American Economic Journal: Macroeconomics 2015, 7(3): 226–258
http://dx.doi.org/10.1257/mac.20130108

The Missing Food Problem: Trade, Agriculture, and International Productivity Differences†

By Trevor Tombe*

Agriculture in poor countries has low productivity, high employment, and negligible trade flows relative to other sectors. These facts motivate a multisector, open-economy view of international productivity differences. With a quantitative multicountry model featuring nonhomothetic preferences, multiple interrelated sectors, distorted labor markets, and costly trade, I find: trade amplifies the negative effect of labor market distortions; trade costs—large for poor countries, especially in agriculture—significantly contribute to international productivity differences; and explicitly modeling agriculture reveals additional channels through which poor countries may gain from trade. (*JEL* F41, J24, J43, O13, O19, Q11, Q17)

Agriculture in poor countries has low productivity and high employment relative to other sectors. Differences in aggregate productivity and income between rich and poor countries are therefore primarily due to differences within agriculture; Schultz (1953) calls this the "Food Problem." These facts motivate an active area of research, which typically abstracts from trade to focus on domestic distortions.[1] Trade data, though, presents a puzzle: with low relative agricultural productivity, developing countries should be massive food importers; yet, they are not (see Section IB). The "missing" food imports suggest trade costs may be important for international productivity differences. After all, food imports could naturally help alleviate the problem of high employment in low productivity agriculture. An open-economy view may also change our understanding of other distortions examined in the literature. This paper quantitatively examines these issues.

How large are trade costs? As they take many forms, I use multiple measures. I begin with observable and policy-relevant costs: tariffs and border delays. Delays

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† Go to http://dx.doi.org/10.1257/mac.20130108 to visit the article page for additional materials and author disclosure statement(s) or to comment in the online discussion forum.

[1] See, for example, Adamopoulos and Restuccia (2014); Gollin, Lagakos, and Waugh (2014); Gollin and Rogerson (2014); Lagakos and Waugh (2013); Adamopoulos (2011); Vollrath (2009); Restuccia, Yang, and Zhu (2008); or Gollin, Parente, and Rogerson (2007).

are particularly costly for agricultural goods and extremely high in developing countries. My primary measure, though, is a modified Head-Ries-Novy index (Head and Ries 2001; Novy 2013). While I leave the details to Section IC, it flexibly infers trade costs (unobservable) from international trade and production data (observable). This method requires very little structure and represents a broad and systematic estimate of trade costs. I extend the index to incorporate country-specific export costs, which are important internationally (Waugh 2010). Regardless of the measure, trade costs are high in poor countries—especially for agricultural goods. To quantify their effects on aggregate productivity across countries, additional structure is required.

To that end, I develop a multisector trade model, built upon Eaton and Kortum (2002) and Caliendo and Parro (2015), that includes many components common to the closed-economy literature. Importantly, labor markets are distorted as in Restuccia, Yang, and Zhu (2008) to capture the often large labor productivity differences between agriculture and nonagriculture in poor countries (Gollin, Lagakos, and Waugh 2014). A variety of quantitative exercises yield three main findings. First, trade amplifies the negative effect on aggregate productivity from labor market distortions. With trade, labor market distortions are 40 percent more costly than in autarky. Previous researchers therefore underestimate this effect. Second, trade costs significantly lower welfare and productivity in poor countries. They do this in two ways: protecting inefficient domestic producers or crop varieties, and increasing agricultural employment to meet subsistence requirements. Overall, agricultural trade costs account for one-quarter of the aggregate productivity difference between rich and poor countries; trade costs in all sectors account for over two-fifths. Tariffs and border delays also have significant effects. Third, and finally, explicitly modeling an agricultural sector—missing from typical trade models, such as Waugh (2010)—reveals additional channels through which trade benefits poor countries.

The model is rich and certain details further illuminate these results. First, I incorporate a full set of empirically reasonable input-output linkages along with labor and other inputs to production. These prove especially important for the interaction between trade and labor market distortions. Specifically, they magnify the costs of labor distortions in autarky and mitigate the costs in an open economy. Second, multiple sectors featuring firms with heterogeneous productivity are key to the results. Within sectors, productivity depends on selection across firms, as imports substitute for the lowest productivity domestic producers. Between sectors, distorted labor markets imply that aggregate productivity depends on the allocation of labor across sectors. Finally, and conveniently, the model admits an expression decomposing welfare changes into real wage effects, standard in trade models; labor market effects, where improved labor allocations or lower labor market distortions increase aggregate output; and nonhomothetic (subsistence) effects, where the marginal utility of a dollar is large for countries close to subsistence. While the trade literature typically investigates only the first of these, I show the other two are quantitatively important for poor countries.

The quantitative analysis is eased by solving the model in relative changes, as in Dekle, Eaton, and Kortum (2007). In particular, I do not require specific values for certain productivity parameters, factor endowments, or subsistence food requirements; it is sufficient that these are invariant to changes in trade costs and labor distortions. This dramatically simplifies the calibration. The model's initial equilibrium only requires data on trade flows, expenditures, and employment by sector. Model parameters all have directly observable counterparts in data, with one exception: firm-level productivity dispersion within sectors. This dispersion governs the trade-cost elasticity of trade flows; many estimates exist for manufacturing but unfortunately few for agriculture. Using the recent method of Caliendo and Parro (2015), I directly estimate the elasticity of trade by sector using global tariff and trade data; I find an elasticity of 4.63 for manufacturing and 4.06 for agriculture.

While the literature in this area typically abstracts from trade, there are recent exceptions. The most closely related papers are Święcki (2013) and Uy, Yi, and Zhang (2013). Święcki (2013) examines the gains from trade and optimal trade policy in the presence of labor market distortions between agriculture, manufacturing, and services. While our models are similar, they differ in important ways. Preferences in Święcki's model are more general, as the focus is on economic growth and structural change, but production technologies abstract from other factors of production and inter-sectoral linkages, which I show are important. Uy, Yi, and Zhang (2013) also focus on growth and show trade is important to explain South Korea's structural change. Distinct from both works, I focus on cross-sectional differences in aggregate and agricultural productivity across a larger sample of countries. Given this focus, I now turn to documenting a set of facts that will be relied on throughout the paper.

I. The Facts: Sectoral Productivity and Trade

In this section, I describe key features of cross-country productivity and trade data for both agriculture and manufacturing. First, I construct labor productivity estimates by sector for a broad cross-section of countries. Next, I compile bilateral trade and production data to reveal a systematic tendency among poor countries to import very little food. Finally, I document significantly higher trade costs for poor countries, particularly in agriculture.

For clarity and consistency throughout the paper, I use a set of 90 countries for which all relevant data exists. The sample countries account for roughly 90 percent of global gross dometsic product (GDP), population, and employment. I provide a full list of data, sources, and countries in the online Appendix. While many variables are individually available for more countries, none of the cross-sectional patterns documented in this section are particular to my sample. Data is for 2005 unless otherwise stated.

A. *Labor Productivity*

I construct real labor productivity for agriculture and nonagriculture following Caselli (2005) and Restuccia, Yang, and Zhu (2008). In the online Appendix, I provide full details behind these estimates and only briefly discuss the approach here. To compare productivity across countries one requires value-added per worker adjusted for international price level differences. The Food and Agricultural Organization of the United Nations (FAO) reports internationally priced agricultural output but not value-added. So, I assume value-added is 50 percent of output.[2] Nonagricultural value-added and employment is inferred by subtracting agriculture from the Penn World Table's (PWT) aggregate data. Labor productivity is then the ratio of value-added to employment in each sector.

Figure 1 displays the results. Agricultural labor productivity differences are an order of magnitude greater than nonagricultural. Agricultural productivity among the richest 10 percent of countries is over 100 times higher than among the poorest 10 percent; the comparable figure is only 12 for nonagriculture. Other measures of variation give similar results. The 90/10 ratio for agriculture is 57 while the ratio for nonagriculture is below 9. Despite such low productivity, the vast majority of poor country employment is agricultural, as illustrated in panel B of Figure 1.

Why is agriculture's share of employment so high and its productivity so low in poor countries? In the model to come, a labor market distortion, as in Restuccia, Yang, and Zhu (2008) and others, will prove key to capture sectoral labor allocations. I postpone further discussion to Sections IID and IIIB. As for agricultural productivity, the literature typically focuses on domestic factors. I argue trade may also be an important contributor. In the next section, I document some less well known facts: agricultural trade in poor countries is small and costly.

B. *International Trade Patterns*

What fraction of a country's total expenditures are spent on imports? To measure this, denote X_{ni}^{j} as imports of sector j goods by country n from country i. Total expenditures by sector j is its absorption (output less net exports). The fraction of country n spending allocated to country i is then

$$(1) \qquad \pi_{ni}^{j} = \frac{X_{ni}^{j}}{Y_{n}^{j} + \sum_{k \neq n} X_{nk}^{j} - \sum_{k \neq n} X_{kn}^{j}},$$

where Y_{n}^{j} is gross output of sector j in country n and $\sum_{k \neq n} X_{nk}^{j}$ and $\sum_{k \neq n} X_{kn}^{j}$ are country n's total exports and imports, respectively. When $n = i$, π_{nn}^{j} is the home share of expenditures.

Measuring π_{ni}^{j} requires gross output and trade data by country and sector. I provide a detailed description in the online Appendix and a brief summary here. Gross output is available for manufacturing from the United Nations Industrial Development Organization (UNIDO) and for agriculture from the FAO and OECD. Trade flow data is from the BACI product-level trade database (Gaulier and Zignago 2010), which classifies trade by harmonized system (HS) codes (2002 version). I aggregate products with two-digit HS codes 01–15 into agriculture, and 16–24 or 28–97

[2] Consistent with evidence from the Organisation for Economic Co-operation and Development (OECD), which I document in online Appendix Section 3.1. For comparison, Restuccia, Yang, and Zhu (2008) exploit internationally priced value-added for 1985 from Rao (1993). The correlations between our measures are 0.87 for agriculture and 0.81 for nonagriculture.

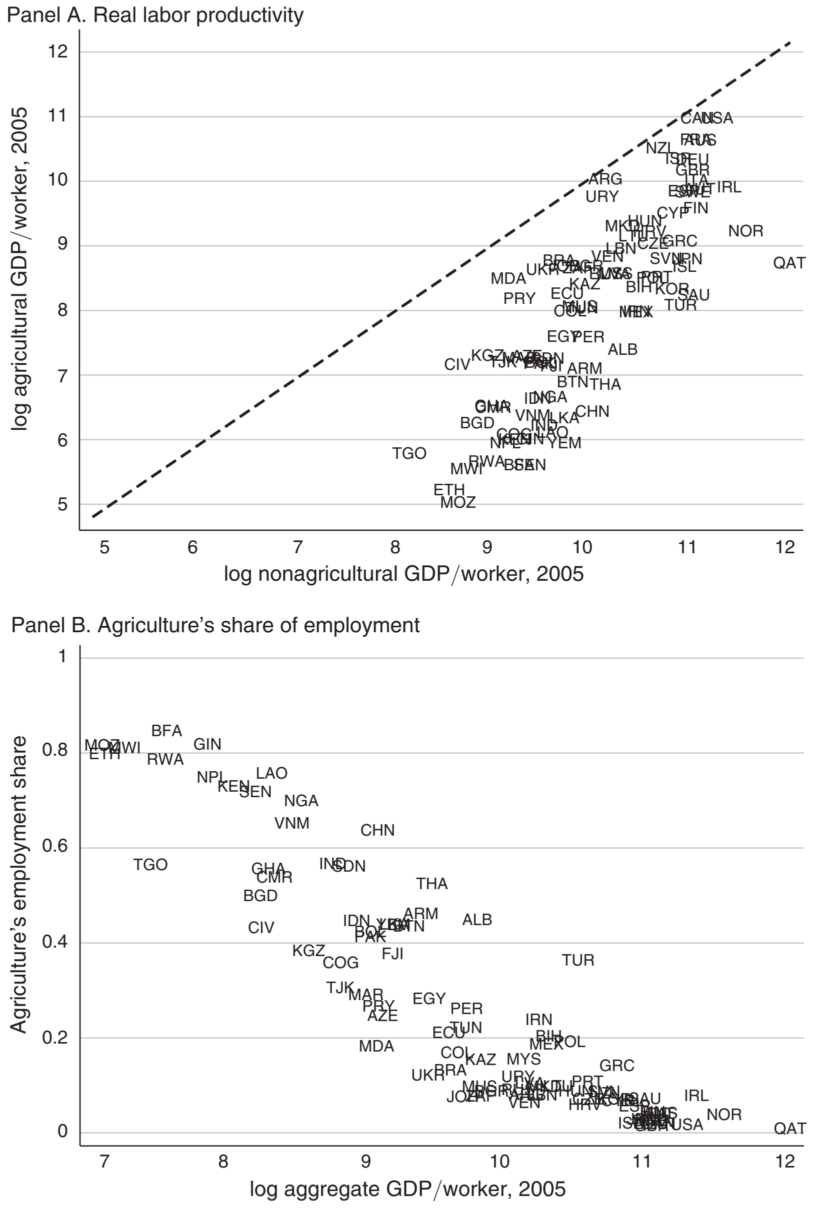


Figure 1. Labor Productivity and Employment

Notes: Labor productivity measured in international prices for agriculture and nonagriculture. Calculations follow Caselli (2005) and Restuccia et al. (2008). Agriculture's share of employment primarily from the FAO. Details in online Appendix.

into manufacturing. Notice this excludes mineral products and services and treats food preparations as manufactured goods. Combining these data gives π_{ni}^{j}—used throughout the paper.

