Why Are Agricultural Goods Not Traded More Intensively: High Trade Costs or Low Productivity Variation?

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Abstract

This paper empirically studies the sizes of agricultural trade costs and productivity variation in the agriculture sector. In a general Ricardian trade model, I identify these two factors as possible causes of the observed low trade intensity of agricultural goods. Using data on bilateral trade flows, prices of agricultural goods, and sectoral production from a sample of 46 countries, I estimate the variation of agricultural productivity as well as trade costs on agricultural and manufactured goods. I find that trade costs are substantial, with agricultural trade costs roughly twice as large as manufacturing trade costs. Moreover, consistent with the existing literature, I find that distance is the dominant part in the estimated trade costs. Lastly, relative to existing estimates of the heterogeneity of manufacturing productivity, the heterogeneity of agricultural productivity is large. These findings suggest that high trade costs are the main impediments to agricultural trade and that there exist large unrealized gains from trading agricultural goods.

Key Words: Trade Costs; Agricultural Trade Costs; Variation of Productivity; Eaton-Kortum Trade Model
JEL Classifications: F11; F13; F17

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1 Introduction

Agricultural goods are traded less than manufactured goods. In 1997, the total value of manufacturing trade was more than 8 times larger than that of agricultural trade.[1] This is despite that the value of manufacturing production was less than 4 times larger than that of agricultural production in 1997. Therefore, more than half of the difference in trade volume between agricultural goods and manufactured goods is due to the lower trade intensity of agricultural goods. To see this, consider a common measure of trade intensity: the ratio of the sum of total exports and imports to gross production. In 1997 and for a sample of 48 countries, trade intensity of agricultural goods was without exception lower than that of manufactured goods. Furthermore, agricultural goods also tend to be produced more locally. For the same group of 48 countries, 33 (about 69%) of them have a higher domestic share of production in agricultural goods than manufactured goods.

Standard trade theories offer two possible explanations to the low trade intensity of agricultural goods. First, trade barriers on agricultural products could be high. Second, the degree of comparative advantage in agriculture could be so low that gains from trading agricultural goods are small. As a result, countries do not have much incentive to engage in agricultural trade with each other, regardless the trade barriers on agricultural goods.

It is important to determine the relative importance of these two factors, as agricultural goods both play an essential economic role and their production often employs the majority of productive resources in low income countries.[2] On the one hand, if high agricultural trade costs are the main impediments, it suggests that countries may not be fully enjoying the gains from agricultural trade because of high trade barriers. As a result, efforts should be directed to measures that can lower trade barriers on agricultural goods. On the other hand, if the degree of comparative advantage in agriculture is small which implies the lack of gains from trading agricultural goods, such practices will not be fruitful.

Motivated by the potential importance of agricultural trade and the lack of it, this essay asks why agricultural goods are not traded more intensively. To quantitatively disentangle the two possible causes, I develop a simple general equilibrium trade model similar to that in Eaton and Kortum (2002). In addition to the tradeable manufacturing sector in the Eaton-Kortum model, the model in this essay also includes a tradeable agriculture sector. In the model, bilateral trade flows are determined by three factors: each country's production costs, bilateral trade costs, and the variation of productivity, which governs the degree of comparative advantage in the tradeable sectors. An advantage of using the Eaton-Kortum framework is that one can derive log-linear gravity equations that relate bilateral trade flows to these three factors. The parameters in these structural equations can then be estimated by common estimation methods such as ordinary least-squares (OLS).

However, given that bilateral trade flows are *jointly* determined by trade costs and productivity variation, one faces the challenge of separating their effects from one another. This is important because the observed low trade intensity of agricultural goods can be rationalized by either small variation of productivity in the agriculture sector or large agricultural trade costs, and hence the

[1] The year 1997 was chosen because the analysis in this essay is based on 1997 data. If anything, the differences between agricultural trade and manufacturing trade have been even larger after 1997.

[2] For instance, in 1997, the poorest five countries in the Penn World Table 6.3 on average devote 58% of their workforce to agriculture, as compared to less than 4% for the richest five countries. See Xu (2012) for more a detailed discussion.

estimation of one factor directly affects the estimation of the other. For example, if one finds that the variation of agricultural productivity is large, the fact that agricultural goods are not traded intensively must necessarily mean that agricultural trade costs are large. As a result, an underestimated variation of agricultural productivity will lead to underestimations of agricultural trade costs.

To address this concern, I follow an approach in Eaton and Kortum (2002), where the estimations are carried out sequentially. First, the variation of agricultural productivity is estimated with *independent* measures of agricultural trade costs. Specifically, bilateral trade costs are approximated by observed maximum price difference on individual agricultural goods between two countries. This approach works, as Eaton and Kortum argue, because a simple no-arbitrage condition ensures that price differences cannot exceed bilateral trade costs, and hence the maximum price difference is a good proxy for trade costs. Second, using the estimated value of the productivity variation, I estimate bilateral trade costs from structural equations that relate bilateral trade flows to countries' production costs, variation of productivity, and bilateral trade costs.

The estimations in essay are based on data on bilateral trade flows and prices of agricultural goods from a sample of 46 countries. There are three main findings. First, relative to existing estimates of the variation of manufacturing productivity in the literature, I find that the variation of agricultural productivity is large. Specifically, my baseline estimate of the variation of agricultural productivity implies that the distribution of agricultural efficiency has a standard deviation that is 75% larger than that of the distribution of manufacturing efficiency in Eaton and Kortum (2002) and 17% larger than those in Waugh (2009).

Second, consistent with the existing literature, I find that distance is the dominant part in the estimated trade costs, and that its effects are large. After dividing bilateral distance into six intervals, I find that, as bilateral distance increases, its effects on increasing trade costs become larger. Specifically, for every one dollar worth of agricultural and manufactured goods, distance adds at least 1.89 and 0.89 dollars to the cost of shipping from one country to another. On the other hand, for a pair of countries in the largest distance interval, the effects of distance on increasing agricultural and manufacturing trade costs are equivalent to 4.89 and 2.65 dollars.

Third, while trade costs on both tradeable goods are substantial, agricultural trade costs are much larger than manufacturing trade costs. Specifically, for every one dollar worth of agricultural goods, trade costs are at least 2.7 dollars and can be as large as 5.48 dollars. On the other hand, trade costs on manufactured goods range from 1.77 to 2.65 dollars. This indicates that agricultural trade costs are at least twice as large as manufacturing trade costs. Combined with the finding of large variation of agricultural productivity, it suggests that the low trade intensity of agricultural goods is largely due to high agricultural trade costs.

The estimation strategy employed in this essay largely addresses what Anderson and van Wincoop (2004) identify as the two main problems in measuring and inferring trade costs. First, by estimating gravity equations, the estimated trade costs in this essay are broad measures of trade costs, which include "all costs incurred in getting a good to a final user". This is important, they argue, since direct measures of trade costs, such as policy barriers, transport costs, and distribution costs, are "remarkably sparse and inaccurate" and make up only a small portion of the costs incurred by trading partners. Second, the model implied gravity equations in this essay satisfy what Anderson and van Wincoop (2004) categorize as "Theory-Based Gravity" and the property of "trade separability". Namely, estimations are based on equations that are derived from a general equilibrium trade model, and their existence is independent of the allocation of production and consumption in the model. As Anderson and van Wincoop (2003) show, unlike the traditional gravity equations, gravity equations with the aforementioned properties tend not to suffer from the problem of omitting variables and yield unbiased estimates of trade costs.

This essay is closely related to the large literature on measuring and estimating agricultural trade costs. However, most existing studies suffer from at least one of the two problems described in Anderson and van Wincoop (2004). For example, in studies such as van der Mensbrugghe and Beghin (2004), agricultural trade costs are computed using data on tariffs, quotas, and price subsidies in agriculture. As a result, their baseline agricultural trade costs are much lower. The ad valorem agricultural trade costs in van der Mensbrugghe and Beghin (2004) range from 16% to 38%, which are drastically smaller than the estimates provided by this essay, which range from 150% to 413%. On the other hand, studies such as Blake, Rayner, and Reed (1999), estimate agricultural trade costs from traditional gravity equations that are not derived from a trade model. As a result, the gravity equations which the estimations are based on appear ad hoc and are prone to specification errors.

This essay is also closely related to a large gravity literature, which investigates the determinants of observed trade flows. In particular, this essay is most closely related to studies that estimate trade barriers using structural models. For instance, Helpman, Melitz, and Rubinstein (2007) derive gravity equations from the Melitz model and study barriers to bilateral trade flows. This essay differs in that it explicitly considers agricultural trade as a separate category in the general merchandize trade and is based on a very different structural model. There are also several studies that utilize the Eaton-Kortum framework to estimate trade barriers. Examples include Eaton and Kortum (2002), Waugh (2009), and Fieler (2010). However, all these studies abstract from agricultural trade and often equate merchandize trade to trade in manufactured goods.

Tombe (2011) is closely related to this essay. As part of the quantitative exercise, Tombe estimates agricultural and manufacturing trade costs using structural equations from the Eaton-Kortum framework that are similar to those in this essay. However, unlike Tombe (2011) where the value of the variation of agricultural productivity is *imposed on*, this essay *estimates* the variation of agricultural productivity by utilizing data on producer prices of individual agricultural goods.[3] The estimation results in this essay indicate that in Tombe (2011) the true variation of productivity in agriculture is likely to be underestimated by about 50% and, consequently, agricultural trade costs are underestimated by at least 50%. This finding highlights the need to estimate *both* the impacts of trade costs and the variation of productivity in the tradeable sectors.

