac{dp_{11}}{d\Delta} - N\tilde{A}\frac{1}{p_{22}}\frac{dp_{22}}{d\Delta} \\
0 =& - \tilde{A}\frac{1}{p_{11}}\frac{dp_{11}}{d\Delta} - \left[A + (N-1)\tilde{A}\right]\frac{1}{p_{22}}\frac{dp_{22}}{d\Delta}
\end{aligned}$$

Solving for the price changes gives

$$\begin{aligned}
\frac{1}{p_{11}}\frac{dp_{11}}{d\Delta} =& - \frac{A + (N-1)\tilde{A}}{\left(A - \tilde{A}\right)\left(A + N\tilde{A}\right)}\frac{1}{X_i}\frac{dX_1}{d\Delta} \\
\frac{1}{p_{22}}\frac{dp_{22}}{d\Delta} =& \frac{\tilde{A}}{\left(A - \tilde{A}\right)\left(A + N\tilde{A}\right)}\frac{1}{X_i}\frac{dX_1}{d\Delta}.
\end{aligned}$$

Imposing symmetry in (27) gives

$$\begin{aligned}
\frac{1}{q_{12}}\frac{dq_{12}}{d\Delta} =& - (1-\sigma)\left(\frac{\tau p + t}{P}\right)^{1-\sigma}\frac{1}{p_{11}}\frac{dp_{11}}{d\Delta} \\
& - \left[(1-\sigma)\left(1 - \left(\frac{\tau p + t}{P}\right)^{1-\sigma}\right) + \sigma\frac{\tau p}{\tau p + t}\right]\frac{1}{p_{22}}\frac{dp_{22}}{d\Delta}.
\end{aligned}$$

Substituting for the price changes gives

$$\begin{aligned}
\frac{1}{q_{12}}\frac{dq_{12}}{d\Delta} =& \frac{(1-\sigma)\left(\frac{\tau p+t}{P}\right)^{1-\sigma}\left(A + (N-1)\tilde{A}\right)}{\left(A - \tilde{A}\right)\left(A + N\tilde{A}\right)}\frac{1}{X_i}\frac{dX_1}{d\Delta} \\
& - \frac{\left[(1-\sigma)\left(1 - \left(\frac{\tau p+t}{P}\right)^{1-\sigma}\right) + \sigma\frac{\tau p}{\tau p+t}\right]\tilde{A}}{\left(A - \tilde{A}\right)\left(A + N\tilde{A}\right)}\frac{1}{X_i}\frac{dX_1}{d\Delta}.
\end{aligned}$$

For the case with only proportional trade costs (i.e. $t = 0$), a decent amount of algebra yields

$$\frac{1}{q_{12}}\frac{dq_{12}}{d\Delta}=\left[1+(\sigma-1)\frac{\frac{q}{X}\left(\left(\frac{p}{P}\right)^{1-\sigma}-\left(\frac{\tau p}{P}\right)^{1-\sigma}\right)}{\sigma+(1-\sigma)\left(\frac{q}{X}-\frac{\tau\tilde{q}}{X}\right)\left(\left(\frac{p}{P}\right)^{1-\sigma}-\left(\frac{\tau p}{P}\right)^{1-\sigma}\right)}\right]\frac{1}{X_i}\frac{dX_1}{d\Delta}.$$

If we set $\tau = 1$, the expression in the square brackets is equal to one (as expected based on the case without trade costs considered above). With $\tau > 1$ it is larger than one. To see this, note that the denominator always is positive since both parenthesis in the numerator are smaller than one in absolute value. Furthermore, $(\sigma - 1)$ and the parenthesis in the numerator will always have the same sign. Hence, without per-unit trade costs, the effect of production on the traded quantity will always be (weakly) larger than one.

With per-unit trade costs the expression becomes significantly messier, but numerical computations show that the effect could be smaller or larger than one, but that it will be somewhat smaller than one if we assume only per-unit trade costs equal to the values found in the empirical analysis. However, for both types of trade costs, the effect will be relatively close to one.