The pattern of trade differs substantially across countries and sectors. Figure 2 displays home shares for agriculture and manufacturing. Among the poorest

Panel A. Share of total expenditures on domestically produced goods

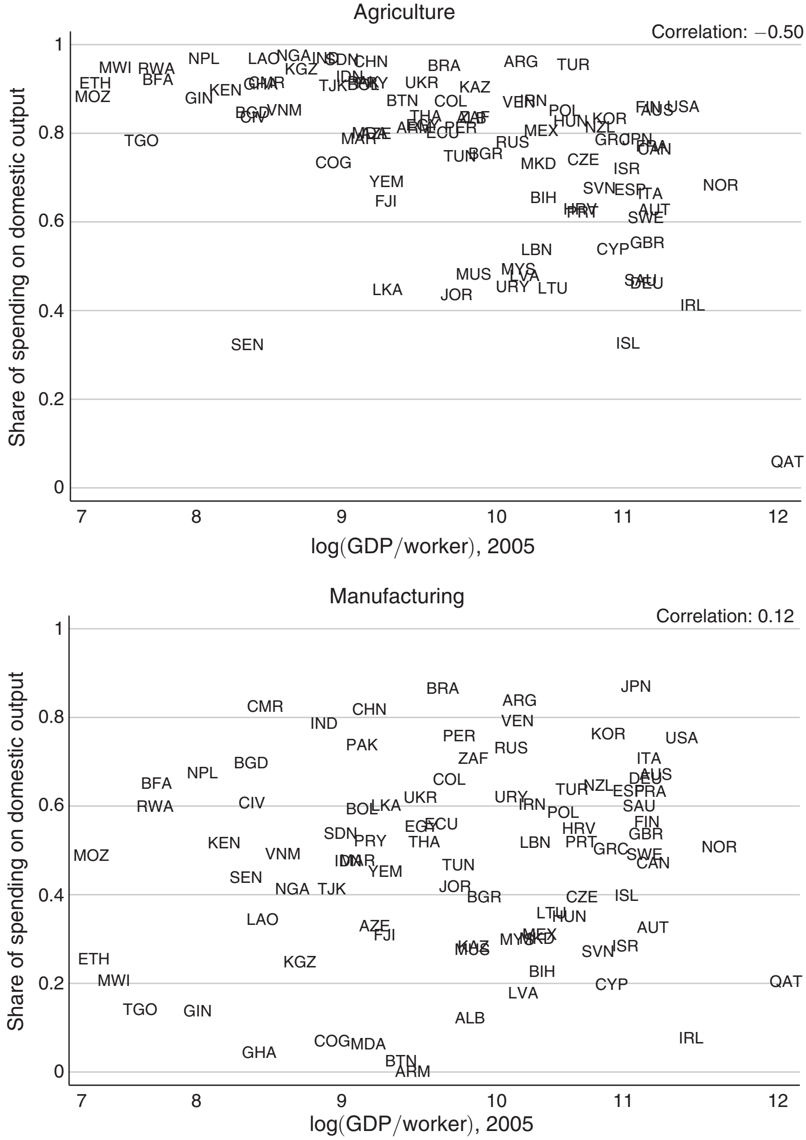


Figure 2. Key Trade Patterns for Agriculture and Manufacturing

(*Continued*)

countries, the share of agricultural expenditures allocated to domestically produced goods is well over 90 percent. While among rich countries the share is highly variable, the average is closer to 60 percent. For manufacturing goods, the pattern is very different. There is little relationship between π_{nn}^{m} and a country's level of development, with home shares generally ranging between 20–80 percent.

The lack of agricultural trade by poor countries is also evident in the number of trading partners each country has. Counting the number of partners from which

Panel B. Number of trading partners

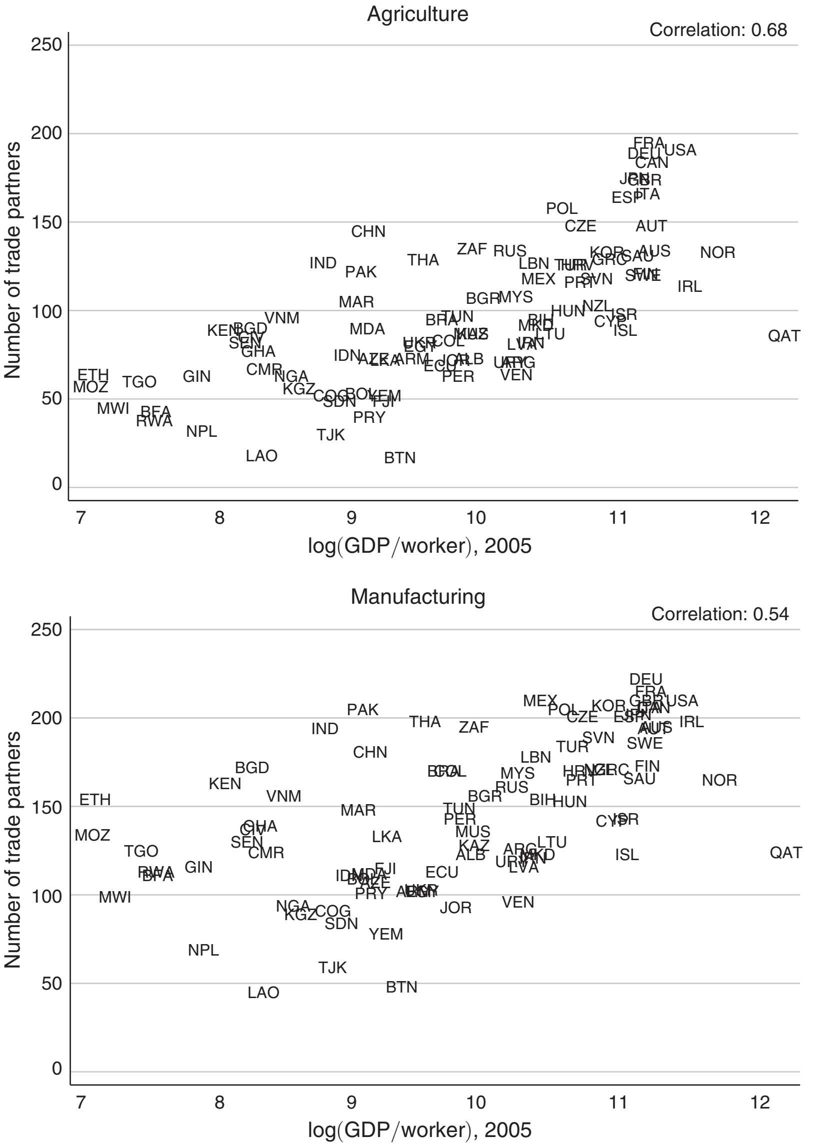


Figure 2. Key Trade Patterns for Agriculture and Manufacturing (*Continued*)

Notes: Displays the share of total expenditures allocated to domestically produced goods (π^j_{nn}). Trading partners is the number of exporters from which each country imports. Trade data are from CEPII's BACI database and production data are from the UNIDO, OECD, and FAO.

each country imports reveals a strong positive relationship between the number of trade partners and a country's level of development. In agriculture, poor countries typically import (what little they do import) from 50 sources while rich countries import from closer to 200. For manufacturing, the positive relationship still holds, though it is far less pronounced. Poor countries have between 100–150 partners for manufactured goods imports.

C. *Trade Costs*

Why do poor countries import so little food despite having such low productivity in that sector? Trade costs are an obvious candidate, though they come in many forms and are difficult to measure. First, consider average tariff levels. Trade-weighted average tariff rates are available from the UN-TRAINS database, classified by sector using the HS codes listed earlier. I plot these tariffs in Figure 3. While poor countries do have larger average tariffs than rich countries, the magnitudes are fairly small at 15–20 percent among the poorest countries compared to less than 5 percent among the richest. An implausibly large elasticity would be required for these small trade costs to have a large influence on trade flows.

Trade costs go beyond tariffs; nontariff barriers and other costs are far more important. For example, border delays can be significant for many developing countries. Data on time to import are available through the World Bank's Doing Business Index. These data are about procedural delays at the border and do not include sea transit time. It takes an average of 38 days to import into a typical sub-Saharan African country—more than a full month longer than the delay for US imports. Among the bottom decile of countries in the PWT8.0 in 2006 (time delay data from Doing Business is not available for 2005), the average time to import is 43 days while the delay among the top decile is 10. Border delays are particularly relevant for policymakers.

For perishable agricultural goods, these long delays may be particularly costly. Hummels and Schaur (2013) recently estimate the ad valorem cost of time to import. They find for food and beverages each day is equivalent to a 3.1 percent tariff, compared to 2 percent for consumer and capital goods generally. Using their estimates, I construct a measure of the overall trade costs in agriculture and manufacturing associated with time delays. Panel B of Figure 3 plots the results of this calculation. The difference in magnitude between rich and poor countries is stark. On average, the ad valorem cost of time delays to import into poor countries is approximately 400 percent in agriculture and 200 percent in manufacturing. The time cost for rich countries are an order of magnitude lower, varying around 25 percent for agriculture and 15–20 percent for manufacturing.