The rest of the essay proceeds as follows. Section 2 details three empirical facts in support of the low trade intensity of agricultural goods. Section 3 describes the model. Section 4 details the data and the estimation. Section 5 concludes.

[3] Specifically, Tombe (2011) sets the variation of agricultural productivity to 0.14, where the baseline estimated value in this essay is 0.21. One reason that the variation of agricultural productivity is not estimated in Tombe (2011) is that, as the author argues, available data on the prices of tradeable goods including agricultural goods are often retail prices, which make them unsuitable for the estimation. This essay addresses this problem by using producer prices of agricultural goods.

2 Empirical Evidence on the Low Trade Intensity of Agricultural Goods

In this section I document three empirical facts in support of the low trade intensity of agricultural goods. First, in terms of trade volume, agricultural goods are traded much less than manufactured goods, and that it cannot be entirely accounted for by the larger size of manufacturing production. Second, for a sample of 48 countries, trade intensity of agricultural goods is lower than that of manufactured goods. Last, relative to that of manufacturing production, the domestic share of agricultural production is higher for a large number of countries.

As a first look at the data, I examine how agricultural trade compares to manufacturing trade as a share of merchandize trade and whether the differences are due to the different size of their production. According to trade data from Food and Agriculture Organization of the United Nations (FAO), in 1997 the volume of world agricultural trade was about 8.3% of total world merchandize trade. On the other hand, data from the World Bank's World Development Indicators (WDI) show that in the same year the volume of world manufacturing trade was about 76.2% of total world merchandize trade. This means that, in terms of trade volume, manufacturing trade was about 818% larger than agricultural trade.

While it is true that the world also produces more manufactured goods, the difference between manufacturing production and agricultural production cannot fully account for the large difference in trade volume. In particular, production data from the WDI show that, in 1997, agriculture as a share of world GDP was about 4.2% while it was 20.3% for manufacturing. This means that the value of manufacturing production was about 383% larger than that of agricultural production. Therefore, the difference in the value of production between agriculture and manufacturing accounts for less than half of the difference in trade volume. This suggests that, agricultural goods are not only traded less than manufactured goods, but also traded *less intensively* than manufactured goods.

The finding that trade intensity of agricultural goods is lower than that of manufactured goods is robust and holds true for a wide range of countries. To see this, consider a common measure of trade intensity: the ratio of the sum of total exports and imports to gross production. Based on 1997 data from the Global Trade Analysis Project (GTAP) data base (version 5), Figure 1 compares the trade intensity of agricultural goods to that of manufactured goods for a group of forty-eight countries.[4] This group of countries is a representative sample of the individual economies in the world, as it covers a wide range of income levels, from 0.03 (Uganda) to 0.82 (Denmark) relative to the U.S.'s real GDP per capita.

One can clearly see that *all* observations are above the forty-five degree line in Figure 1. This indicates that for *all* sample countries agricultural goods are traded less intensively than manufactured goods. Moreover, for 39 of the 48 countries (more than 80% of the sample), this measure of trade intensity of manufactured goods is at least twice as large as that of agricultural goods.

The two empirical facts discussed above are consistent with a large number of studies in the literature of agricultural trade, which also find that agricultural goods are traded less intensively than other types of tradeable goods. For example, after examining detailed trade data on agri-

[4] 48 is the maximum number of countries GTAP (version 5) has data on.

cultural goods and other traded goods, Aksoy (2004) concludes that the "trade-to-output ratios in agriculture" are substantially smaller than those in"manufacturing and services". Focusing on trade policies, the author argues that this is consistent with the fact that the degree of trade liberalization in manufacturing has been much higher than that in agriculture since 1990.

Besides trade intensity, one can also compare the ratio of self-sufficiency of agricultural goods to that of manufactured goods. Calculated as the ratio of gross production to gross production minus net exports (total exports minus total imports), it measures the share of a country's supply of a certain good originates from its own production. From Figure 2, one can see that for most countries, this ratio is higher for agricultural goods than manufactured goods. Specifically, 33 of the 48 countries (about 70% of the sample) have a higher self-sufficiency ratio on agricultural goods than manufactured goods. This means that for these countries the domestic share of agricultural production is higher than that of manufacturing production.

In summary, the three empirical facts discussed above show that, relative to other tradeable goods such as manufactured goods, agricultural goods are traded less intensively.

3 The Model

The model extends the multi-country Ricardian trade model in Eaton and Kortum (2002) to include two tradeable sectors: agriculture and manufacturing. As in Dornbusch, Fischer, and Samuelson (1977), this framework features a continuum of tradeable goods in each tradeable sector.

3.1 Tradeable Goods Sectors

The world economy consists of n countries. Within each country i, there are two tradeable sectors: agriculture (a) and manufacturing (m). A continuum of intermediate goods, indexed by $x^a, x^m \in [0,1]$, exist in each tradeable sector. The production of intermediate agricultural good $q_i^a(x^a)$ and intermediate manufactured good $q_i^m(x^m)$ is constant-return and given by:

$$\begin{aligned} q_i^a(x^a) &= z_i(x^a)^{-\theta^a} c_i^a\,, \\ q_i^m(x^m) &= z_i(x^m)^{-\theta^m} c_i^m\,, \end{aligned}$$

where $z(x^a)^{-\theta^a}$ and $z(x^m)^{-\theta^m}$ are the productivities used in producing x^a and x^m. c_i^a and c_i^m are the unit costs of producing each intermediate tradeable good x^a and x^m in country i. It is assumed that θ^a and θ^m are the same across countries, i.e. both parameters are sector-specific but not country-specific.

3.2 Distribution of Productivity

As in Eaton and Kortum (2002), productivities $z_i(x^a)$ and $z_i(x^m)$ are assumed to be random variables independently drawn from a density function that is exponential with parameters λ_i^a and λ_i^m. $z_i(x^a)$ and $z_i(x^m)$ are then amplified by the parameters θ^a and θ^m.

In this environment, the parameters λ_i^a and λ_i^m govern country i's average efficiency level in the agriculture and manufacturing sector. The larger the λ_i^a or λ_i^m, the more competitive country

i tends to be in the respective tradeable sector. Parameters θ^a and θ^m, on the other hand, control the dispersion of the distribution from which productivities $z_i(x^a)$ and $z_i(x^m)$ are drawn. As a result, θ^a and θ^m directly determine the degree of comparative advantage in their respective sector. The larger θ^a or θ^m is, the more dispersed the productivity draws are relative to the mean. Hence countries are more likely to trade with each other, as there exist larger gains from trade.

In each tradeable sector of country i there exists a firm that simply aggregates the tradeable intermediate goods. The productions of aggregate agricultural and manufactured good are given by:

$$
\begin{aligned}
Q_i^a &= \left[\int_0^\infty q_i^a(x^a)^{1-1/\eta}\phi(x^a)dx^a\right]^{\eta/(\eta-1)}, \\
Q_i^m &= \left[\int_0^\infty q_i^m(x^m)^{1-1/\eta}\phi(x^m)dx^m\right]^{\eta/(\eta-1)}.
\end{aligned}
$$

3.3 International Trade

Trade costs are assumed to take the form of "iceberg" trade costs, which are positive ad valorem costs required to ship one unit of tradeable good from one country to another country. These trade costs are the same within sectors, but different across sectors.

Respectively, let τ_{ij}^a and τ_{ij}^m be the trade costs on intermediate agricultural goods and intermediate manufactured goods, from country j to country i. It is assumed that $\tau_{ij} > 1$ for $j \neq i$ and $\tau_{ii} = 1$ for all i, as well as that it obeys the triangle inequality: $\tau_{ij} \leq \tau_{ik}\tau_{kj}$ for all i, j, k. Therefore, given trade costs τ_{ij}^a and τ_{ij}^m, the prices of country i importing tradeable goods x^a and x^m from country j are:

$$
\begin{aligned}
p_{ij}^a(x^a) &= (x^a)^{\theta^a} c_j^a \tau_{ij}^a, \\
p_{ij}^m(x^m) &= (x^m)^{\theta^m} c_j^m \tau_{ij}^m.
\end{aligned}
$$

When country i is open to trade, the producer that delivers the lowest price for $q^a(x^a)$ or $q^m(x^m)$ in i captures the market for that particular good:

$$p_i^a(x^a) = \min\{p_{ij}^a(x^a) : j = 1, ..., n\}, \tag{1}$$
$$p_i^m(x^m) = \min\{p_{ij}^m(x^m) : j = 1, ..., n\}. \tag{2}$$

Let P_i^a and P_i^m be the prices of aggregate agricultural good and aggregate manufactured good in country i. By making use of the properties of the extreme value distribution, one can show that the prices of the aggregate agricultural goods and manufactured goods are:

$$P_i^a = \Upsilon\left[\sum_{j=1}^n (c_j^a \tau_{ij}^a)^{-1/\theta^a} \lambda_j^a\right]^{-\theta^a}, \tag{3}$$

$$P_i^m = \Upsilon\left[\sum_{j=1}^n (c_j^m \tau_{ij}^m)^{-1/\theta^m} \lambda_j^m\right]^{-\theta^m}, \tag{4}$$

where Υ is a collection of constants.[5]

Let D^a_{ij} and D^m_{ij} be country j's share of country i's total spending on agricultural goods and manufactured goods. One can show that:

$$D^a_{ij} = \frac{(c^a_j \tau^a_{ij})^{-1/\theta^a} \lambda^a_j}{\sum_{k=1}^n (c^a_k \tau^a_{ik})^{-1/\theta^a} \lambda^a_k}, \quad (5)$$

$$D^m_{ij} = \frac{(c^m_j \tau^m_{ij})^{-1/\theta^m} \lambda^m_j}{\sum_{k=1}^n (c^m_k \tau^m_{ik})^{-1/\theta^m} \lambda^m_k}. \quad (6)$$

4 Estimating Variation of Agricultural Productivity and Sectoral Trade Costs

The estimation in this section proceeds in two steps. First, the variation of technology in agriculture is estimated with *independent* measures of agricultural trade costs. Second, after deriving the values of sectoral productivity variation, trade costs on agricultural and manufactured goods are estimated. The estimation is based on model implied structural gravity equations that relate bilateral trade flows to the variation of productivity and trade costs in each tradeable sector.