C Normalization Using Importing Country

As a robustness check, we present results that include the effects of production in the importer country on traded quantities and unit values. For these regressions we employ an odds ratio gravity specification similar to that in Head and Mayer (2000). On the left-hand side, we use ratios of prices or quantities for trade between importing country j and exporting country i and the price or quantity of the non traded quantity in country j. Normalizing the data in this way subsumes any unobserved importer-product-year fixed effects, including the importer's price index. On the right-hand side, we include production in both countries.

For the model without trade costs, we can use Equation (12) to derive the quantity equation

$$\log\left(\frac{q_{ij}}{q_{jj}}\right)=\log(X_i)-\log(X_j)$$

and Equation (13) to derive the price equation

$$\log\left(\frac{p_{ij}}{p_{jj}}\right)=-\frac{1}{\sigma}\log(X_i)+\frac{1}{\sigma}\log(X_j).$$

For the model with trade costs, Equation (14) implies

$$\log\left(\frac{q_{ij}}{q_{jj}}\right) = -\sigma \log\left(\frac{p_{ij}}{p_{jj}}\right).$$

Hence, the predictions about sizes of coefficients carry over to this setting where we use ratios on the left-hand side.

We do not have direct data on either q_{jj} or p_{jj}. We construct q_{jj} using domestic production minus total reported exports. For p_{jj} we use the domestic price of the good reported by FAOSTAT. This measure of quantity is potentially problematic since it relies on the data capturing all exports of the good. The price measure is also problematic since it is the average domestic price paid for the good in the importing country, which is not necessarily the domestically produced variety of the good. As instruments for production we now use yield in the importing and exporting countries. The results for the quantity and price regressions are given in Tables C.1 and C.2 respectively. We can see that the results for the exporting country are similar to those in the baseline regressions (in Tables 2 and 4). The results in Table C.1 suggest that the effect of contemporaneous production in the importing country is (in absolute value) larger than one, while lagged importer production is less important. Since the left hand side variable is imported quantity relative to consumed quantity of the domestically produced variety, the relatively strong effect of importer production is consistent with a relatively weak response of international trade. If a change in domestic production results in a relatively small change in exports, the change in consumption of the domestically produced quantity must be relatively large. Similarly, looking at the effects in the price regressions in Table C.2, the point estimate for production in the exporting country is similar to those in the baseline regression (Table 4) while the effects of importer production are larger. These results are consistent with the existence of larger trade frictions for internationally traded goods compared to domestically traded goods.

D Additional Figures and Tables

Table C.1: Traded quantities, importer reference country

	(1)	(2)	(3)	(4)
Exporter production: $\Delta\ln(X_{git})$	0.328***	0.329***	0.313***	0.321***
	(0.0652)	(0.0636)	(0.0618)	(0.0624)
Lagged exporter prod.: $\Delta\ln(X_{gi,t-1})$	0.142***	0.149***	0.144***	0.144***
	(0.0516)	(0.0509)	(0.0417)	(0.0409)
Importer prod.: $\Delta\ln(X_{gjt})$	-1.365***	-1.359***	-1.345***	-1.356***
	(0.0504)	(0.0486)	(0.0451)	(0.0473)
Lagged importer prod.: $\Delta\ln(X_{gj,t-1})$	-0.0790**	-0.0694*	-0.0723**	-0.0711**
	(0.0389)	(0.0385)	(0.0312)	(0.0281)
$\Delta\ln(pop_{it})$	0.0611	-0.107		
	(0.482)	(0.518)		
$\Delta\ln(pop_{jt})$	0.172	0.164		
	(0.776)	(0.760)		
$\Delta\ln(gdppc_{it})$	0.0537	-0.0892		
	(0.173)	(0.166)		
$\Delta\ln(gdppc_{jt})$	1.122***	0.899***		
	(0.215)	(0.178)		
Fixed Effects		t	it	it, jt
Kleibergen-Paap LM stat:	21	21	21	19
Kleibergen-Paap Wald F stat:	120	109	138	128
Observations	141,572	141,572	184,552	184,471
R-squared	0.042	0.043	0.065	0.096

Notes: Dependent variable is first-differenced ratio of log quantity exported from country i to country j to logged domestic production (net of exports) in country j , using importer-reported values. A constant term is included, but not reported, in all specifications Robust standard errors in parenthesis, clustered by exporter and importer country.
*** p<0.01, ** p<0.05, * p<0.1

