International Trade and Income Differences

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Abstract

Standards of living between the richest and poorest countries differ by more than a factor of 30. Is there a role for international trade in accounting for this fact? To answer this question, I construct a multi-country general equilibrium model. Within this framework, I derive an accounting procedure analytically decomposing income per worker into three components: differences in capital-output ratios, productivity, and a contribution from trade. Since the contribution from trade is measurable, I am able to quantify the variation in income per worker attributable to trade. In a sample of 77 countries, I show that the contribution from trade is negligible, less than 1 percent. That is, trade's contribution is so small that relative incomes are almost the same in a model with *no* trade. To further understand this result and how cross-country income differences respond to changes in barriers to trade, I calibrate the model by picking country specific productivity parameters and trade costs so the pattern of bilateral trade implied by the model matches the data. I find the calibrated trade costs are systematically asymmetric with poor countries facing higher costs to export their goods relative to rich countries. Furthermore, my calibrated model generates both prices and cross-country income differences consistent with the data. Through counterfactual exercises, I find that by removing the asymmetry in trade costs (i.e. provide poor countries with equivalent market access to rich countries markets) cross-country income differences decline by up to 34 percent. Eliminating all barriers to trade reduces cross-country income differences by up to 56 percent. By facilitating a more efficient allocation of production across countries, reductions in barriers to trade are quantitatively important for economic development.

Key Words: trade, income, bilateral, total factor productivity, trade costs
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1 Introduction

Standards of living between the richest and poorest countries differ by more than a factor of 30. A large literature has evolved attempting to explain this fact within the context of a standard (closed-economy) neoclassical growth model. Beginning with Mankiw, Romer, and Weil (1992)—and the competing views of Klenow and Rodriguez-Clare (1997), Hall and Jones (1999), and Parente and Prescott (2002)—the consensus is that physical and human capital accounts for only 50 percent of the variation in income per worker; the rest is unobserved productivity differences. Given this finding, a growing literature has attempted to understand how differences in economic fundamentals can result in large productivity differences across countries; see Caselli (2005) for a survey.

In most of this literature there is no explicit role for international trade. Yet there are many reasons to think that international trade might be important to understand cross-country income differences. For example, a majority of all trade is between rich countries, very little is between rich and poor countries. Furthermore, there are many studies documenting the positive correlation between the amount a country trades and its income level; see Frankel and Romer (1999) for example. In policy circles, various anti-globalization movements make claims suggesting rich countries exploit poor countries through trade; see Oxfam International (2002). While international organizations (e.g., The World Bank) emphasize trade as a means of development.

In this paper, I ask and answer the following question: What is the quantitative relationship between international trade and a country's standard of living? To answer this question, I bridge the gap between existing quantitative closed-economy analysis of cross-country income differences and international trade by studying their joint relationship in a quantitative multi-country general equilibrium model. Focusing on the implications of international trade on income, I argue several points: Given the current volume of trade, trade per-se is not an important factor in explaining cross-country income differences; exogenous productivity differences are the driving force. However, underlying the pattern of trade there are differences in the barriers to trade poor countries face relative to rich countries. Eliminating these differences allows poor countries to gain relative to rich countries reducing cross-country income differences through the reallocation of production both within and across countries.

To argue these points, I construct a multi-country model of trade. In each country, there are two sectors: an intermediate goods sector and a final goods sector, both with constant returns technologies. Labor, capital, and intermediate goods are used as factors of production. In the intermediate goods sector there is a continuum of goods. As in Dornbusch, Fischer, and Samuelson (1977), production technologies differ across goods on the continuum only in their efficiency levels. As in Eaton and Kortum (2002), efficiency levels are treated as random variables drawn from a parameterized distribution. Each country's distribution differs in its average efficiency level. Trades only occur within intermediate goods, which are purchased from the country with the lowest price that includes "iceberg" costs to trade. The final goods sector produces a non-traded consumption good with a technology common to all countries.