Beyond these observable measures, Novy (2013) generalizes Head and Ries (2001) to provide an aggregate summary measure of bilateral trade costs. In a broad class of trade models, including Eaton and Kortum (2002); Anderson and van Wincoop (2003); Melitz (2003); and this paper's model, the average cost for sector j trade (in both directions) between countries n and i is

$$\bar{\tau}_{ni}^{j} \equiv \sqrt{\tau_{ni}^{j}\tau_{in}^{j}} = \left(\frac{\pi_{nn}^{j}\pi_{ii}^{j}}{\pi_{ni}^{j}\pi_{in}^{j}}\right)^{\frac{1}{2\theta^{j}}}, \tag{2}$$

where π_{ni}^{j} are the expenditure shares defined earlier and θ^{j} is the (negative) cost-elasticity of trade. This expression has been used successfully as a flexible measure of trade costs in many contexts. It is especially useful when other measures of trade costs do not exist or are limited, such as historically (Jacks, Meissner, and

Panel A. Average tariff rates

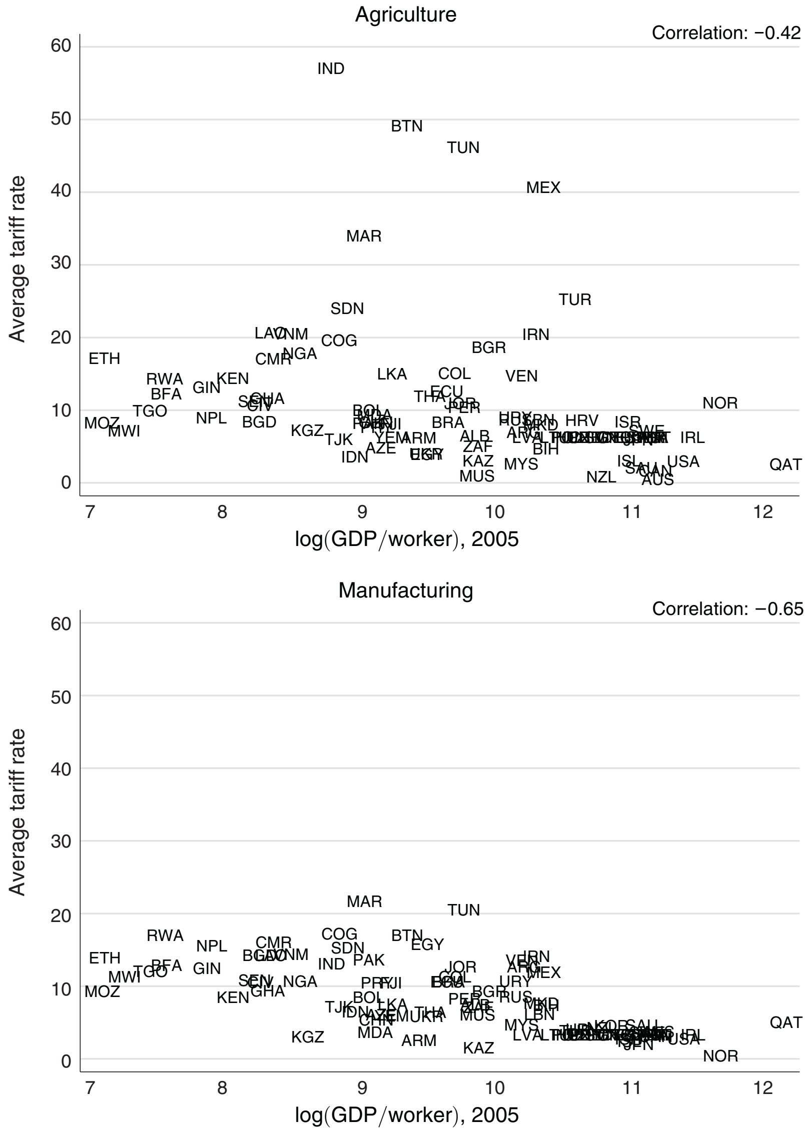


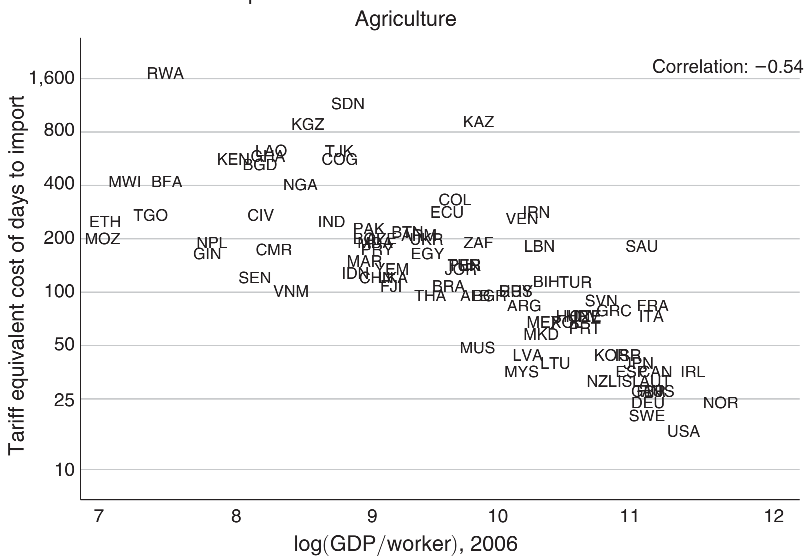
Figure 3. Trade Costs in Agriculture and Manufacturing

(*Continued*)

Novy 2008, 2010, 2011) or within countries (Albrecht and Tombe forthcoming). The World Bank's UNESCAP Trade Cost Database also uses this method.

This measure has many strengths. It is intuitive to interpret: $\overline{\tau}_{ni}^{j} = 1.5$ is equivalent to a 50 percent iceberg trade cost, where 1.5 units must be shipped for 1 unit to arrive. It is also simple to implement, requiring only trade and production data. There is, however, an important weakness: it is symmetric by construction $(\overline{\tau}_{ni}^{j} = \overline{\tau}_{in}^{j})$, implying US imports from Ghana are as costly as Ghana's imports from the United States. But, trade cost asymmetries are known to be important. Waugh (2010), for example, demonstrates that poor countries systematically face higher export costs

Panel B. Time costs to import



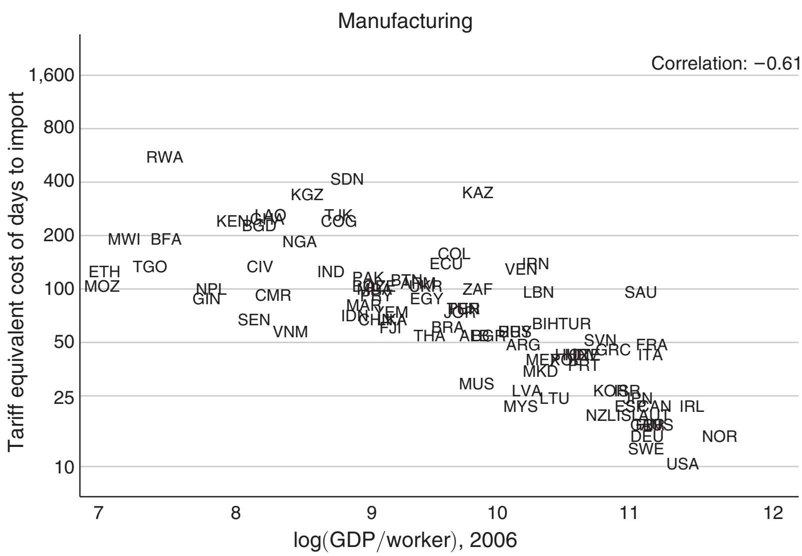


FIGURE 3. TRADE COSTS IN AGRICULTURE AND MANUFACTURING (*Continued*)

Notes: Displays observable measures of trade costs in agriculture and manufacturing. First, observable trade-weighted MFN tariffs from UN-TRAINS. Second, the ad valorem equivalent cost of border delays. Days to import are from the World Bank Doing Business Index for 2006 (2005 is unavailable). The results of Hummels and Schaur (2013) suggest a tariff-equivalent cost of 3.1 percent per day for food and beverages, and roughly 2 percent per day for consumer and capital goods. These rates are used to convert the single Days to Import variable to ad valorem rates that differ by sector.

(regardless of the destination) than rich countries in manufacturing. In the online Appendix, I show this holds for agricultural goods as well.[3]

[3] Briefly, for the same broad class of models, one can show $\tau^{j}_{ni} = \left(P^{j}_{n}/P^{j}_{i}\right)\left(\pi^{j}_{ni}/\pi^{j}_{ii}\right)^{-1/\theta^{j}}$ holds, where P^{j}_{n} is country n's price for good j. Using food price data from ICP 2005, I estimate this expression. Its correlation with the import cost specification is zero while its correlation with the export cost specification is nearly 0.8.

To measure these asymmetries and adjust $\overline{\tau}^j_{ni}$ is straightforward. In the same broad class of trade models for which equation (2) holds, a gravity relationship

$$\ln\left(\frac{\pi^j_{ni}}{\pi^j_{nn}}\right) = S^j_i - S^j_n - \theta^j \ln\left(\tau^j_{ni}\right) \tag{3}$$

exists, where S^j denotes a country's sector j competitiveness (productivity, factor prices, and the like). The precise nature of S^j does not concern us, so long as it is country-specific. Suppose trade costs τ^j_{ni} depend in part on common bilateral components such as distance, shared border, and shared language. Further suppose there is a country-specific additional cost of exporting (following Waugh 2010). To measure these export costs, estimate

$$\ln\left(\frac{\pi^j_{ni}}{\pi^j_{nn}}\right) = \beta^{j\prime}\mathbf{X}_{ni} + \iota^j_n + \eta^j_i + \epsilon^j_{ni}, \tag{4}$$

where $\mathbf{X}_{ni}$ is a matrix of observable bilateral components, ι^j_n and η^j_i are a set of importer and exporter fixed-effects, respectively. The importer fixed-effect identifies S^j_n. The exporter fixed-effect captures both S^j_i and country-specific export costs. Combining the two yields a measure of export costs: $\ln t^j_n = -(\iota^j_n + \eta^j_n)/\theta^j$.

With this regression, I measure agricultural export costs t^a_n and manufacturing export costs t^m_n. The only difficulty is determining a value for θ^j. The details of how I estimate these parameters are postponed to Section IIIC; for now, I set $\theta^m = 4.63$ and $\theta^a = 4.06$ (both of which are consistent with existing estimates). Combining the export cost estimates with equation (2) yields a measure of trade costs $\tau^j_{ni} = \overline{\tau}^j_{ni}\left(t^j_i/t^j_n\right)^{1/2}$. I summarize these in Figure 4 as the trade-weighted average across country pairs. The top panel reports the average cost by importer; the bottom panel, by exporter. Poor countries systematically face higher trade costs, particularly in agriculture. The typical poor countries face import costs of approximately 300 percent in agriculture and 150–200 percent in manufacturing. The average cost of exporting for these countries is even higher.

Of course, there are many sources of trade costs, from health regulations and road infrastructure to language, cultural, or taste differences. My goal is to gauge the quantitative implications of these costs rather than explain their sources. The trade costs I measured here will be key for the quantitative analysis to come.

II. A Multisector Ricardian Trade Model

In this section, I lay out the model structure and equilibrium relationships. With an eye towards the quantitative analysis, I follow Dekle, Eaton, and Kortum (2007) and solve the model for relative changes.

A. *Households*

Each country n is populated by a household of size L_n. Households earn income I_n primarily from (inelastically supplied) labor earnings $w^j_n L^j_n$. Households also receive lump-sum rebates of payments to other factors of production.