4.1 Data

Data from a group of 46 countries are used, and they are from 1997. Data on the bilateral trade flows and gross productions of agricultural and manufactured goods are from the Global Trade Analysis Project (GTAP). These data are mainly used in constructing bilateral trade shares D^a_{ij} and D^m_{ij} as:

$$D^{a,m}_{ij} = \frac{\text{Imports}_{ij}}{\text{Gross Agricultural Production} - \text{Total Exports}_i + \text{Imports}_i},$$

$$D^{a,m}_{ii} = 1 - \sum_{j \neq i}^{n} D^a_{ij}.$$

Data on the prices of individual agricultural goods are used in the estimation of the variation of technology in agriculture. They are from the PriceSTAT database of the Food and Agriculture Organization of the United Nations (FAO). PriceSTAT is a database on the prices of over 140 individual agricultural goods for more than 130 countries. These price data are producer price and denominated in the unit of either local currency per tonne or U.S. dollar per tonne, and each observation corresponds to the individual agricultural price $p^a_i(x^a)$ in equation (1).

Lastly, data on distance, border, and language are from Centre D'Etudes Prospectives Et D'Informations Internationales (http://www.cpeii.fr).

[5] See Alvarez and Lucas (2007) for a detailed derivation.

4.2 High Agricultural Trade Costs and Large Variation of Agricultural Productivity: Evidence from Price Data

Before estimating the relative effects of trade barriers and the variation of agricultural productivity in determining the low trade intensity of agricultural goods, in this section I examine how the prices of agricultural goods differ across countries. Given that they are producer prices that exclude most types of distribution costs and are expressed in the same currency and same unit ($USD/tonne), the price data from FAO enables cross-country comparison on agricultural prices and their implied trade barriers.

I first examine how the prices of the same individual agricultural goods differ across countries. For the 48 countries sampled by Figure 1, I calculate price difference as the ratio of the prices of the same agricultural good in two countries. This calculation is carried out for all agricultural goods in the FAO database as long as price data are available for a pair of countries. In total, there are 50,380 observations.[6] Summary statistics of the calculated price differences are provided in Table 1, and Figure 3 plots the distribution of all calculated price ratios.

From Table 1 and Figure 3, one can see that prices of agricultural goods differ substantially across countries. For example, more than 28% of the observed price differences exceed 2.5, which indicates that the price of the same agricultural good in one country is more than 150% larger than in another country. Moreover, it is not uncommon to observe large price differences. About 4.3% of the sample (2166 observations) have a price ratio larger than 7.5 - a 650% price difference between two countries. More than 1% of the sample (more than 503 observations) are larger than 12.5, which indicates the price of the same agricultural good in one country is more than 11 times larger than in another country.

To further focus the discussion on cross-country differences in agricultural prices, Figure 4 surveys the prices of eight agricultural goods.[7] These eight agricultural goods are chosen because they have the most observations among all the agricultural goods in the FAO database. Figure 4 clearly shows that the law of one price does not hold. It is not uncommon for the price of the same agricultural good in two countries to differ by more than 200%. It is worth noting that the country with the highest price or with the lowest price changes constantly. No particular country is consistently having high or low prices for its agricultural goods.

That the law of one price fails to hold suggests that there are significant barriers to trading agricultural goods. If this were not the case, then the no-arbitrage condition would imply that the prices of individual agricultural goods should be similar across countries. Figure 3 and 4 clearly reject this notion.

After examining *absolute* agricultural prices *across* countries, I turn to *relative* prices of agricultural goods *within* each country. If within a country input costs are similar (as in this essay's model) for a pair of agricultural goods, the ratio of output prices should be approximately equal to relative productivity. Therefore, the distribution of observed relative agricultural prices provides a measure of the dispersion of productivity in agriculture.

[6] Except for the case of two countries having the exact same price for an agricultural good, for each pair of countries on one agricultural good there will be two calculated price ratios - one greater than one and another smaller than one. To avoid repetitive reporting, I only include the ones that are equal or greater than one.

[7] Summary statistics are provided in Table 2.

Figure 5 surveys the relative prices of five pairs of agricultural goods, and the summary statistics are provided in Table 3.[8][9] A similar pattern as Figure 4 is observed. The relative prices of the five pairs of agricultural goods all have wide distributions, suggesting that relative prices of agricultural goods differ substantially across countries. A larger than 200% difference in the relative prices of two agricultural goods is frequently observed. A comparison between Table 2 and 3 shows that the variability of the relative prices of agricultural goods is similar to that of the absolute prices of agricultural goods. That we observe relative prices differ considerably across countries suggests that there exist large cross-country differences in relative agricultural productivity.

Ideally, one would also like to compare the variation of agricultural prices in this section to that of prices of other tradeable goods such as manufactured goods. However, unlike agricultural prices, data on prices of a large sample of tradeable goods for a large sample of countries are hard to come by. A potential source of data is the International Comparison Program (ICP) from the World Bank. For example, in the latest round completed in 2005, the ICP has surveyed the prices of 129 goods in more than 100 countries. However, these data are not publicly available. I am currently in the process of requesting this data set from the World Bank office.

4.3 Estimating the Variation of Agricultural Productivity

This section describes the first step of the estimation procedure. In particular, the variation of agricultural productivity is inferred by estimating a structural equation that relates bilateral trade flows of agricultural goods to the ratio of two countries' agricultural prices, bilateral agricultural trade costs, and the target variable. Data on prices of individual agricultural goods and agricultural trade flows are used. This estimation strategy corresponds to the preferred method that yields the baseline value of the variation of productivity in manufacturing in Eaton and Kortum (2002).[10]

The estimated structural equation is derived from equation (5) by writing down the ratio of trade shares D^a_{ij} to D^a_{jj} as:

$$\frac{D^a_{ij}}{D^a_{jj}} = \left(\frac{P^a_j \tau^a_{ij}}{P^a_i}\right)^{-\frac{1}{\theta^a}} , \tag{7}$$

where D^a_{ij}/D^a_{jj} is the trade share of exporter j in country i, normalized by j's home trade share. P^a_i/P^a_j is the ratio of the prices of aggregate agricultural goods in country i and country j. θ^a is the variation of technology in agriculture, and τ^a_{ij} is the trade cost country j faces in exporting agricultural goods to country i.

[8] Again, these five pairs of agricultural goods are chosen for no particular reason other than they have the most observations in the sample.

[9] Compared to that of *absolute* prices of agricultural goods, a plotted distribution of all *relative* prices across countries is much less informative because it lacks a consistent measure that enables comparisons between relative prices of *different pairs* of agricultural goods. Therefore, I focus on how the relative prices of the *same pair* of agricultural goods differ across countries.

[10] Eaton and Kortum (2002) also consider two other methods to estimate the variation of productivity in manufacturing. The first method is based on the structural equation implied by this model that relates bilateral trade flows to wages and measures of country's average efficiency levels, such as national stocks of R&D and years of schooling. This approach is infeasible in my study as data on agricultural wages as well as country's R&D are not available for my sample countries. Another method Eaton and Kortum (2002) use is based on a structural equation similar to equation (7). However, as argued by the authors, this method tends to suffer from the "errors-in-variables" problem and overestimate the sectoral variation of productivity. As a result, I do not use this method.

Taking the log of equation (7) yields an expression that resembles a log-linear gravity equation:

$$\log\left(\frac{D^a_{ij}}{D^a_{jj}}\right) = -\frac{1}{\theta^a}\log\left(\frac{P^a_j \tau^a_{ij}}{P^a_i}\right). \tag{8}$$

Let χ_{ij} denote the ratio $\frac{P^a_j \tau^a_{ij}}{P^a_i}$, then the value of θ^a can be recovered by estimating the slope on $\log \chi_{ij}$ in equation (8).

Since bilateral trade flows are jointly determined by τ^a_{ij} and θ^a, I face an identification problem in estimating θ^a. To see this, suppose that the ratio of D^a_{ij} to D^a_{jj} is large, which suggests that agricultural trade intensity between i and j is relatively high. Given the observed price ratio $\frac{P^a_i}{P^a_j}$, this could be due to either high variation of agricultural productivity θ^a or low bilateral agricultural trade cost τ^a_{ij} (or the combination of the two). As a result, to estimate θ^a, one must first take a stand on the trade cost τ^a_{ij}.

As a measure on χ_{ij}, I follow Eaton and Kortum (2002) and use the model implication that, for each tradeable good, the ratio of its price in country i and country j ($p^a_i(x)/p^a_j(x)$) cannot exceed trade cost τ^a_{ij}. Therefore, one can approximate τ^a_{ij} by using the highest ratios of $p^a_i(x)/p^a_j(x)$ observed in the data.[11][12] As in Eaton and Kortum (2002), I use the mean of the ratios of prices of individual agricultural goods as the aggregate price ratio P^a_i/P^a_j.