Table C.2: CIF unit values, importer reference country

	(1)	(2)	(3)	(4)
Exporter production: $\Delta \ln(X_{git})$	-0.0219	-0.0435***	-0.0484***	-0.0511***
	(0.0163)	(0.0145)	(0.0181)	(0.0176)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.00825	-0.0267	-0.0251*	-0.0262**
	(0.0184)	(0.0170)	(0.0135)	(0.0131)
Importer prod.: $\Delta \ln(X_{gjt})$	0.222***	0.206***	0.220***	0.201***
	(0.0253)	(0.0239)	(0.0200)	(0.0226)
Lagged importer prod.: $\Delta \ln(X_{gj,t-1})$	0.0578***	0.0462**	0.0393**	0.0431**
	(0.0222)	(0.0214)	(0.0176)	(0.0180)
$\Delta \ln(pop_{it})$	0.0163	0.185		
	(0.250)	(0.215)		
$\Delta \ln(pop_{jt})$	-0.231	-0.152		
	(0.526)	(0.528)		
$\Delta \ln(gdppc_{it})$	-0.00454	0.0734**		
	(0.0514)	(0.0364)		
$\Delta \ln(gdppc_{jt})$	-0.336***	-0.247**		
	(0.103)	(0.0959)		
Constant	0.0130**			
	(0.00549)			
Fixed Effects		t	it	it, jt
Kleibergen-Paap LM stat:	21	20	21	19
Kleibergen-Paap Wald F stat:	139	123	276	191
Observations	140,825	140,825	185,863	185,837
R-squared	0.003	0.008	0.027	0.104

Notes: Dependent variable is first-differenced ratio of log unit values for exports from country i to country j to logged domestic prices in country j , using importer-reported (CIF) values.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter and importer country.

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

Table D.1: List of FAOSTAT Commodities

Almonds	Eggplants	Peas, dry
Apples	Garlic	Peas, green
Apricots	Grapefruit and pomelo	Pineapples
Asparagus	Grapes	Pistachios
Avocados	Groundnuts, in shell	Plums
Bananas	Hazelnuts (Filberts)	Poppy seed
Barley	Hops	Potatoes
Beans, dry	Kiwi fruit	Rapeseed or colza seed
Brazil nuts	Leeks and other alliaceous vegetables	Raspberries
Broad beans, Green	Lemons and limes	Rice, milled
Broad beans, dry	Lentils, dry	Rye
Buckwheat	Lettuce and chicory	Sesame seed
Cabbages	Linseed	Sorghum
Canary seed	Maize	Soybeans
Carrot	Mangoes	Spinach
Cashew nuts	Mate	Strawberries
Cassava	Melons, Cantaloupes	Dates
Cauliflowers and broccoli	Millet	Sunflower seed
Cherries	Mushrooms	Tangerines, mandarins etc.
Chestnuts	Mustard seed	Tea
Chick-peas, dry	Oats	Tomatoes, fresh
Chillies and peppers (green)	Onions, shallots (green)	Triticale
Cocoa beans	Oranges	Walnuts
Coconuts	Papayas	Watermelons
Coffee green	Peaches and nectarines	Wheat
Cucumbers and gherkins	Pears	

Based on observations from column (4) of Table D.5.

Table D.2: First stage results

	(1) $\Delta \ln(X_{git})$	(2) $\Delta \ln(X_{gi,t-1})$
Exporter yield: $\Delta \ln(\psi_{git})$	0.784***	-0.0656***
	(0.0283)	(0.0105)
Lagged exporter yield: $\Delta \ln(\psi_{gi,t-1})$	-0.0227**	0.776***
	(0.0102)	(0.0245)
Observations	540,453	540,453
R-squared	0.580	0.579

Notes: Dependent variable reported at the top of each column.

Robust standard errors in parenthesis, clustered by exporter country.

Exporter*year och importer*product*year fixed effects included in all specifications.

A constant term is included, but not reported, in all specifications.