Panel A. Average trade costs, by importer

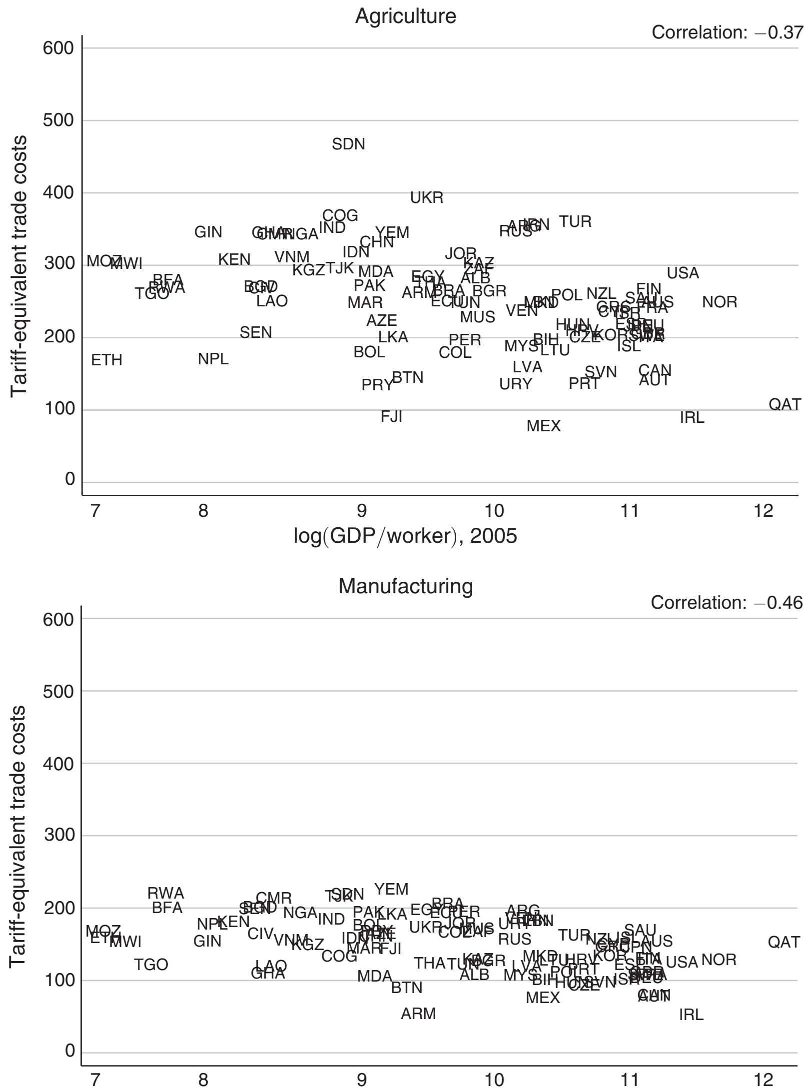


Figure 4. Trade Costs in Agriculture and Manufacturing

(*Continued*)

Preferences are defined over three types of final goods: agriculture, manufactured goods, and services. Agricultural consumption is subject to subsistence food requirements within a Stone-Geary utility function. Given sector j prices P_n^j and total income I_n, each household maximizes

$$U_n = \left(C_n^a - \bar{a}\right)^{\epsilon^a} C_n^{m\ \epsilon^m} C_n^{s\ \epsilon^s} \tag{5}$$

Panel B. Average trade costs, by exporter

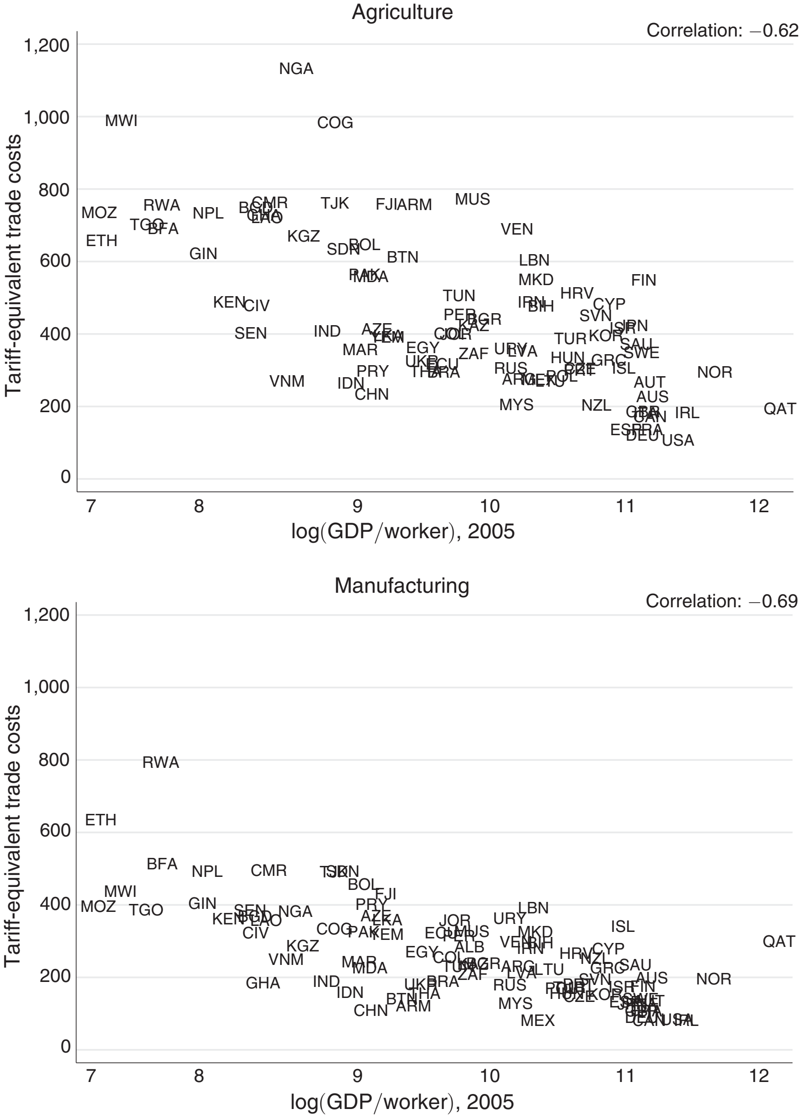


FIGURE 4. TRADE COSTS IN AGRICULTURE AND MANUFACTURING (*Continued*)

Notes: Displays trade costs in agriculture and manufacturing. The top panel averages trade costs τ_{ni}^{j} across all exporters i for each importer n, weighted by trade volumes. The bottom panel averages across importers for each exporter.

subject to a budget constraint $I_n = \sum_{j \in \{a,m,s\}} P_n^j C_n^j \equiv \sum_{j \in \{a,m,s\}} D_n^j$, where preference weights ϵ^j sum to one.

Household demand for each good j are familiar. For agriculture, $D_n^a = P_n^a \overline{a} + \epsilon^a (I_n - P_n^a \overline{a})$ while for manufacturing and services $D_n^j = \epsilon^j (I_n - P_n^a \overline{a})$. Nonhomothetic preferences play an important role. Higher food subsistence requirements (higher $\overline{a}$), higher agricultural prices, and lower total income all increase food's share of total expenditures D_n^a/I_n. It will prove useful to define agricultural spending by households as a fraction of their total income as s_n^a. With this,

$$(6) \qquad D_n^j = \begin{cases} s_n^a I_n & \text{if } j = a \\ \epsilon^j\left(\frac{1 - s_n^a}{1 - \epsilon^a}\right) I_n & \text{if } j \in \{m, s\} \end{cases}$$

defines household demand, given s_n^a.

In the language of Herrendorf, Rogerson, and Valentinyi (2014), household preferences are defined over final consumption expenditures. This provides a good match to data when production technologies, to which we turn next, incorporate full input-output linkages between sectors.

B. *Production Technologies*

Final goods in the agriculture and manufacturing sector Y_n^j are CES composites of a continuum of individual tradable varieties

$$Y_n^j = \left(\int_0^1 y_n^j(\omega)^{\frac{\sigma^j - 1}{\sigma^j}} d\omega\right)^{\frac{\sigma^j}{\sigma^j - 1}} \qquad j \in \{a, m\},$$

where the elasticity of substitution σ^j can potentially vary by sector and $y_n^j(\omega)$ denotes the amount of variety ω used to produce sector j's final output in country n. This can be sourced domestically or imported. Unlike agriculture and manufacturing, services are a homogeneous and nontradable good.

A firm in each sector j and country n can produce variety ω with labor, intermediate inputs, and other factors using

$$y_n^j(\omega) = \varphi_n^j(\omega)\left[L_n^j(\omega)^{\beta} H_n^j(\omega)^{1-\beta}\right]^{\phi^j}\left[\prod_{k \in \{a, m, s\}} m_n^{jk}(\omega)^{\gamma^{jk}}\right]^{1-\phi^j}.$$

Labor demanded by firm ω in country n and sector j is $L_n^j(\omega)$, other factors are $H_n^j(\omega)$, and intermediate inputs from sector k are $m_n^{jk}(\omega)$. Other factors (such as land, capital, or structures) are mobile across sectors but fixed in total supply. Finally, value-added share of output is ϕ^j and the share of intermediate inputs in sector j from sector k is γ^{jk}. Importantly, note that labor's share of value-added β is constant across all sectors and countries.

Given these production technologies, the cost of an input bundle is

$$(7) \qquad c_n^j = \left[\left(\frac{w_n^j}{\beta}\right)^{\beta}\left(\frac{r_n}{1 - \beta}\right)^{1-\beta}\right]^{\phi^j}\left[\prod_{k \in \{a, m, s\}}\left(\frac{P_n^k}{\gamma^{jk}}\right)^{\gamma^{jk}}\right]^{1-\phi^j},$$

where w_n^j is labor's wage in sector j, r_n is the price of other factors, and P_n^j is the price of sector j's final good.

C. *International Trade*

Markets are competitive and trade is costly: producers charge $P_i^j(\omega) = c_i^j/\varphi_i^j(\omega)$ and consumers pay $P_{ni}^j(\omega) = \tau_{ni}^j c_i^j/\varphi_i^j(\omega)$, where $\tau_{ni}^j \geq 1$ is an iceberg trade cost to ship sector j goods from country i to country n; within a country, $\tau_{nn}^j = 1$. There are no revenues raised by these trade costs, not too unreasonable as tariffs are small. In the online Appendix, I show incorporating tariff revenue complicates the model with little change to the main results.

Price differences across firms results from differences in productivity. Following Eaton and Kortum (2002), φ follows a Fréchet distribution

$$F_n^j(\varphi) = e^{-T_n^j \varphi^{-\theta^j}},$$

where the parameter θ^j governs productivity variation (larger θ^j gives lower variation) and T_n^j governs average productivity.

The final goods producer is perfectly competitive and sources individual varieties from either domestic or foreign producers—whichever minimizes costs. Expenditures are allocated to sources according to their productivity T_n^j, input costs c_n^j, and trade costs τ_{ni}^j. Denote π_{ni}^j the fraction of region n spending on good j allocated to producers in region i. Given the Fréchet distribution of technology, Eaton and Kortum (2002) show

$$\pi_{ni}^j = \frac{T_i^j \left(\tau_{ni}^j c_i^j\right)^{-\theta^j}}{\sum_{k=1}^{N} T_k^j \left(\tau_{nk}^j c_k^j\right)^{-\theta^j}}, \tag{8}$$

which results in an aggregate price index of

$$P_n^j = \gamma^j \left[\sum_{i=1}^{N} T_i^j \left(\tau_{ni}^j c_i^j\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{9}$$

where $\gamma^j = \Gamma\left(1 + \frac{1-\sigma^j}{\theta^j}\right)^{1/\left(1-\sigma^j\right)}$.

Both domestic and foreign sales contribute to revenue. Given π_{ni}^j, combine total domestic sales $\pi_{nn}^j X_n^j$ and total exports $\sum_{i \neq n} \pi_{in}^j X_i^j$ to yield

$$R_n^j = \sum_{i=1}^{N} \pi_{in}^j X_i^j. \tag{10}$$

Revenue need not equal expenditures, and deviations between the two is a trade imbalance. To see this, subtract imports from exports for a trade surplus $S_n^j = \sum_{i \neq n} \pi_{in}^j X_i^j - \sum_{i \neq n} \pi_{ni}^j X_n^j$. Since $\sum_{i \neq n} \pi_{ni}^j = 1 - \pi_{nn}^j$,

$$S_n^j = \sum_{i=1}^{N} \pi_{in}^j X_i^j - X_n^j \tag{11}$$

and therefore $R_n^j = X_n^j + S_n^j$.

How are expenditures determined? Goods market clearing implies $Y_n^j = C_n^j + \sum_{k \in \{a,m,s\}} m^{kj}$ and therefore

$$X_n^j = D_n^j + \sum_{k \in \{a,m,s\}} \left(1 - \phi^k\right)\gamma^{kj} R_n^k, \tag{12}$$

where D_n^j is final goods expenditures by the household, defined in Section IIA.

D. *Labor and Other Factor Markets*

Labor demanded by firm ω in sector j is $L_n^j(\omega)$. Total labor demand by the whole sector is then $L_n^j = \left[\int_0^1 L_n^j(\omega)\, d\omega\right]$. For the whole economy, the labor market must clear and therefore $L_n = L_n^a + L_n^m + L_n^s$. For many expressions, it is useful to define sector j's share of employment as $l_n^j = L_n^j / L_n$.