In Figure 6, I plot the log of the ratio χ_{ij} against the log of normalized trade shares $\frac{D^a_{ij}}{D^a_{jj}}$. A point estimate of the variation of agricultural productivity θ^a is derived by estimating the slope on $\log(\chi_{ij})$, which is equal to $-\frac{1}{\theta^a}$ (see equation (8)). Two methods are used in the estimation: OLS (without intercept) and method-of-moments. They yield similar results for θ^a: $\hat{\theta^a} = 0.24$ for OLS and $\hat{\theta^a} = 0.21$ for method-of-moments. I use 0.21 as the baseline value.

Using data on 19 OECD countries, Eaton-Kortum (2002) provide three estimates for the variation of technology in manufacturing: 0.08, 0.12, and 0.28. 0.12 is the estimate obtained using the method described in this section. It is also the preferred estimate and used as the baseline value in Eaton and Kortum (2002). Using the same method and based on data from 43 countries, Waugh (2009) provides an estimate of 0.18 for the variation of technology in manufacturing. Compared to these estimates for manufacturing, the estimate $\hat{\theta^a} = 0.21$ suggests that the variation of technology in agriculture is high.[13]

Lacking data on prices of individual manufactured goods from the sample countries, I do not estimate the variation of technology in the manufacturing sector. Given that the estimation in Waugh (2009) is based on a group of countries that share similar characteristics to the sample countries in this essay, I use Waugh's estimate $\hat{\theta^m} = 0.18$ as the variation of technology in manufacturing in my study.

[11] In practice, as in Eaton and Kortum (2002), τ^a_{ij} is approximated by using the second highest observed value of the ratio $p^a_i(x)/p^a_j(x)$. The reason τ^a_{ij} is estimated by second-order statistics, rather than the maximum, is to reduce the potential impact of measurement error. Generally speaking, using the maximum of the observed price ratio yields higher bilateral trade costs. As a result, the estimated variation of productivity in agriculture tends to be smaller.

[12] Section 4.5 discusses the robustness of approximating trade costs τ^a_{ij} by maximum price differences in estimating θ^a.

[13] See Section 4.5 for a detailed discussion on the magnitude of θ^a and its implication on trade costs.

4.4 Estimating Trade Costs

After taking a stand on the magnitude of the variation of technology in the two tradeable sectors, I proceed to estimate trade costs. The estimation is based on the structural equation that defines bilateral trade shares (equation (5)):

$$\frac{D^a_{ij}}{D^a_{ii}} = \frac{(c^a_j \tau^a_{ij})^{-1/\theta^a} \lambda^a_j}{(c^a_i)^{-1/\theta^a} \lambda^a_i} .$$

Rewriting in logs:

$$\log\left(\frac{D^a_{ij}}{D^a_{ii}}\right) = S^a_j - S^a_i - \frac{1}{\theta^a} \log \tau^a_{ij} , \tag{9}$$

where S^a_j is defined as

$$S^a_j = \log \lambda^a_j - \frac{1}{\theta^a} \log c^a_j . \tag{10}$$

S^a_j can be thought as country j's "competitiveness" in exporting agricultural goods, as higher S^a_j implies a larger share of country i's spending on agricultural goods from country j. Holding everything else constant, the more efficient country j is in producing agricultural goods (higher λ^a_j) the more likely country j exports agricultural goods to country i (larger D^a_{ij}). On the other hand, the higher the unit cost of producing agricultural goods in country j (higher c^a_j) the less likely country j exports agricultural goods to country i (smaller D^a_{ij}).

To model trade costs τ^a_{ij}, I turn to the gravity literature. A number of studies, such as Eaton and Kortum (2002), Anderson and van Wincoop (2004), and Waugh (2009), find that distance is the main impediment to bilateral trade flows. This also seems to hold true for agricultural trade. In Figure 7, the normalized trade share $\frac{D^a_{ij}}{D^a_{ii}}$ is plotted against bilateral distance. One can clearly see that a negative relationship exists between the two variables, with a correlation of -0.46.

Motivated by the observation in Figure 7, I follow the gravity literature and assume that

$$\log \tau^a_{ij} = d^a_k + b^a + l^a + \epsilon^a_{ij} , \tag{11}$$

where d^a_k $(k = 1, ..., 6)$ are the effects of distance on the trade costs of agricultural goods, and distance is divided in six intervals (in miles): [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,maximum).[14] b^a is effect of shared border, and l^a is effect of having a common language.

The estimation of the trade equation on manufactured goods follows the same procedure. Results of the OLS estimations on agricultural trade costs and manufacturing trade costs are included in Table 4.

The estimated values of the parameters in Table 4 all have the expected signs. Namely, distance increases trade costs, while shared border and shared language help to reduce trade costs. However, quantitatively, the effects of distance are much larger than those of shared border and shared language. For example, the effects of distance are such that it requires at least additional 1.89 units and up to additional 4.48 units of agricultural goods to ship one unit from one country to

[14] As in Eaton and Kortum (2002), the estimation of distance effects are based on discreet intervals of distance. As argued in Anderson and van Wincoop (2004), this is a flexible way to model distance effects and tends "to be more robust to specification error."

another. One the other hand, shared border and shared language decrease agricultural trade costs by about 0.1 unit and 0.09 unit of the traded agricultural goods. Similar to the case of agricultural trade costs, the effects of distance on increasing manufacturing trade costs are more than 10 times (from 0.89 units to 2.65 units of manufactured goods) larger compared to the effects of shared border (0.06 units) and shared language (0.05 units) on reducing trade costs.

From Table 4, one can see that trade costs on both tradeable goods are substantial. The estimated bilateral trade costs on agricultural goods range from 2.70 to 5.48, while those on manufactured goods range from 1.77 to 3.65. This means that it requires at least 2.70 and 1.77 units of agricultural and manufactured goods to ship one unit of them from one country to another. Moreover, the required units of goods can be as high as 5.48 and 3.65 for agricultural and manufactured goods.

Lastly, the results in Table 4 also indicate that bilateral trade costs on agricultural goods are at least twice as large as those on manufactured goods. Specifically, for a pair of countries, agricultural trade costs are at least 50% and up to 63% larger than manufacturing trade costs.

The Eaton-Kortum model predicts that all bilateral trade shares are non-zero. In practice, zero bilateral trade flows are frequently observed in the data. For the 46 sample countries, about 26% of bilateral agricultural trade are zero, while about 13% are zero for manufacturing trade. To avoid possible bias from the omission of zero trade flows, I also estimate the trade equations using the poisson pseudo-maximum-likelihood method proposed in Silva and Tenreyro (2006). The results are included in Table 5. Compared to results in Table 4, one can see that OLS without zero trade tends to yield higher trade costs for both tradeable goods. However, quantitatively the differences, which range from 3% to 17%, are not in the order of magnitude. Results provided by the poisson pseudo-maximum-likelihood method still indicate substantial trade costs, with agricultural trade costs about twice as large as manufacturing trade costs.

4.5 Robustness and Discussion

The estimation results in Section 4.3 and 4.4 indicate that productivity variation is large in agriculture and that the low trade intensity in agricultural goods shown in Figure 1 is primarily due to high agricultural trade costs. In this section, I provide some discussions on the robustness of these findings.

It is worth emphasizing that estimations in this essay proceed sequentially and that the variation of agricultural productivity is determined *before* bilateral trade costs are estimated. This is importance since the estimated value of the variation of agricultural productivity directly affects the values of the estimated trade costs. To see this, first consider the case that the estimated variation of agricultural productivity is large. This suggests that gains from agricultural trade are large and, as a result, countries should have a lot of incentives in trading agricultural goods with one another. The fact that we observe the contrary must necessarily mean that *high* agricultural costs are preventing them from doing so. On the other hand, if the estimated variation of agricultural productivity is sufficiently small, it suggests that the available gains from agricultural trade are small, which provides few incentives for countries to trade agricultural goods. In this case, agricultural trade costs can be *either* high *or* low.

In fact, quantitatively, values of the estimated agricultural trade costs are highly sensitive to the estimated variation of agricultural productivity θ^a. For example, setting the baseline value 0.21 for θ^a to 0.14 - a value used in Tombe (2011) - will lower the estimated agricultural trade costs by about 50%. On the other hand, if θ^a is set to 0.24, which is another estimate provided in Section 4.3, agricultural trade costs would be 22% higher.

Is the baseline value 0.21 a reliable estimate for θ^a? A concern one may have is whether the use of observed price ratios on individual agricultural goods, as in Section 4.3, is a robust way to approximate bilateral agricultural trade costs. It is important because these approximated agricultural trade costs are used in estimating the variation of agricultural productivity θ^a and, consequently, affect the values of the estimated agricultural trade costs τ_{ij}^a. To ensure its robustness, I first check how much the ratio χ_{ij} will differ between using observed price ratios and the estimated bilateral trade costs in Section 4.4. As Figure 8 shows, the majority of the two measures of χ_{ij} are clustered around the forty-five degree line. Moreover, when the variation of agricultural productivity is estimated using the estimated agricultural trade costs provided in Table 4, OLS yields 0.25 and method-of-moment yields 0.22 for θ^a.

Compared to the baseline results of 0.24 for OLS and 0.21 for method-of-moment, the new estimates of 0.25 and 0.22 are larger, but only slightly so - less than 5%.[15] These larger estimated θ^a have two implications. First, it implies larger variance for the distribution of agricultural productivity. Specifically, the standard deviation of the productivity distribution increases by 4.2% with the new estimated θ^a.[16] Second, the larger estimated θ^a will result in higher estimated trade costs on agricultural goods. When 0.25 and 0.22 are used in estimating trade costs, agricultural trade costs are on average 7.7% larger than those estimated using the baseline values of θ^a (0.21 and 0.24).[17] These results imply that, if anything, the baseline estimated agricultural trade costs reported in Section 4.4 are *understated*.