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

Table D.3: Production shocks and import quantities by country

	(1) both OECD	(2) neither OECD	(3) origin OECD	(4) dest OECD
Exp. prod.:	0.265***	0.339***	0.248**	0.308***
$\Delta \ln(X_{git})$	(0.0491)	(0.0589)	(0.0983)	(0.0472)
Lagged exp. prod.:	0.188***	0.0578	0.313***	0.141***
$\Delta \ln(X_{gi,t-1})$	(0.0468)	(0.0605)	(0.0836)	(0.0417)
Kleibergen-Paap				
LM stat:	13	46	11	41
Wald F stat:	292	55	270	295
Observations	105,878	148,443	121,153	127,326
R-squared	0.255	0.300	0.353	0.223

Notes: Dependent variable is first-differenced log quantity exported from country i to country j, using importer-reported values.

Exporter*year och importer*product*year fixed effects included in all specifications.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter country.

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

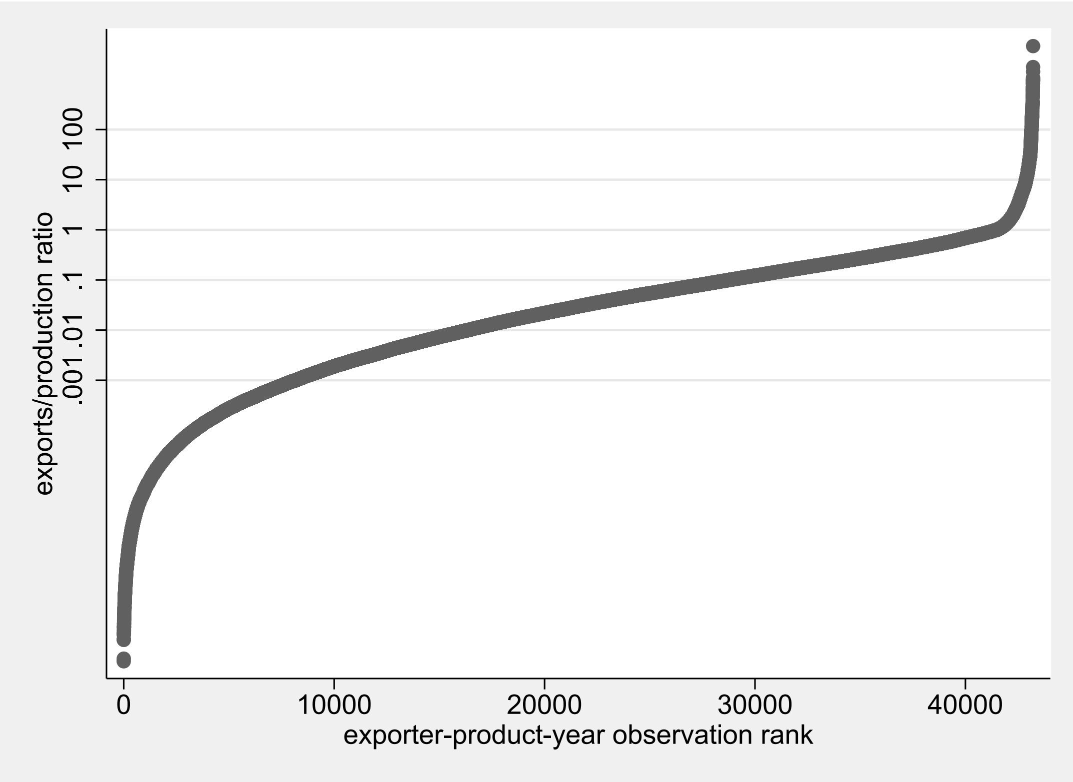

Figure D.1: Distribution of export intensities. Notes: Based on observations from column (4) of Table 4. Source: FAOSTAT

Table D.4: Production shocks and CIF unit values by country

	(1) both OECD	(2) neither OECD	(3) origin OECD	(4) dest OECD
Exp. prod.:	-0.0698***	-0.0609***	-0.0378**	-0.0344**
$\Delta \ln(X_{git})$	(0.0171)	(0.0129)	(0.0178)	(0.0147)
Lagged exp. prod.:	-0.0332*	-0.0106	-0.0372	-0.0273**
$\Delta \ln(X_{gi,t-1})$	(0.0174)	(0.0140)	(0.0226)	(0.0112)
Kleibergen-Paap				
LM stat:	13	46	11	41
Wald F stat:	292	55	270	295
Observations	105,878	148,443	121,153	127,326
R-squared	0.292	0.382	0.413	0.289

Notes: Dependent variable is first-differenced log unit values for exports from country i to country j, using importer-reported (CIF) values.