Labor allocations, however, are not efficient. As in Restuccia, Yang, and Zhu (2008) and others, suppose labor markets are distorted such that agricultural wages are below nonagricultural wages. Specifically, let $w_n^a = \xi_n w_n$ and $w_n^m = w_n^s = w_n$, where ξ_n is the labor distortion in country n. While this approach is common in the literature, Lagakos and Waugh (2013) recently develop a model where wage differences result not from explicit barriers but from worker heterogeneity and selection. There, relative wages are related to labor allocations. Here, relative wages are constant. In the quantitative exercises, I explore the relationship between trade-induced reallocation and labor distortions by varying τ_{ni}^j and ξ_n together (exogenously).

Since labor earnings are a fixed fraction β of value-added, we have $w_n^j L_n^j = \beta \phi^j R^j$. Taking the ratio of this for agriculture to the sum across sectors, and imposing labor market clearing, we have agriculture's initial employment share

$$l_n^a = \left(1 + \frac{\xi_n\left(\phi^m R_n^m + \phi^s R_n^s\right)}{\phi^s R_n^a}\right)^{-1}. \tag{13}$$

Labor is not the only primary factor of production. The total supply of other factors in country n is fixed at H_n. Demand comes only from firms, which allocate a share $1 - \beta$ of value-added to other factors. Total demand is therefore $(1 - \beta)\sum_{j \in \{a,m,s\}} \phi^j R_n^j$. Market clearing pins down the rental rate r_n. As payments to labor and other factors accrue to the household, total income equals total value-added in this economy $I_n = \sum_{j \in \{a,m,s\}} \phi^j R_n^j$. Therefore, $r_n = (1 - \beta) I_n / H_n$.

Adding total payments to labor and other factors yields each country's total income. Given labor's share of value-added β, $I_n = \frac{1}{\beta}\sum_{j \in \{a,m,s\}} w_n^j L_n^j$ or, using the definition of ξ_n,

$$I_n = \beta^{-1} w_n L_n \lambda_n, \tag{14}$$

where $\lambda_n = 1 - l_n^a(1 - \xi_n)$. With labor market distortions, λ_n decreases with agriculture's share of employment l_n^a; without distortions, $\lambda_n = 1$.

E. *Solving the Model*

To simplify the model calibration and quantitative analysis, I solve the model in two steps: the initial equilibrium, and counterfactual relative changes.

Initial Equilibrium.—An initial equilibrium of this economy is a set of expenditures X_n^j, revenues R_n^j, household demands D_n^j, labor allocations L_n^j, and aggregate income I_n for each country n and sector j—given trade shares π_{ni}^j, aggregate labor supply L_n, and food expenditure shares s_n^a—such that equations (6), (10), (12), (14), and (13) hold.

Notice the initial equilibrium does not impose trade balance. Although, as the following proposition proves, trade must indeed balance in this economy. Balanced trade is not necessary, though. In the online Appendix, I model trade imbalances (matched to data) and show the key quantitative results hold.

PROPOSITION 1: *If sectoral expenditures X_n^j and revenues R_n^j solve equations* (10) *and* (12), *households spend all of their income*, *and total income equals total value added*, *then $S_n^a = -S_n^m$ and*

$$X_n^a + X_n^m = \sum_{i=1}^{N} \pi_{in}^a X_i^a + \sum_{i=1}^{N} \pi_{in}^m X_i^m, \tag{15}$$

must hold for all n. That is, *aggregate trade balances for all countries.*

PROOF:

See online Appendix.

Counterfactual Relative Changes.—Denote the ratio of counterfactual to initial values $\hat{x} \equiv x'/x$. An equilibrium response for each country n and sector j to exogenous changes in trade costs $\hat{\tau}_{ni}^j$ and/or labor market distortions $\hat{\xi}_n$ is a set of new expenditures $X_n^{j'}$, revenues $R_n^{j'}$, demands $D_n^{j'}$, and trade shares $\pi_{ni}^{j'}$ along with relative changes in labor allocations $\hat{l}_n^j$, prices $\hat{P}_n^j$, and income $\hat{I}_n$—given initial trade shares π_{ni}^j, labor allocations l_n^j, and food expenditure shares s_n^a—such that the following hold.

From the definition of r_n and I_n, we have $\hat{r}_n = \hat{I}_n = \hat{w}_n \hat{\lambda}_n$, where

$$\hat{\lambda}_n = \frac{1 - l_n^{a'}(1 - \xi_n')}{1 - l_n^a(1 - \xi_n)}. \tag{16}$$

Equations (7) through (9) give changes in costs and prices

$$\hat{c}_n^j = \left[\hat{w}_n^j \hat{\lambda}_n^{1-\beta}\right]^{\phi^j} \left[\prod_{k \in \{a,m,s\}} \left(\hat{P}_n^k\right)^{\gamma^{jk}}\right]^{1-\phi^j}, \tag{17}$$

$$\hat{P}_n^j = \left[\sum_{i=1}^{N+1} \pi_{ni}^j \left(\hat{\tau}_{ni}^j \hat{c}_i\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{18}$$

and new trade shares,

$$(19) \qquad \pi_{ni}^{j'} = \frac{\pi_{ni}^{j}\left(\hat{\tau}_{ni}^{j}\hat{c}_{i}^{j}\right)^{-\theta^{j}}}{\sum_{k=1}^{N+1}\pi_{nk}^{j}\left(\hat{\tau}_{nk}^{j}\hat{c}_{k}\right)^{-\theta^{j}}}.$$

With these, equations (10) and (12) give new revenue and expenditures

$$(20) \qquad R_n^{j'} = \sum_{i=1}^{N} \pi_{in}^{j'} X_i^{j'},$$

$$(21) \qquad X_n^{j'} = D_n^{j'} + \sum_{k \in \{a,m,s\}} \left(1 - \phi^k\right)\gamma^{kj} R_n^{k'},$$

where new household demands are $D_n^{a'} = \overline{a} P_n^{a'} + \epsilon^a\left(I_n' - \overline{a} P_n^{a'}\right)$ for agriculture and $D_n^{j'} = \epsilon^j\left(I_n' - \overline{a} P_n^{a'}\right)$ for manufacturing and services.

In this form, the household demands are not useful, since $P_n^{a'}$ and $\overline{a}$ are not known. Given s_n^a from before, $P_n^{a'}\overline{a} = \left(\frac{s_n^a - \epsilon^a}{1-\epsilon^a}\right) I_n \hat{P}_n^a$ and therefore

$$(22) \qquad D_n^{j'} = \begin{cases} \left(\frac{s_n^a - \epsilon^a}{1-\epsilon^a}\right) I_n \hat{P}_n^a + \epsilon^a I_n\left(\hat{I}_n - \left(\frac{s_n^a - \epsilon^a}{1-\epsilon^a}\right)\hat{P}_n^a\right) & \text{if } j = a \\ \epsilon^j I_n\left(\hat{I}_n - \left(\frac{s_n^a - \epsilon^a}{1-\epsilon^a}\right)\hat{P}_n^a\right) & \text{if } j \in \{m, s\} \end{cases}.$$

Finally, new labor allocations are $L_n^{j'} = L_n^j \hat{l}_n^j$, where $\hat{l}_n^j = \hat{R}_n^j / \hat{w}_n^j$ and $\hat{w}_n^a = \hat{\xi}_n \hat{w}_n$.

With the model solved for relative changes, the next section provides and discusses two powerful propositions for welfare and productivity changes.

F. *Aggregate Welfare and Productivity*

Aggregate welfare can be represented in a compact and intuitive way.

PROPOSITION 2: *The change in welfare $\hat{U}_n$ can be decomposed into*

$$(23) \qquad \hat{U}_n = \underbrace{\hat{w}_n \hat{P}_n^{-1}}_{\text{Real wages}} \cdot \underbrace{\hat{\lambda}_n}_{\text{Labor}} \cdot \underbrace{\hat{\Gamma}_n}_{\text{Subsistence}}$$

where $\hat{P}_n = \left(\hat{P}_n^a\right)^{\epsilon^a}\left(\hat{P}_n^m\right)^{\epsilon^m}\left(\hat{P}_n^s\right)^{\epsilon^s}$ *and* $\hat{\Gamma}_n = \frac{1-\epsilon^a}{1-s_n^a}\left(1 - \left(\frac{s_n^a - \epsilon^a}{1-\epsilon^a}\right)\frac{\hat{P}_n^a}{\hat{I}_n}\right)$.

PROOF:

See online Appendix.

This expression warrants discussion. First, $\hat{w}_n \hat{P}_n^{-1}$ is the standard real-wage effect found in nearly all trade models of this type, from Eaton and Kortum (2002) to Melitz (2003). The welfare gains from trade through this channel result from higher incomes or lower prices. The trade literature typically includes only this channel. This proposition establishes that the gains from trade go beyond changes in real wages and includes two other forces.

The second term, $\hat{\lambda}_n$, captures changes in labor allocations and the degree of labor distortions. From equation (14), $\lambda_n = 1 - l_n^a(1 - \xi_n)$ is the ratio of aggregate to nonagricultural labor productivity, which is generally decreasing in a country's level of development. As labor moves out of agriculture towards higher productivity nonagricultural sectors, aggregate labor productivity grows relative to nonagricultural productivity and $\hat{\lambda}_n > 1$. If labor market distortions decline (ξ_n increases) then the same effect occurs.

Finally, $\hat{\Gamma}_n$ captures the nonhomothetic effect of changes in food prices and income on welfare. Increases in income or decreases in agricultural prices matter more for households that spend a large fraction of their income on food. Both $\frac{1 - \epsilon^a}{1 - s_n^a}$ and $\frac{s_n^a - \epsilon^a}{1 - \epsilon^a}$ are larger for poor countries relative to rich countries, since their spending share for agricultural products s_n^a is high. As initial food expenditure shares approach the preference weight (as $s_n^a \to \epsilon^a$), the $\frac{1 - \epsilon^a}{1 - s_n^a}$ approaches one from above while $\frac{s_n^a - \epsilon^a}{1 - \epsilon^a}$ approaches zero. Changes in income or the price of agricultural goods would then have little effect on $\hat{\Gamma}_n$.

This framework nests models with homothetic preferences and no labor distortions between sectors. If labor was perfectly mobile across sectors, then $\xi_n = 1$ and consequently $\hat{\lambda}_n = 1$ for all countries. If there was no subsistence food requirement ($\overline{a} = 0$) then $s_n^a = \epsilon^a$ and $\hat{\Gamma}_n = 1$ for all countries. The only remaining source of gains are changes in real wages. In the quantitative exercises, I use equation (23) to cleanly decompose welfare gains. I show distorted labor markets and nonhomothetic preferences significantly amplify gains from trade in poor countries.

Aggregate real GDP, and therefore aggregate labor productivity, can also be expressed in relative changes. Proposition 3 shows changes in real GDP depend on sectoral labor productivity changes and on labor reallocation.

PROPOSITION 3: *The change in real GDP is*

$$\hat{Y}_n = \sum_{j \in \{a,m,s\}} \frac{\hat{w}_n^j}{\hat{P}_n^j} \hat{l}_n^j \omega_n^j, \tag{24}$$

where the weights $\omega_n^j = \phi^j R_n^j / \sum_{k \in \{a,m,s\}} \phi^k R_n^k$ *are the initial GDP shares and changes in sectoral real wages (and therefore sectoral labor productivity) are*

$$\frac{\hat{w}_n^j}{\hat{P}_n^j} = \left(\hat{\pi}_{nn}^j\right)^{-\frac{1}{\theta^j \phi^j}} \hat{\lambda}_n^{\beta - 1} \left[\prod_{k \in \{a,m,s\}} \left(\hat{P}_n^k\right)^{\gamma^{jk}} / \hat{P}_n^j\right]^{-\frac{1-\phi^j}{\phi^j}}. \tag{25}$$

PROOF:

See online Appendix.

Proposition 3 provides a clear and intuitive way to determine counterfactual real GDP for each country n. If labor allocations do not change ($\hat{l}_n^j = 0$) then aggregate GDP changes by the weighted average change in underlying sectoral labor productivity. The weights are the initial GDP shares of each sector j. Labor reallocation increases aggregate GDP if labor moves towards sectors with larger productivity increases.