A direct comparison of the estimated θ^a in this essay to the existing literature is difficult since, to the best of my knowledge, no prior study has estimated the variation of productivity in agriculture using the Eaton-Kortum framework. Compared to existing estimates for manufacturing, which range from 0.08 to 0.28, my estimates of 0.21 and 0.24 suggest that the variation of technology in agriculture is high. These estimates, however, are consistent with the conjectures of other researchers. For example, in Eaton and Kortum (2002), the authors state that "(since) productivity in agriculture or mining is likely to be much more heterogeneous across countries, applying our model to trade in these goods could well deliver a much (higher) value of θ".

The estimated manufacturing trade costs in this essay fall in the middle of the range of recent estimates. Compared to Eaton and Kortum (2002), these estimates are roughly 100% higher than their baseline manufacturing trade costs. This is due to two reasons. First, Eaton and Kortum (2002) estimate trade costs using data from 19 OECD countries. Since rich countries trade more intensively with each other, it is not surprising that trade costs are lower in Eaton and Kortum

[15] In contrast, the value used in Tombe (2011) - 0.14 - is about 50% smaller than my baseline value of the variation of agricultural productivity. This difference proves to be very important since the value of the estimated variation of agricultural productivity (θ^a) affects the estimated trade costs (τ_{ij}^a) non-linearly. In particular, a 5% larger θ^a leads to about 6% larger estimated trade costs, while a 17% smaller θ^a leads to about 30% smaller estimated trade costs.

[16] As in Eaton and Kortum (2002), the standard deviation is calculated as $(\pi\theta^a)/\sqrt{6}$.

[17] The fact that the new estimated θ^a and agricultural trade costs are higher implies that a fix point does not exist when one iterates on this process. This is because, given observed bilateral trade flows and price ratios ($\frac{D_{ij}^a}{D_{jj}^a}$ and $\frac{P_j^a}{P_i^a}$ in equation (7)), higher trade costs τ_{ij}^a will result in a higher estimated θ^a. When the higher θ^a is used in estimating τ_{ij}^a, it will in turn result in higher τ_{ij}^a. Therefore, both τ_{ij}^a and θ^a will just keep increasing if one iterates on this process. I am currently investigating this finding's implication on the consistency of the estimation strategy.

(2002), as the sample countries in this essay include more poor countries with lower trade intensity.[18] Second, Eaton and Kortum (2002) use a lower value (0.12) for the heterogeneity of manufacturing productivity. Generally speaking, given observed bilateral trade shares, lower dispersion of productivity implies lower trade costs. If 0.12 were used (as in Eaton and Kortum (2002)), my estimates of manufacturing trade costs are about 40% higher than their baseline estimates.

On the other hand, my estimates of manufacturing trade costs are about 60% lower than Waugh (2009). This is mainly because trade costs are allowed to be asymmetric in Waugh (2009). Specifically, in his study Waugh argues that rich countries systematically face lower trade costs than poor countries. As a result, the estimated impacts of distance, language and border on trade costs in Waugh (2009) are higher than the estimates provided in this essay since trade costs are symmetric and consequently represent more like averages for rich and poor countries.

Another finding in this essay is that agricultural trade costs are substantially larger than manufacturing trade costs. Although this essay is agnostic about the exact causes of the estimated trade costs, various direct measures do support larger trade costs on agricultural goods. Based on the GTAP data base, Figure 9 shows the ad valorem import tax rates for agricultural goods and manufacturing goods for a sample of 77 countries and regions. This measure of import tax rate includes a wide range of trade policies such as tariffs, quotas, and the like. One can clearly see that, for all sample countries, policy barriers on agricultural goods are substantially higher than those on manufactured goods. Moreover, as reported by Hummels (2001) and Hummels (2007), transportation costs on agricultural goods are on average about 50% higher than those on manufactured goods. This is mainly due to the low value-to-weight nature of agricultural products.

5 Conclusion

Why are agricultural goods not more intensively traded? Is it because trade costs are high on these goods or the gains from trading them are small? In this essay, based on structural gravity equations, I estimate both agricultural trade costs and the variation of technology in agriculture. I find that, relative to manufacturing trade, trade costs on agricultural goods are high and the variation of technology is large in agriculture. This finding suggests that there exist large potential gains from trade on agricultural goods.

[18] Of the 46 sample countries, 7 countries (15% of the sample countries) have a level of real GDP per capita that is less than 10% of the U.S.'s level. 13 countries (28% of the sample countries) have a level of real GDP per capita that is less than 20% of the U.S.'s level.

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Table 1: Summary statistics of absolute price differences of *all* agricultural goods

	Mean	Max	Mean	Max / Min	Standard Deviation	Within One Standard Deviation	Within Two Standard Deviations	Within Three Standard Deviations	
	1.00	38.82	2.56	38.82	2.59	83.7%	93.6%	97.0%	
	Within $[1, 2.5]$	Within $(2.5, 7.5]$	Within $(7.5, 12.5]$	Within $(12.5, 17.5]$	Within $(17.5, 22.5]$	Within $(22.5, 27.5]$	Within $(27.5, 32.5]$	Within $(32.5, 37.5]$	Within $(37.5, 40]$
Frequency (total 50380)	35942 (71.34%)	12272 (24.36%)	1523 (3.02%)	381 (0.76%)	144 (0.29%)	64 (0.13%)	30 (0.06%)	19 (0.04%)	5 (0.01%)

Table 2: Summary statistics of absolute prices of eight agricultural goods

Agricultural Good	Mean	Max	Mean	Max / Min	Standard Deviation	Within One Standard Deviation	Within Two Standard Deviations	Within Three Standard Deviations
Chicken	1553	3162	833	3.80	546	77%	93%	100%
Sheep	3211	8096	434	18.64	1549	72%	98%	98%
Milk	330	795	171	4.66	122.34	83%	95%	98%
Tomato	547	2039	110	18.57	437	85%	95%	98%
Cabbage	247	898	58	15.61	163	83%	98%	98%
Potato	227	531	44	12.18	132	66%	92%	100%
Apple	473	1743	74	23.72	333	84%	97%	97%
Banana	459	1301	126	10.29	336	79%	95%	100%

Table 3: Summary statistics of relative prices of five pairs of agricultural goods

Pair	Mean	Max	Mean	Max / Min	Standard Deviation	Within One Standard Deviation	Within Two Standard Deviations	Within Three Standard Deviations
Wheat / Rice	0.71	1.37	0.28	4.86	0.28	73%	96%	100%
Sheep / Chicken	0.62	3.21	0.23	13.82	0.49	93%	98%	98%
Tomato / Cabbage	2.60	10.0	0.38	26.08	1.95	79%	95%	97%
Apple / Banana	1.08	3.57	0.26	13.49	0.99	82%	91%	100%
Milk / Potato	1.91	4.76	0.44	10.88	1.15	72%	95%	100%

Table 4: Geographic barriers on tradeable goods

	Estimates		Std. Err.		% on Costs	
Variables	Ag.	Man.	Ag.	Man.	Ag.	Man.
Distance [0,375)	-5.05	-3.55	0.21	0.23	189	89
Distance [375,750)	-5.86	-4.15	0.13	0.14	242	111
Distance [750,1500)	-6.58	-4.86	0.10	0.10	298	140
Distance [1500,3000)	-7.44	-5.92	0.12	0.12	377	190
Distance [3000,6000)	-7.86	-6.56	0.05	0.06	421	226
Distance [6000,max)	-8.10	-7.20	0.06	0.06	448	265
Shared border	0.50	0.36	0.10	0.11	-10.0	-6.27
Shared language	0.45	0.30	0.18	0.20	-9.07	-5.26

Summary Statistics				
	No. Obs	TSS	SSR	σ_ϵ^2
OLS on Ag.	1666	95736	2699	1.68
OLS on Man	1884	78820	3709	2.03

Table 5: Geographic barriers on tradeable goods accounting for zero trade

	Estimates		Std. Err.		% on Costs	
Variables	Ag.	Man.	Ag.	Man.	Ag.	Man.
Distance [0,375)	-4.45	-3.26	0.16	0.13	155	98
Distance [375,750)	-5.34	-3.91	0.10	0.08	207	127
Distance [750,1500)	-6.05	-4.57	0.10	0.08	256	161
Distance [1500,3000)	-6.80	-5.14	0.12	0.12	317	194
Distance [3000,6000)	-7.62	-5.89	0.07	0.07	395	244
Distance [6000,max)	-7.79	-6.61	0.09	0.10	413	300
Shared border	0.05	0.38	0.15	0.12	-1.04	-6.27
Shared language	0.59	0.27	0.14	0.13	-11.65	-5.51
Summary Statistics						
	No. Obs	Log pseudolikelihood	Wald chi2(55)	Prob > chi2		
Poisson Regression on Ag.	2256	-25.57	38452	0.00		
Poisson Regression on Man	2256	-108.03	26817	0.00		