Robust standard errors in parenthesis, clustered by exporter country.

Exporter*year och importer*product*year fixed effects included in all specifications.

A constant term is included, but not reported, in all specifications.

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

Table D.5: Production shocks and (CIF) unit values, CEPII data

	(1)	(2)	(3)
Exporter production: $\Delta \ln(X_{git})$	-0.0526***	-0.0468***	-0.0418***
	(0.0124)	(0.00814)	(0.00816)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.0959***	-0.0399***	-0.0236***
	(0.0128)	(0.00660)	(0.00749)
$\Delta \ln(pop_{it})$	0.117	0.0279	
	(0.198)	(0.131)	
$\Delta \ln(gdppc_{it})$	0.377***	0.0688***	
	(0.0601)	(0.0258)	
$\Delta \ln(pop_{jt})$	-0.343***		
	(0.0845)		
$\Delta \ln(gdppc_{jt})$	0.312***		
	(0.0351)		
Fixed Effects		gjt	gjt, it
Kleibergen-Paap LM stat:	45	49	45
Kleibergen-Paap Wald F stat:	234	337	306
Observations	180,112	308,526	310,215
R-squared	0.006	0.255	0.267

Notes: Dependent variable is first-differenced log unit values for exports from country i to country j, using importer-reported (CIF) values.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter country.

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

Table D.6: Production shocks and import values

	(1)	(2)	(3)
Exporter production: $\Delta \ln(X_{git})$	0.241***	0.256***	0.242***
	(0.0393)	(0.0341)	(0.0309)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	0.0848*	0.181***	0.153***
	(0.0439)	(0.0354)	(0.0286)
$\Delta \ln(pop_{it})$	0.211	-0.0825	
	(0.391)	(0.567)	
$\Delta \ln(gdppc_{it})$	0.332***	-0.0303	
	(0.126)	(0.101)	
$\Delta \ln(pop_{jt})$	-0.420		
	(0.377)		
$\Delta \ln(gdppc_{jt})$	1.083***		
	(0.0948)		
Fixed Effects		gjt	gjt, it
Kleibergen-Paap LM stat:	46	48	46
Kleibergen-Paap Wald F stat:	142	231	337
Observations	224,652	417,342	540,453
R-squared	0.003	0.194	0.212

Notes: Dependent variable is first-differenced log value exported from country i to country j, using importer-reported values.

A constant term is included, but not reported, in all specifications

Robust standard errors in parenthesis, clustered by exporter country.

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

Table D.7: CIF versus FOB estimates, CEPII data

	(1) CIF	(2) FOB
Exporter production: $\Delta \ln(X_{git})$	-0.0490**	-0.0537***
	(0.0188)	(0.0192)
Lagged exporter prod.: $\Delta \ln(X_{gi,t-1})$	-0.0365**	-0.0475***
	(0.0165)	(0.0179)
Kleibergen-Paap LM stat:	47	47
Kleibergen-Paap Wald F stat:	138	138
Observations	37,296	37,296
R-squared	0.495	0.463

Notes: Dependent variable is first-differenced ratio of log unit values for exports from country i to country j relative to reference country k, using CIF trade unit values in column (1) and FOB trade unit values in column (2)
Robust standard errors in parenthesis, clustered by exporter and reference country.
Exporter*year and importer*product*year fixed effects included in all specifications.
A constant term is included, but not reported, in all specifications
specifications. *** p<0.01, ** p<0.05, * p<0.1

Table D.8: Poisson IV regression of traded quantities including no-trade observations

	(1)
Exporter production: $\ln(X_{git})$	0.414**
	(0.166)
Lagged exporter prod.: $\ln(X_{gi,t-1})$	0.557***
	(0.132)
Fixed effects:	gij
Observations	2,190,176

Notes: Dependent variable is traded quantity of good g from country i to country j
Robust standard errors in parenthesis, clustered by exporter country.
*** p<0.01, ** p<0.05, * p<0.1