Changes in each sector's productivity are expressed by equation (25), which is similar to many Eaton and Kortum (2002) type models and identical to Caliendo and Parro (2012) but for $\hat{\lambda}_n^{\beta-1}$. Nonetheless, I will briefly discuss each component. First, as the share of expenditures allocated to domestic firms declines ($\hat{\pi}_{nn}^j < 1$) the average productivity of the remaining firms is higher as the lowest productivity firms shut down. The strength of this effect depends on productivity dispersion $1/\theta^j$ and on the value-added to output ratio ϕ^j. Second, labor reallocation affects productivity through changes in the rental rate of other productive factors, as $\hat{r}_n = \hat{w}_n \hat{\lambda}_n$, and exists only if $\beta < 1$. Finally, intermediate input prices affect productivity through changes in inputs used per worker. If intermediate input prices decline more than sector j's output price, then labor productivity rises. If intermediate inputs come only from a sector's own output ($\gamma^{jk} = 1$ if $j = k$ and 0 otherwise) then the final term of equation (25) is always one. Intersectoral linkages will play an important role in the quantitative analysis.

III. Model Calibration

Solving for relative changes allows for a simple and empirically reasonable calibration. Productivity parameters T_n^j, endowment of other factors H_n, subsistence consumption $\bar{a}$, and within-sector elasticities of substitution σ^j are not required. The remaining parameters are household preference weights $\{\epsilon^a, \epsilon^m, \epsilon^s\}$, production function parameters $\{\beta, \phi^j, \gamma^{jk}\}$, elasticities of trade $\{\theta^a, \theta^m\}$, labor market distortions ξ_n, total employment L_n, and initial values for trade shares π_{ni}^j and agricultural consumption's share of income s_n^a. Each is listed in Table 1.

Many of these parameters map in a clear way to observable data. I use trade shares π_{ni}^j from Section IB, employment L_n from the Penn World Table (version 8.0), and agricultural consumption's share of income s_n^a from the World Bank's International Comparison Program 2005 Final Tables. All data is for 2005. Household preference parameters $\{\epsilon^a, \epsilon^m, \epsilon^s\}$ determine sectoral spending shares as countries grow rich. That is, as income grows sufficiently large and subsistence food requirements become negligible, ϵ^s of household spending is allocated to services, ϵ^m to manufacturing, and ϵ^a to agriculture. I set $\epsilon_a = 0.01$, $\epsilon_m = 0.24$, and $\epsilon_s = 0.75$ to match common values in the literature, for example, Caselli and Coleman (2001).[4]

The remaining parameters require more detailed discussion. Production function parameters $\{\beta, \phi^j, \gamma^{jk}\}$ and labor market distortions ξ_n also map to observable data and I calibrate these parameters next in Sections IIIA and IIIB. Finally, in Section IIIC, I calibrate the cost-elasticities of trade for agriculture and manufacturing $\{\theta^a, \theta^m\}$.

[4] Using slightly more general preferences that incorporate a service-sector nonhomotheticity term, Herrendorf, Rogerson, and Valentinyi (2014) estimate $\epsilon^a = 0.02$, $\epsilon^m = 0.15$, and $\epsilon^s = 0.83$. In the online Appendix, I demonstrate the quantitative exercises are robust to these alternative values.

Table 1—Calibrated Model Parameters

Parameters	Description	Values/sources
$\{\epsilon^a, \epsilon^m, \epsilon^s\}$	Preference weights	$\{0.01, 0.24, 0.75\}$
$\{\theta^a, \theta^m\}$	Elasticities of trade	$\{4.06, 4.63\}$
$\beta, \phi^j, \gamma^{jk}$	Production function parameters	See Table 2
ξ_n	Relative Ag value-added per worker	From WDI and FAO
L_n	Total employment	From PWT 8.0
s_n^a	Food budget share	From ICP 2005
π_{ni}^j	Bilateral trade shares	See Section IB

Notes: Lists model parameters that are calibrated from 2005 data or from common values in the literature. To estimate the elasticities of trade $\{\theta^a, \theta^m\}$ I use the Caliendo and Parro (2012) method and provide details in Section IIIC and the online Appendix. Value-added per worker in agriculture relative to nonagriculture uses sectoral GDP data from the World Development Indicators and employment shares from the FAO; see Section IIIB for details.

There is a large literature estimating trade elasticities for manufactured goods but few estimates for agriculture. I review existing estimates and apply the recent method of Caliendo and Parro (2012) to directly estimate $\{\theta^a, \theta^m\}$.

A. *Production Function Parameters*

To calibrate each sector's production function parameters ($\beta, \phi^j, \gamma^{jk}$ for all $j, k \in \{a, m, s\}$) I use data from the Input-Output tables in the OECD Structural Analysis Database (STAN). Countries included in the database are typically rich but there are also data for poor and middle-income countries, including India, China, Turkey, South Africa, and Mexico. Output, value-added, labor compensation, and intermediate input spending are available for two-digit industries. I aggregate each into agriculture, manufacturing, and services. Details are in the online Appendix.

Overall, intermediate input shares γ^{jk} and value-added to output ratios ϕ^j vary across sectors but not across countries. Labor's share of value-added is common not only across countries but also across sectors.[5] This latter observation is consistent with much evidence. Consider measures of input use compiled by Fuglie (2010). Aggregating various studies, he finds a worldwide average agricultural labor inputs relative to gross output of 0.35. The share of land and structures is 0.21, suggesting labor's share of value-added of 0.63. His evidence also suggests little variation across countries. More broadly, Gollin (2002) finds little variation in labor's aggregate share of value-added across per capita countries. Since a country's employment share in agriculture does vary with income, labor's share of value added across sectors must be close to equal. Gollin, Lagakos, and Waugh (2014) review more evidence on this point.

I report the output-weighted average values in Table 2. The importance of intermediate inputs varies across sectors. The value-added to gross output ratio in services is nearly double that in manufacturing and roughly 50 percent in agriculture. The source of intermediates also varies substantially across sectors. Agriculture demands inputs from the three sectors in roughly even proportion. Manufacturing

[5] Apportioning operating surpluses to labor is a complication I describe in the online Appendix.

Table 2—Production Function Parameters

Parameters		Sector j		
		Agriculture	Manufacturing	Services
Labor's share of value-added	β	0.65	0.65	0.65
Value-added share of output	ϕ^j	0.50	0.35	0.59
Agricultural input's share	γ^{ja}	0.31	0.06	0.01
Manufactured input's share	γ^{jm}	0.39	0.61	0.24
Services input's share	γ^{js}	0.30	0.33	0.75

Notes: Displays the production-weighted average share of labor in value-added, value-added in output, and the intermediate input shares from the OECD STAN Input-Output (Total) tables for mid-2000s. Industries are classified by ISIC Revision 3, with Agriculture as 01–09, Manufacturing as 15–39, and Services as 40–95. Further details are described in the online Appendix.

and services use almost no agricultural inputs and rely largely on own-sector inputs. The shares are fairly uniform across different levels of development. I plot each country's shares against per capita GDP in the online Appendix.

B. *Labor Market Distortions*

Labor's value-added share is equal across sectors. If labor can freely move between sectors, value-added per worker will equalize across sectors; if labor cannot, it may differ. Relative agricultural wages in the model are $\xi_n = \frac{\phi^a R_n^a / L_n^a}{(I_n - \phi^a R_n^a)/(L_n - L_n^a)}$. I set them to match relative value-added per worker in data.

Figure 5 plots data on sectoral value-added and employment shares from the World Development Indicators and FAO. There are stark differences in value-added and employment shares in poor countries. The difference between employment and GDP shares for agriculture is strongly decreasing with a country's level of development. This fact is a well-known and systematic pattern (Herrendorf, Rogerson, and Valentinyi 2014). Among the poorest countries, the agricultural employment share is 0.8 while the GDP share is 0.4; the implication: $\xi_n = (0.4/0.6)/(0.2/0.8) \approx 0.17$. I plot the implied labor distortion for all countries in the bottom panel of Figure 5.

Gollin, Lagakos, and Waugh (2014) construct the inverse of ξ_n using an identical approach. They go much further to demonstrate these labor productivity differences are robust. They use multiple sources and data (both macro and micro) for a variety of countries and find consistently larger gaps in developing countries. Differences in hours worked, human-capital, or alternative measures of value-added by sector cannot fully account for these large gaps. They find weak evidence of geographic and institutional factors may be important. Whatever the underlying source of the labor productivity differences, I take its magnitude as given and exogenously vary it in the quantitative exercises to come.

Why are labor market frictions important? After all, given trade shares $\left(\pi_{ni}^j\right)$ and household spending shares (s_n^a) from data, the initial equilibrium income and sectoral expenditures do not depend on ξ_n. Without frictions, though, the model implies highly counterfactual labor allocations. From equation (13), sectoral GDP shares equal employment shares if labor markets are flexible $(\xi_n = 1)$ but in data value-added shares are roughly half of employment shares in poor countries

Figure 5. Agriculture's Share of GDP and Employment, by Country

Notes: Displays agriculture's share of GDP (top left) and employment (top right). The World Bank's World Development Indicators (WDI) is the principle source of data on agriculture's share of GDP. The FAO provides data on agriculture's share of employment and is augmented where necessary with data from the WDI. Details are in the online Appendix. Combined, these shares measure value-added per worker in agriculture relative to nonagriculture (bottom).

(recall Figure 5). Using initial equilibrium revenues, I use equation (13) to plot in Figure 6 the implied agricultural employment share when $\xi_n = 1$ and when ξ_n is calibrated to match relative value-added per worker data. Despite not explicitly targeting employment shares, the calibrated model closely matches data while the model without labor frictions systematically underestimates agriculture's employment share in poor countries.

C. *Elasticities of Trade for Agriculture and Manufacturing*

The parameter θ^j governs productivity dispersion and therefore determines how sensitive trade flows are to trade costs (higher θ implies a lower cost-elasticity of trade flows). Many estimates exist for θ^m. For instance, using plant-level data, Bernard et al. (2003) find $\theta = 3.6$. Another approach is to estimate productivity dispersion from price and trade flows. Eaton and Kortum (2002) and Waugh (2010) use this approach and find values of 8.28 and 5.5, respectively. More recently, Simonovska and Waugh (2014) relax some assumptions and correct bias in the estimation and find a value closer to 4.

For agriculture, there are far fewer estimates. For colonial India, Donaldson (forthcoming) finds $\theta^a = 3.8$ across 17 commodities. Using tariffs and trade flows

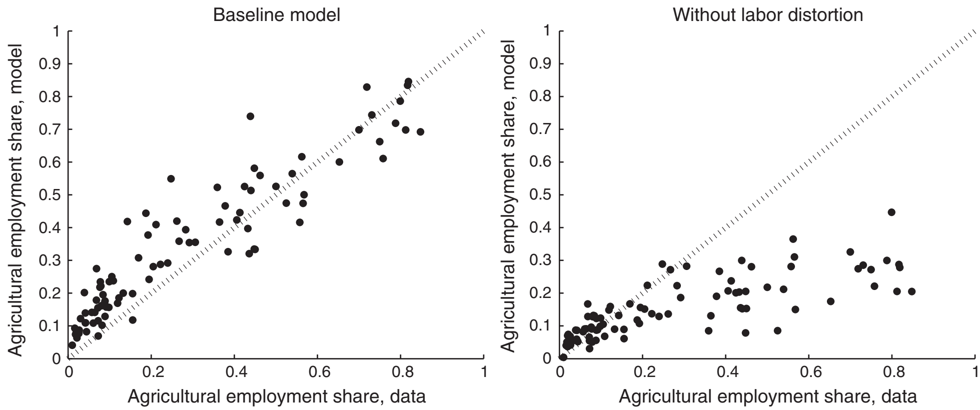


FIGURE 6. AGRICULTURE'S SHARE OF EMPLOYMENT, MODEL VERSUS DATA

Notes: Displays agriculture's share of employment under various model assumptions. First, the baseline model displays the fit for the baseline model that includes labor distortions and nonhomothetic preferences. Next, without labor distortions ($\xi_n = 1$ for all n) the share of employment in agriculture is systematically underestimated for poor countries.

between Canada, the United States, and Mexico, Caliendo and Parro (2012) estimate θ for many product categories, averaging $\theta^a = 8.11$ and $\theta^m = 8.22$. Given the scarcity of estimates for agriculture, I apply their method to global trade and tariffs. I provide details in the online Appendix, but the core of the method is straightforward.