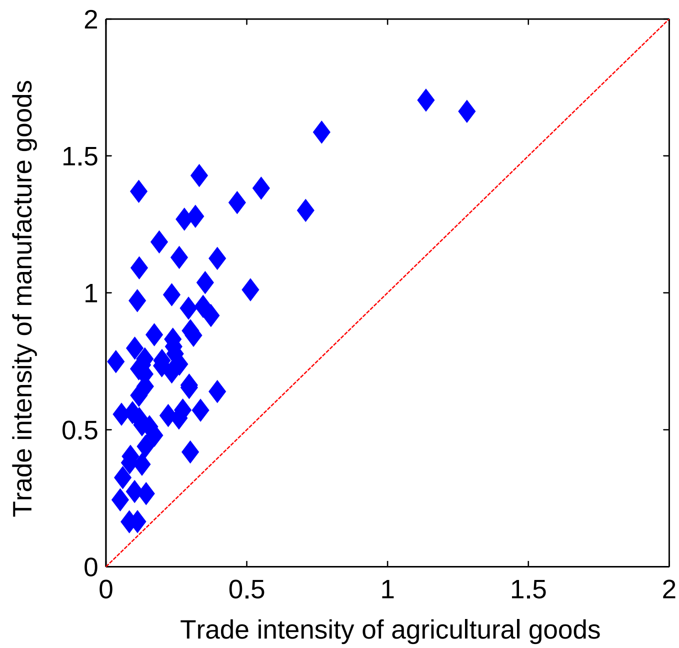

Figure 1: Trade intensity of agricultural and manufactured goods

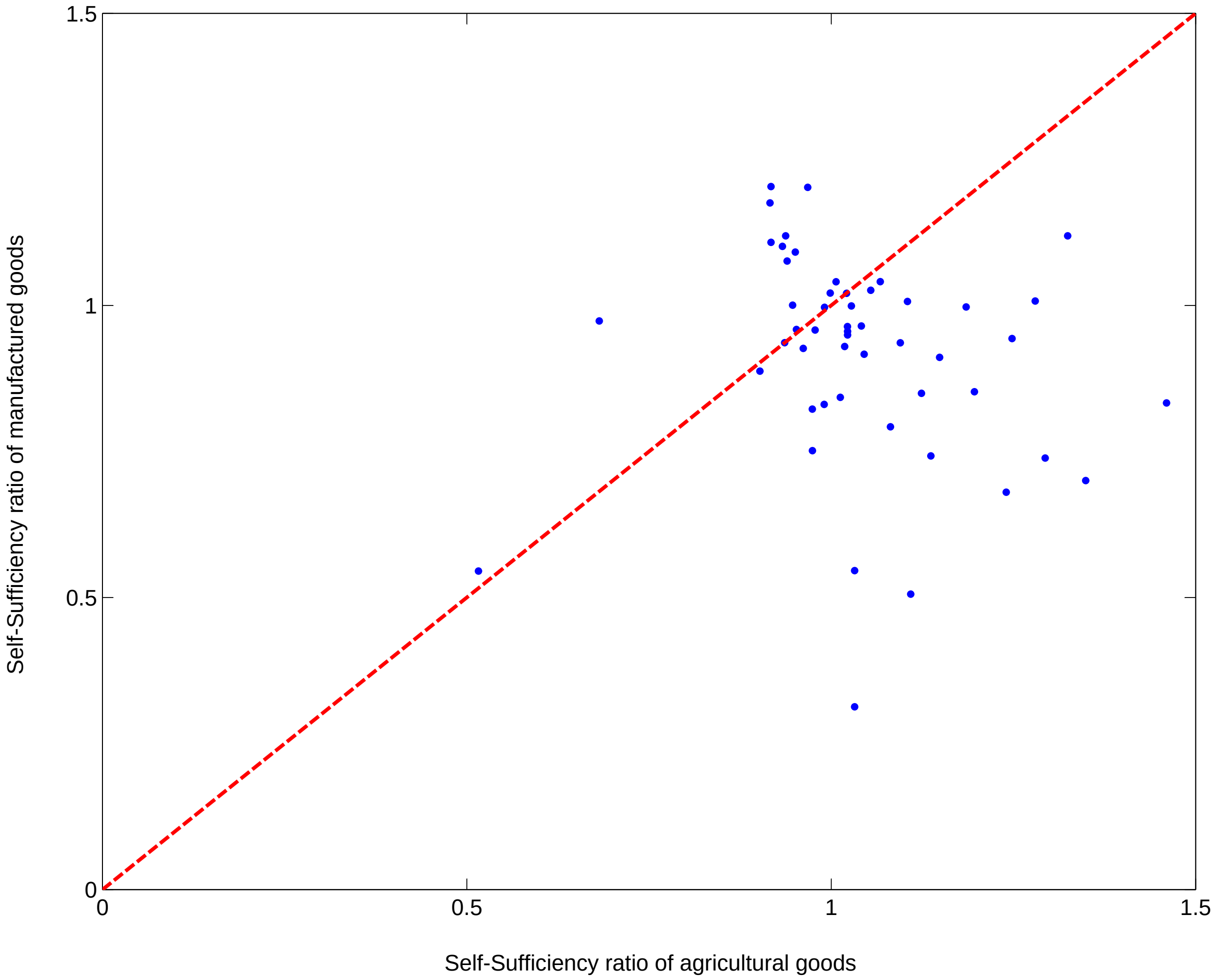

Figure 2: Self-sufficiency ratio of agricultural and manufactured goods

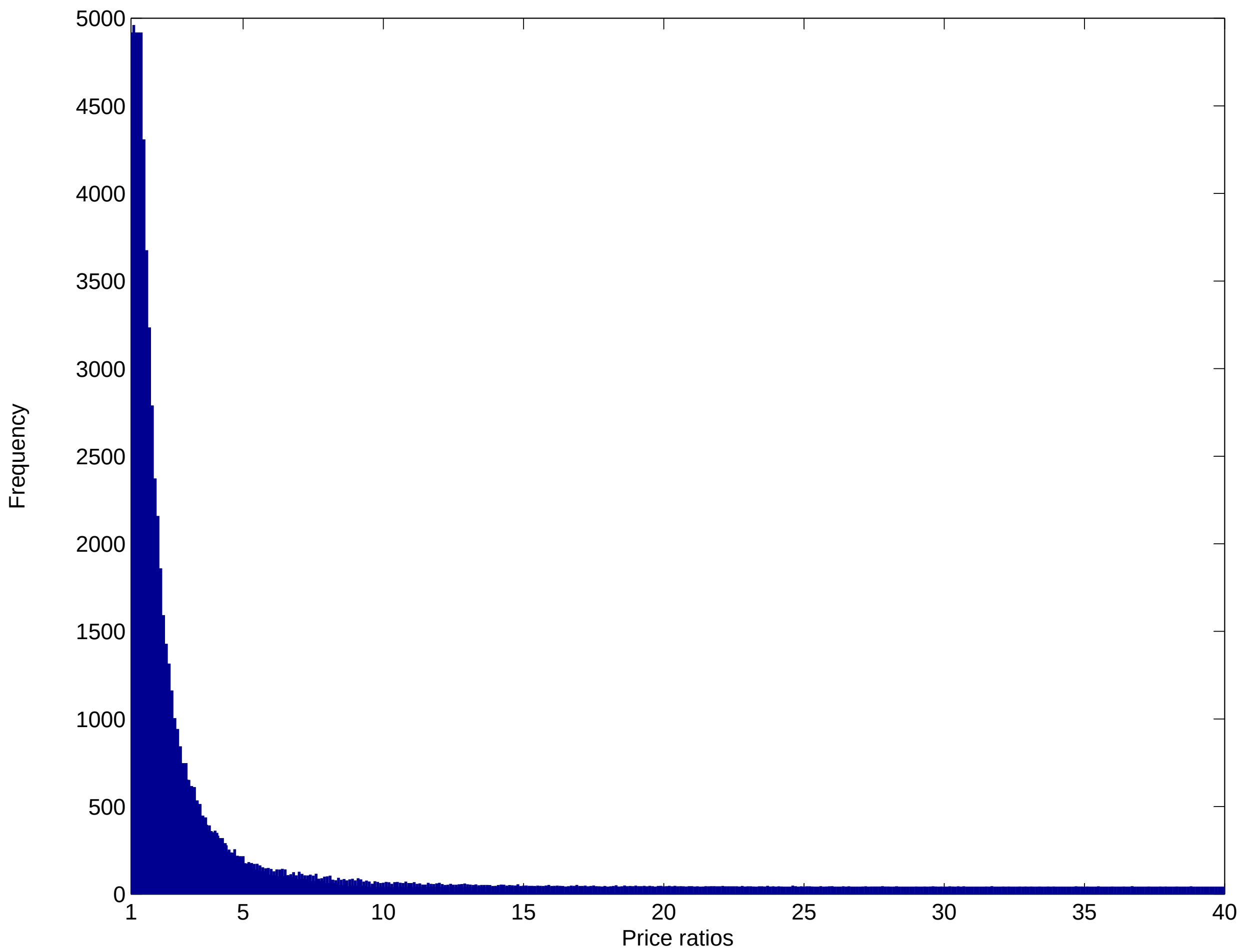

Figure 3: Price difference of the same agricultural goods across countries

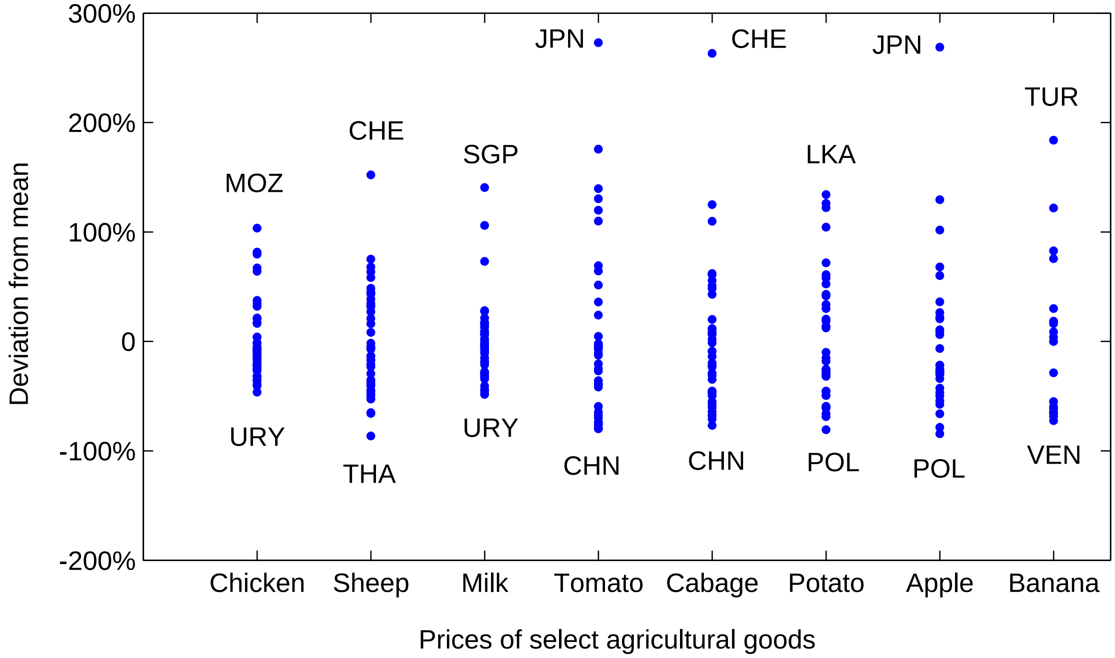

Figure 4: Cross-country price dispersion of agricultural goods

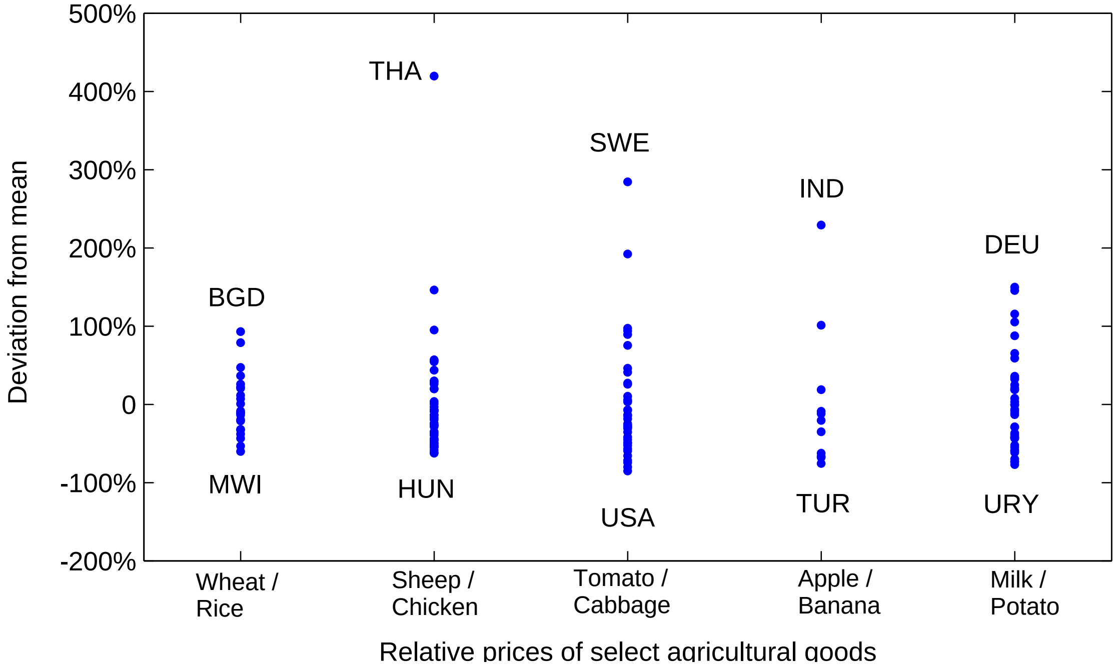

Figure 5: Dispersion of relative prices of select pairs of agricultural goods

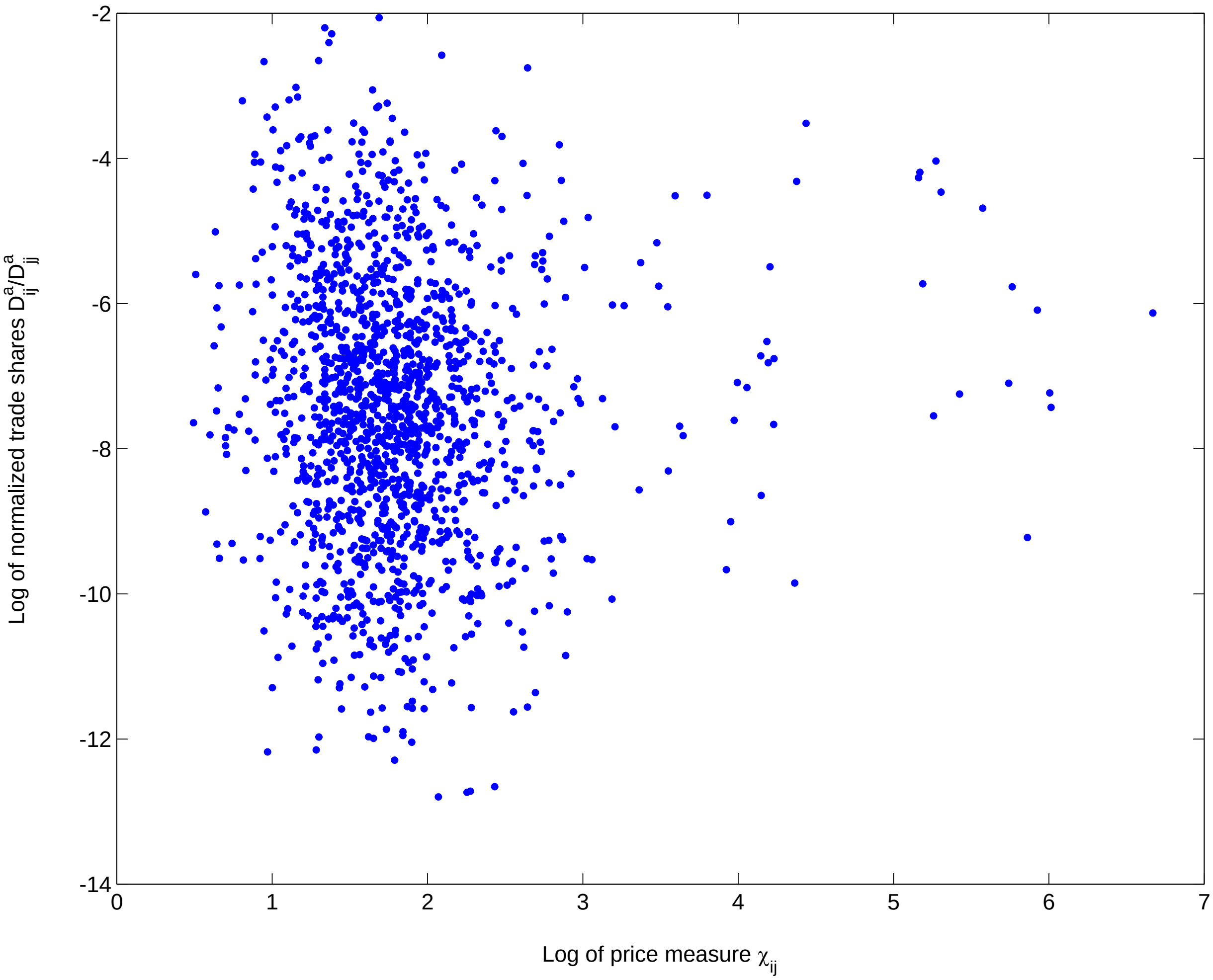

Figure 6: Normalized trade shares against price measure