Consider overall trade costs τ_{ni}^j as a composite of importer-specific costs μ_n^j, such as border delays or other nontariff barriers; exporter-specific costs δ_i^j, which Waugh (2010) finds particularly important for developing countries; symmetric bilateral trade costs ν_{ni}^j that inhibit trade between two countries in a similar way, such as distance, language, regional trade agreements, and so on; and, finally, asymmetric bilateral trade costs t_{ni}^j that may be different for trade from country i to n than from n to i. In summary, suppose trade costs are $\ln \tau_{ni}^j = \ln t_{ni}^j + \nu_{ni}^j + \mu_n^j + \delta_i^j + \epsilon_{ni}^j$.

With these trade costs, manipulating equation (8) yields

$$\ln\left(\frac{\pi_{ni}^j}{\pi_{in}^j}\frac{\pi_{ih}^j}{\pi_{hi}^j}\frac{\pi_{hn}^j}{\pi_{nh}^j}\right) = -\theta^j \ln\left(\frac{t_{ni}^j}{t_{in}^j}\frac{t_{ih}^j}{t_{hi}^j}\frac{t_{hn}^j}{t_{nh}^j}\right) + \varepsilon_{ni}^j, \tag{26}$$

where $\varepsilon_{ni}^j = -\theta^j\left(\epsilon_{ni}^j - \epsilon_{in}^j + \epsilon_{hi}^j - \epsilon_{hi}^j + \epsilon_{nh}^j - \epsilon_{hn}^j\right)$. Since tariffs are an important component of asymmetric bilateral trade costs, consider those as a proxy for t_{ni}^j. If other factors affecting trade flows ε_{ni}^j are unrelated to tariffs between countries, then this expression can be used to estimate θ^j.

To implement this approach, complete trade and tariff data on all country triples (i, n, h) are required. My estimates for both sectors in 2005 use the biggest ten trading countries for which I have complete tariff and trade data. The resulting estimates, displayed in Table 3, are largely consistent with other estimates in the literature. I begin, though, with a direct comparison to Parro (2013), who finds $\theta = 4.6$ for capital goods and $\theta = 5.2$ for other manufactured goods in 1990. Using the same countries as in his paper, I find a similar elasticity of $\theta^m = 5.27$. For the big-10

Table 3—Trade Elasticities, Agriculture, and Manufacturing, 2005

	Manufacturing		Agriculture
	Parro set	Top 10	Top 10
Elasticity estimate, $\hat{\theta}^j$	5.27***	4.63***	4.06***
	(0.315)	(1.267)	(0.512)
Countries	18	10	10
Observations	5,814	990	990
R^2	0.07	0.03	0.05

Notes: Displays results of regression equation (26) to estimate the elasticity of trade by sector. The "Parro Set" of countries is provided for comparison to Parro (2013), who uses this method for 1990 and finds $\theta^m \in [4.6, 5.2]$. Standard errors are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

countries, I find $\theta^m = 4.63$ for manufacturing and a slightly smaller elasticity of $\theta^a = 4.06$ for agriculture. Based on these results, I set $\theta^m = 4.63$ and $\theta^a = 4.06$. In the online Appendix, I provide further details behind these estimates, which countries are included, and how tariffs are constructed. I also show the quantitative results are robust to alternative (higher) values for θ^j.

IV. Quantitative Analysis

With the calibrated model, I estimate the contribution of labor market distortions and international trade costs to cross-country productivity differences. I begin with labor market distortions, explicitly contrasting their productivity effects in both an open- and a closed-economy. I go on to examine the direct contributions of trade costs to productivity differences, with and without distorted labor markets.

A. *Domestic Labor Market Distortions*

Is an open-economy model important to investigate the effects of domestic labor distortions on productivity? It turns out the answer is yes. Trade amplifies the negative effect of labor distortions on aggregate productivity. The intuition is simple. Eliminating labor distortions makes domestically produced food more expensive (by increasing agricultural wages). Without trade, minimum food requirements necessitate sufficient labor be allocated to agricultural production domestically. With trade, food can be imported and more labor allocated to nonagricultural production. In addition, food imports substitute for low productivity domestic producers. Increased imports will then increase agricultural productivity by more than would be the case without trade.

To quantify these effects, I simulate the model with $\hat{\xi}_n = \xi_n^{-1}$. I repeat the experiment with autarky, which corresponds to an initial equilibrium with $\pi_{ni}^j = 0$ for $n \neq i$ and $\pi_{nn}^j = 1$. The results of this experiment for the poorest 10 percent of countries are in Table 4. In autarky, eliminating labor distortions increases aggregate productivity among poor countries by roughly 50 percent. With trade, the change is closer to 70 percent as labor moves off the farm. Agriculture's share of employment

Table 4—Eliminating Labor Market Distortions in Poor Countries

	Baseline model		No intersectoral linkages or other factors	
	Autarky	With trade	Autarky	With trade
Change in welfare (percent)				
Total welfare	49.82	70.72	4.63	181.39
Real wage effect	−27.74	−34.45	−1.89	−9.64
Labor market effect	132.87	167.12	204.84	236.15
Subsistence effect	−10.97	−2.50	−65.01	−7.36
Change in productivity (percent)				
Aggregate	49.07	65.46	3.90	190.73
Agricultural	143.69	150.16	0.00	112.14
Manufacturing	−28.86	−40.54	0.00	−29.50
Services	−26.01	−30.72	0.00	0.00
Change in employment and trade shares (p.p.)				
Agricultural employment	−38.42	−53.17	−1.28	−67.26
Agricultural home trade	—	−24.20	—	−57.49
Manufacturing home trade	—	19.03	—	31.52

Notes: Displays the average effects among the poorest 10 percent of countries from eliminating domestic labor market distortions in those countries. Results are displayed with and without trade. "Autarky" requires $\pi_{ni}^{j} = 0$ for $n \neq i$ and $\pi_{nn}^{j} = 1$ for all n. "With Trade" is the baseline model where π_{ni}^{j} is data. In the last two columns, labor's share of value-added is set to one and the matrix of intermediate input shares γ equals the identity matrix ($\gamma^{jk} = 1$ if $j = k$ and 0 otherwise). Trade costs do not change in any of these experiments, so $\hat{\tau}_{ni}^{j} = 1$ for all n, i, and j.

declines by over 50 percentage points. In terms of welfare gains, lower labor distortions have a negative real wage effect. This offsets a large welfare gain from an improved labor allocation. The subsistence effects matter little here. Overall, a closed-economy framework *underestimates* the welfare and productivity costs of labor distortions, which are over 40 percent higher with trade than in autarky.

There are also substantial productivity changes within sectors. Agricultural labor productivity increases 150 percent when trade is possible. This results from two effects: a smaller home-share of expenditures (which declines nearly 25 percentage points); and substituting other inputs for labor. Neither effect should be surprising. Labor distortions lower agricultural wages, inducing firms to choose more of other inputs relative to labor. In nonagricultural sectors, productivity declines as labor becomes relatively cheaper and more expenditures are allocated to domestic producers.

These results critically depend on intersectoral linkages and other factors of production. Without other factors, the allocation of labor between sectors has no effect on sectoral labor productivity. The only source of within-sector productivity change is trade—through Ricardian selection. The last two columns of Table 4 repeat the experiment when labor's share of value-added is one ($\beta = 1$) and when there are no intersectoral linkages ($\gamma^{jk} = 1$ when $j = k$ and 0 otherwise). When trade is possible, labor distortions have significant aggregate productivity effects while in autarky the effects are negligible. Viewed another way, intersectoral linkages and other factors of production magnify the costs of labor distortions in autarky and mitigate their costs in an open-economy.[6]

[6]Święcki (2013) does not incorporate other factors or intersectoral linkages. He finds large differences between open- and closed-economy models, as I do in the last two columns of Table 4. Restuccia, Yang, and Zhu

Consider first the case of autarky. Without other factors, employment in agriculture is required to meet subsistence when imports are unavailable. So, labor distortions do little as their removal would not lead to fewer agricultural workers. With other factors, labor can move off the farm without agricultural production declining. So, labor distortions affect agricultural employment and productivity. Consider next the case of trade. Imports substitute for domestic production, so labor distortions increase agricultural employment and lower productivity. This is true even without other factors. With other factors, however, productivity in nontradables depends on the allocation of employment. Labor distortions increase agricultural employment and therefore increase nontradables productivity, mitigating the costs of labor distortions.

In the next section, I hold labor market distortions fixed and estimate the direct effect of trade costs on cross-country productivity differences.

B. *Trade Costs in Agriculture and Manufacturing*

Do trade barriers contribute to cross-country agricultural and aggregate productivity differences? By how much? To answer these questions, I simulate a complete elimination of trade costs in both agriculture and manufacturing, holding labor distortions fixed at their initial level. Specifically, I simulate the model with $\hat{\tau}^j_{ni} = 1/\tau^j_{ni}$, where τ^j_{ni} are the barriers measured in Section IB. This abstracts from changes in the number of trade partners (an extensive margin), only allowing trade flow changes between country-pairs that actually trade in the data. For country-pairs that do not trade, trade costs will not change in this simulation, as $\tau^j_{ni} = \infty$.[7] The results of this exercise are in Table 5, with countries grouped by aggregate GDP/worker. Trade costs affect poor countries significantly more than rich countries. I discuss welfare and productivity changes separately.

Welfare.—Welfare gains strongly decrease with a country's level of development, as evidenced by the first row of the table. The poorest 10 percent of countries see welfare increase by more than 113 percent, compared to only 7 percent for the richest 10 percent of countries. To understand these gains, I decompose welfare changes into the three component parts of equation (23). Real wages for poor countries increase by 50 percent, accounting for half of overall gains. Nonhomothetic preference also significantly increase welfare gains by 50 percent. A slight 1 percentage point increase in the share of employment in agriculture subtracts 4 percent from welfare gains. Labor allocations and subsistence consumption effects are not typically a feature of trade models in this area (see, for example, Waugh 2010). These results suggest they are quantitatively important.

Why does agricultural employment increase? While it is costly for poor countries to import, it is significantly more costly for them to export. Removing this type of trade cost results in increased agricultural exports. The home share of expenditures

(2008) incorporate limited intersectoral linkages and has nonlabor agricultural inputs, which is why even with a closed-economy model they found labor distortions matter for aggregate productivity.

[7] In the online Appendix, I replace zeros with imputed values based on a standard gravity regression; the results are similar, as zero-pairs have extremely small imputed values for π^j_{ni}.

Table 5—The Effect of Trade Costs

	Cross-country GDP/worker categories				
	Bottom 10 percent	Bottom 25 percent	Middle 50 percent	Top 25 percent	Top 10 percent
Panel A. Eliminate trade costs in agriculture					
Change in welfare (percent)					
Total welfare	113.8	93.3	37.3	11.3	7.4
Real wage effect	49.3	41.1	23.8	11.4	8.5
Labor market effect	−3.9	−5.3	−6.8	−4.6	−4.4
Subsistence effect	49.1	44.6	19.0	4.7	3.5
Change in productivity (percent)					
Aggregate	227.3	190.2	105.6	37.9	22.0
Agricultural	755.5	679.2	470.8	292.3	240.3
Manufacturing	198.6	160.5	77.0	28.5	17.5
Services	19.0	17.0	11.0	5.7	4.4
Change in employment and trade shares (p.p.)					
Agricultural employment	1.0	2.2	9.0	5.4	4.4
Agricultural home trade	−91.4	−88.5	−75.9	−71.4	−74.9
Manufacturing home trade	−37.8	−32.5	−21.2	−8.3	−5.2
Panel B. Eliminate trade costs in manufacturing					
Change in welfare (percent)					
Total welfare	593.7	424.3	175.4	78.8	62.7
Real wage effect	96.0	101.8	100.1	66.2	55.0
Labor market effect	142.2	86.5	19.6	4.8	3.2
Subsistence effect	46.1	39.3	15.1	2.7	1.7
Change in productivity (percent)					
Aggregate	867.5	666.0	301.8	123.3	81.2
Agricultural	133.2	129.7	146.5	75.2	48.0
Manufacturing	1,156.4	1,095.0	806.5	397.4	268.7
Services	10.7	18.4	28.5	22.2	19.0
Change in employment and trade shares (p.p.)					
Agricultural employment	−61.1	−49.2	−23.0	−7.6	−5.0
Agricultural home trade	−64.9	−54.7	−40.9	−18.9	−12.8
Manufacturing home trade	−44.7	−47.0	−50.0	−54.1	−53.2
Panel C. Eliminate trade costs in both sectors					
Change in welfare (percent)					
Total welfare	614.1	473.1	206.1	92.1	72.9
Real wage effect	133.9	132.6	118.6	75.9	64.0
Labor market effect	97.6	64.4	15.2	3.7	1.5
Subsistence effect	54.5	49.9	21.6	5.3	4.0
Change in productivity (percent)					
Aggregate	906.5	712.7	344.4	147.3	100.6
Agricultural	1,395.3	1,308.9	1,081.6	546.7	383.6
Manufacturing	1,583.3	1,453.3	995.8	464.6	312.7
Services	24.0	28.6	34.3	25.5	22.2
Change in employment and trade shares (p.p.)					
Agricultural employment	−42.9	−37.0	−18.0	−6.8	−3.9
Agricultural home trade	−91.6	−88.7	−75.9	−71.1	−74.5
Manufacturing home trade	−44.7	−47.1	−50.0	−54.0	−53.1

Notes: Reports changes in welfare and productivity from eliminating bilateral trade costs measured in Section IB, averaged across countries within each GDP/worker category. Welfare gains are decomposed using equation (23). Changes in employment and trade shares are in percentage points.

in agriculture, however, declines significantly (by over 91 percentage points). This implies that while agricultural employment changes little, they concentrate in a smaller number of agricultural varieties with higher productivity.

Trade costs in both sectors have a larger effect on labor allocations and welfare. First, consider panel B where only manufactured goods trade is liberalized. Here, agricultural employment declines significantly. Next, panel C reports the results when both sectors are liberalized. For poor countries, welfare increases by well over 600 percent, compared to only 73 percent for rich countries. The importance of labor market effects on welfare are also significantly positive in this case, increasing welfare by over 100 percent. This is from a large (43 percentage point) reduction in the share of employment in agriculture. With lower trade costs in manufacturing, and improved export costs in particular, labor can reallocate to this sector and produce goods for export. Real wage increases are also larger (from dramatically higher export demand) adding over 130 percent to welfare gains. Subsistence effects are largely unchanged from before.

Large gains for poor countries are not merely due to their higher initial trade costs. The trade-cost *elasticity* of welfare is actually higher in poor countries. For each 1 percent reduction in the average cost of trade (across import partners) in agriculture, welfare increases by 1.32 percent in poor countries compared to only 0.1 percent in rich countries. In manufacturing, welfare in poor countries increases by nearly 7 percent for each 1 percent reduction in trade cost compared to only 1 percent among rich countries.

Productivity.—Labor reallocation and changes in trade shares also affect productivity. Eliminating agricultural trade costs increases aggregate productivity by over 227 percent in the poorest countries and by only 22 percent in the richest. Eliminating trade costs in both sectors yields substantially larger changes. These large productivity increases are driven by labor reallocation from agriculture to nonagriculture, and within-sector increases in productivity, particularly in agriculture. The first effect is straightforward, so I will elaborate only on the second.

A sector's productivity increases as fewer low-productivity domestic producers operate (Ricardian selection) and as other inputs are substituted for labor (see equation (25)). Removing trade costs results in a massive reduction in expenditures allocated to domestic farmers. The lowest productivity farms shut down, resulting in productivity gains. As poor countries initially have a low share of spending allocated to agricultural imports, there are potentially large gains from liberalization.

Overall, agricultural productivity in poor countries increases by over 750 percent, which accounts for over 70 percent of the aggregate gains, when agricultural trade is liberalized. When both sectors are liberalized, agricultural productivity increases nearly 1,400 percent. Decomposing these overall gains (following equation (25)) shows Ricardian selection is particularly important. In the case of agricultural liberalization alone, Ricardian selection accounts for approximately 150 percent of the sectoral gains (for rich and poor) and intermediate input use accounts for -50 percent. Changes in λ_n contribute little. Intermediate use declines as agricultural prices decline relative to manufactured goods and services. In models without intersectoral linkages, this effect is absent. When both sectors' trade costs are eliminated, the story is similar although the magnitudes differ. For poor countries, selection accounts for roughly 135 percent of agriculture's productivity change while intermediates account for -25 percent and $\hat{\lambda}_n^{\beta-1}$ accounts for -10 percent.

Table 6—Counterfactual Productivity Ratios (*Rich/poor*)

	Labor distortions	
	Initial level	Eliminated
Initial trade costs	40.89 (data)	24.64
Eliminate trade costs in agriculture	15.92	15.05
Eliminate trade costs in both sectors	8.39	7.70
Share of productivity difference explained		
Initial trade costs	0.00	0.14
Eliminate trade costs in agriculture	0.25	0.27
Eliminate trade costs in both sectors	0.43	0.45

Notes: Displays counterfactual aggregate productivity ratios (richest 10 percent relative to the poorest 10 percent of countries). The share accounted for by each factor is, for example, $0.25 = 1 - \ln(15.92)/\ln(40.89)$.

Turning to the nonagricultural sectors, manufacturing and services productivity also increase. Higher nominal wages raise input costs in poor countries relative to rich. As a result, expenditures increase for manufactured goods from rich countries. The resulting Ricardian selection increases manufacturing productivity in poor countries. For services, there is no selection but higher wages lead to increased use of other inputs relative to labor and therefore higher labor productivity.

How do these productivity changes translate into cross-country differences? In Table 6, I document the counterfactual ratios of aggregate productivity between the richest 10 percent of countries and the poorest 10 percent. The aggregate difference falls from 41 to 16 when agricultural trade costs are eliminated, and to just over 8 when both sectors are liberalized. I interpret these counterfactual ratios as the cross-country difference unexplained by trade costs. The share accounted for by trade costs is then the (log) ratio of the explained to the initial gap. That is, $0.25 = 1 - \ln(15.92)/\ln(40.89)$ and therefore one-quarter of the aggregate cross-country difference is accounted for by trade costs in agriculture. Trade costs in both sectors account for 43 percent of the aggregate productivity difference between rich and poor countries, three quarters of which is from within-sector Ricardian selection. For comparison, domestic labor distortions account for 14 percent of the difference.[8] Trade costs, typically absent in the literature, accounts for a substantial share of cross-country productivity differences—even more than domestic labor distortions.

These exercises do not suggest policy reforms can achieve such gains; it is an accounting exercise. In the next section, I show policy-relevant trade costs (tariffs and border delays) also have substantial effects on productivity and welfare.

C. *Policy-Relevant Trade Costs*

Many barriers to trade are the direct result of public policy choices. In Section IB, I presented evidence that tariffs and border delays are substantially higher and more costly in poor countries than in rich countries. In this section, I simulate the welfare

[8] From the previous section, 24.64 is the rich/poor ratio without labor distortions.

Table 7—Effect of Policy-Relevant Trade Costs in Poor Countries

	Agriculture		Manufacturing		Both sectors	
	Tariffs	Delays	Tariffs	Delays	Tariffs	Delays
Change in welfare (percent)						
Total welfare	−0.7	65.8	6.5	129.4	5.7	211.6
Real wage effect	1.7	0.9	3.4	46.6	5.2	50.0
Labor market effect	−2.7	19.9	1.1	28.2	−1.7	44.1
Subsistence effect	0.3	37.0	2.0	22.1	2.2	44.1
Change in productivity (percent)						
Aggregate	−0.6	74.5	4.1	105.3	3.3	201.6
Agricultural	3.1	233.3	2.4	31.9	5.7	389.5
Manufacturing	3.2	11.0	10.8	282.9	14.4	345.7
Services	1.3	−3.2	1.2	11.5	2.5	10.4
Change in employment and trade shares (p.p.)						
Agricultural employment	1.0	−9.7	−0.6	−12.8	0.5	−20.5
Agricultural home trade	−4.7	−86.0	−0.2	−3.2	−4.8	−86.4
Manufacturing home trade	−1.9	−7.5	−8.9	−42.7	−10.6	−42.9

Notes: Reports effect of eliminating policy-relevant trade costs (import tariffs and the tariff-equivalent of border delays) for the bottom decile of countries. I decompose welfare changes using equation (23) for details. Changes in employment and trade shares are in percentage points.

and productivity consequences of these costs. I report results in Table 7, reporting only the average among the poorest 10 percent of countries.

Tariffs, as they are fairly low and represent a small fraction of overall trade costs, have small welfare and productivity costs. Eliminating each country's average observed agricultural tariff lowers welfare by just under 1 percent in poor countries. Why? Poor countries increase agricultural exports and production, and therefore require more agricultural employment. While not reported, if *only* poor countries eliminate agricultural tariffs, their welfare increases by 2.3 percent and agricultural employment declines. Welfare also grows in poor countries (by 5.7 percent) if tariffs in both sectors are eliminated.

A more costly trade barrier, especially for agricultural goods, are border delays. As described in Section IB, time is a significant barrier to trade, with Hummels and Schaur (2013) estimating a 3.1 percent tariff-equivalent cost for each day of delay for food and beverage products. Eliminating these delays results in substantial welfare and productivity increases, as reported in Table 7. For agricultural delays, the welfare gains are almost exclusively the result of improved labor allocations and the declining importance of subsistence consumption.

Of course, eliminating border delays affects both sectors, so the final column is most relevant. Here, welfare more than triples in poor countries, with roughly equal importance between the three sources of welfare gains. Productivity also increases substantially. Aggregate productivity triples, agricultural productivity increases by nearly 400 percent, and manufacturing productivity grows by nearly 350 percent. In comparison, rich countries have shorter border delays, so experience much smaller gains. Aggregate productivity in rich countries increases by only 11 percent (not reported). The aggregate productivity ratio between rich and poor declines from 40.89 to 15.07 in this experiment. Border delays therefore account for 27 percent of the productivity gap. Policymakers are (rightly) making efforts to speed customs clearance and lower import times in poor countries. The World Trade Organization (WTO) Bali Package is a recent example.

V. Conclusion

This paper examines the relationship between the international food trade and differences in aggregate labor productivity between rich and poor countries. A large literature finds labor productivity differences within the agricultural sector, where most developing country employment concentrates, accounts for nearly the entire productivity gap. With poor countries importing so little of their food, a closed-economy framework to investigate cross-country productivity differences is natural. The existing literature therefore abstracts from open-economy considerations. Instead, I exploit a general equilibrium model of international trade that embeds features commonly used in the macroeconomics literature within a modified Eaton-Kortum trade model to show explicitly incorporating trade flows, and trade distortions, in multiple sectors can yield important contributions.

In particular, the productivity costs of domestic labor market distortions are higher in an open-economy framework than in a closed-economy one. Overall, trade amplifies the productivity costs of labor distortions in poor countries by 40 percent. Similarly, labor market distortions and nonhomothetic preferences substantially amplify the gains from trade for poor countries (roughly double) relative to standard trade models. Finally, and most importantly, trade costs directly contribute to cross-country productivity differences. Agricultural trade costs account for roughly 25 percent of the aggregate differences between rich and poor countries. Trade costs in agriculture and manufacturing together account for over 40 percent. Even observable, policy-relevant trade costs (tariffs and border delays) have important negative productivity effects in poor countries. The food trade is missing in poor countries and in our models; it should be no longer.

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