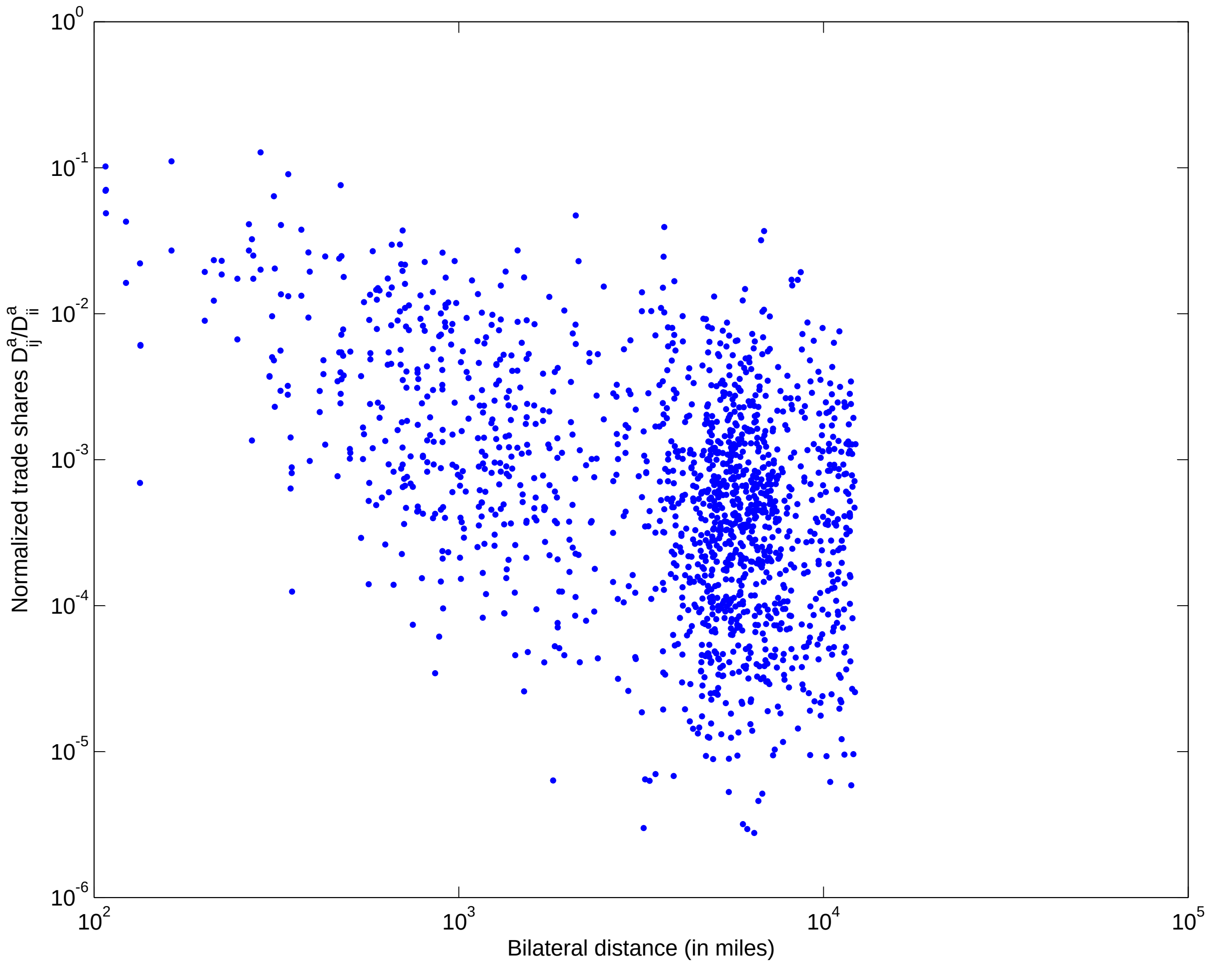

Figure 7: Normalized trade shares against bilateral distance

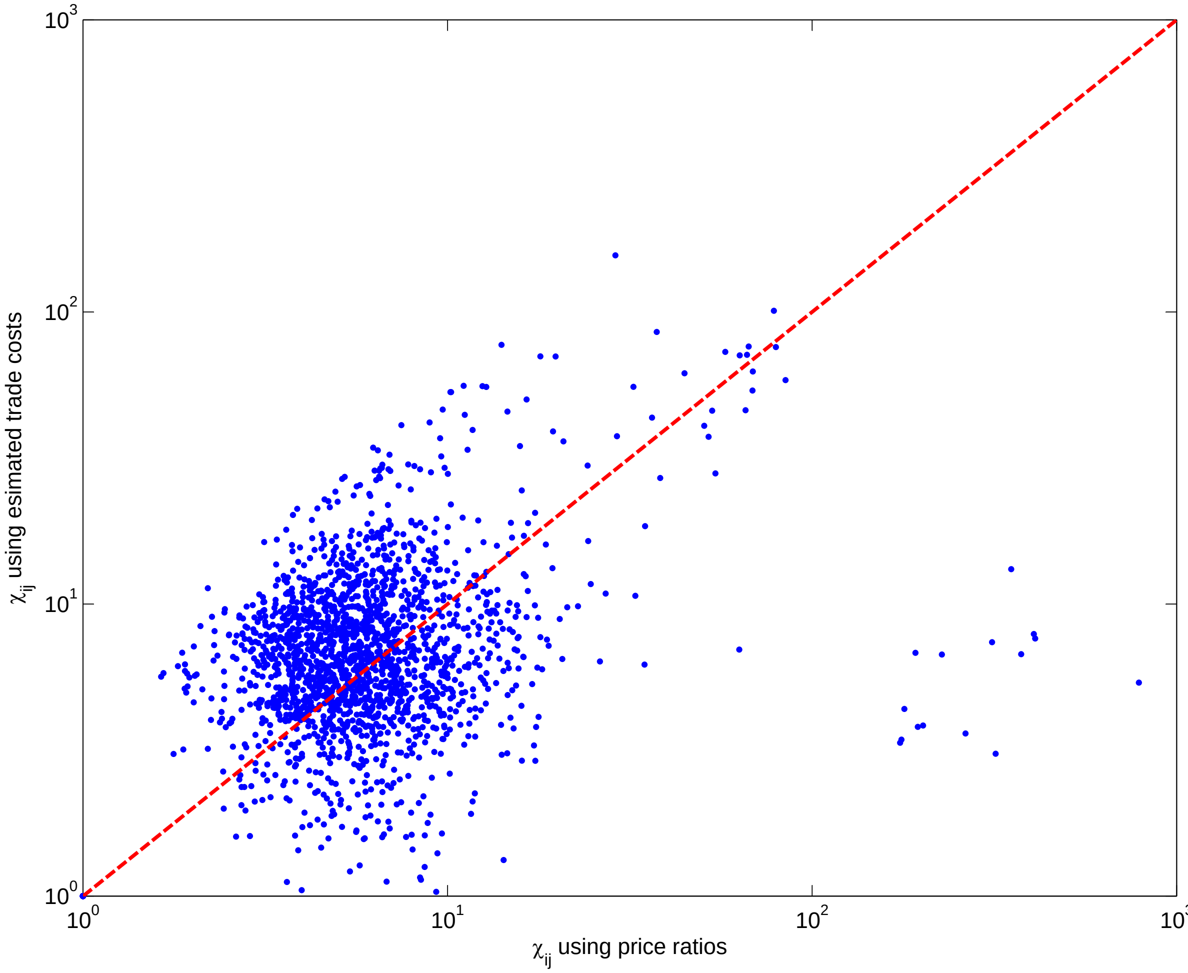

Figure 8: Robustness of using price ratios to approximate trade costs

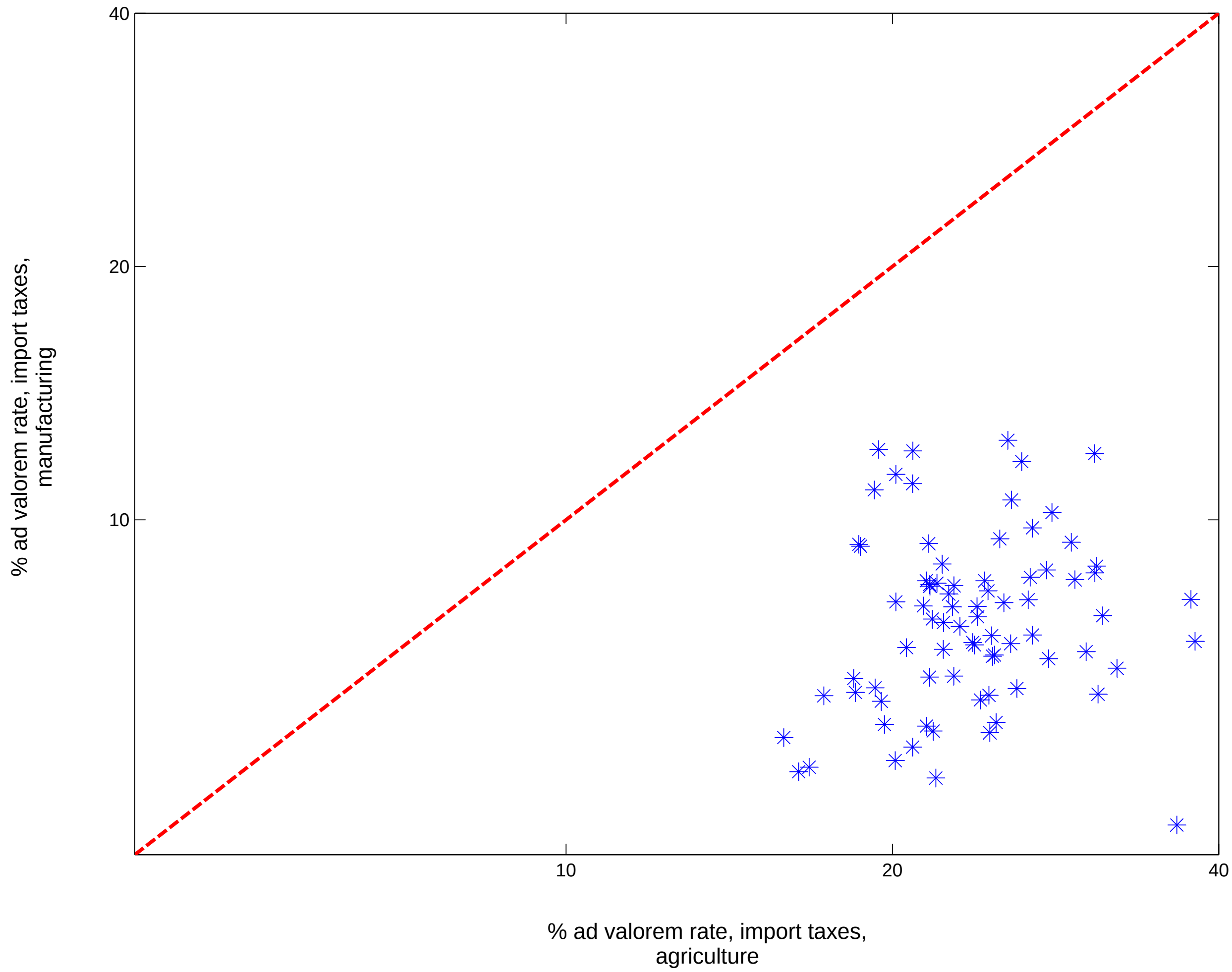

Figure 9: Ad valorem import tax rate, by source