To quantify the relationship between international trade and a country's income level, I proceed in two directions. First, using the model I derive an accounting procedure that analytically decomposes differences in income per worker into three components: differences in capital-output ratios, differences in average efficiency, and a contribution from trade. The contribution from trade is a function of a countries aggregate volume of trade and hence measurable. With this approach I am able to quantify the variation in income per worker attributable to trade, circumventing otherwise difficult decisions necessary to calibrate and solve the entire model. Implementing this procedure, I find trade per-se is not quantitatively important in explaining cross-country income differences. In a sample of 77 countries, there is a 26-fold difference in income per worker between the top 10th percentile and bottom 10th percentile. The contribution from trade is only a factor of 1.13. That is trade's contribution is so small that relative incomes are almost the same in a model with *no* trade.

It is important to emphasize the meaning and implications of this result. First, though relative incomes would be similar if there was no trade, this result not about the level of trade but about how the volume of trade covaries with level of development. Hence, this results says that the observed volume of trade does not covary systematically enough for trade per-se to be quantitatively meaningful. However, this raises the following question: Rich and poor countries seem very different in both the technologies and factors used, yet why is trade's impact quantitatively similar? I argue that the pattern of bilateral trade is distorted, the distortions poor countries face are systematically different than those faced by rich countries, and that cross-country income differences reflect these distortions.

To argue these points, I proceed in a second direction to quantify the relationship between international trade and a country's income level. I calibrate the model by recovering trade costs and each country's average efficiency level from the pattern of bilateral trade. With the recovered parameters, I compute the model's equilibrium and study the model's implications for cross-country income differences. In contrast to alternative approaches, I find that my model generates both prices and differences in income per worker consistent with the data. Furthermore, similar to the implications of the accounting exercise, my calibration results in large differences in average efficiency across countries.

This is not the only impediment poor countries face. Consistent with the empirical trade literature, there are significant distortions in the form of trade costs present in the pattern of trade; see Anderson and van Wincoop (2004) for a survey. In contrast to this literature, I allow for asymmetries in trade costs. Using my approach, I find that poor countries face systematically higher costs to export relative to rich countries. Indirectly these distortions—both symmetric and asymmetric—affect cross-country income differences because the distribution of income across countries depends on the entire general equilibrium allocation of production. Thus, changes in trade policies and trade costs provide an avenue for poor countries to gain relative to rich countries reducing cross-country income differences.

I illustrate this point through several counterfactual experiments by adjusting trade costs, but fixing the calibrated efficiency levels. In one experiment, trade costs are set so that between two countries they both face the minimum of the calibrated trade costs between them. Given how the recovered trade costs impact poor countries relative to rich countries, the question motivating this counterfactual exercise is: If poor countries had equivalent market access to rich countries markets, how would cross-country income differences change? In this experiment, the variance in log income per worker is reduced from 1.43 to 1.18 and the difference between 90th percentile and 10th percentile in income per worker is reduced from 32 to 21. Providing poor countries with equal market access reduces cross-country income differences by 17-34 percent.

In a second experiment all trade costs are eliminated. Here, the ratio of the variance in log income per worker is reduced is reduced to 0.87 and the difference between 90th percentile and 10th percentile in income per worker is reduced to 14. Removing all trade costs reduces cross-country income differences by 40-56 percent. Admittedly, this is an extreme exercise. However, it is a quantitative measure of trade's *potential* to reduce cross-country income differences. For example, even if one takes the position that much of the distortions to trade are outside of the policy realm, this result suggests that non-policy related changes such as technological improvements in shipping, infrastructure, and communications are quantitatively important to reducing cross-country income differences.

As mentioned, these results relate to the income accounting literature. Klenow and Rodriguez-Clare (1997), Hall and Jones (1999), Parente and Prescott (2002), and Caselli (2005) are examples that find cross-country income differences mostly result from differences in total factor productivity. Extending these exercises to an open economy framework, I derive a relationship in which total factor productivity is endogenous and decomposable into two components: an exogenous efficiency level and an endogenous and measurable contribution from trade. As noted, I show that the latter is not quantitatively important in explaining cross-country income differences. However, eliminating barriers to trade reallocates production across countries allowing poor countries to close the gap in income.

Most recent empirical studies of the relationship between international trade and a country's standard of living have focused on the statistical relationship between the aggregate volume of trade and income level often finding a moderate positive correlation. These studies have faced two difficulties. The first difficulty is that both trade and income are endogenous. For example, a positive correlation between income level and trade may result from high income countries being more productive, have better policies, etc. not because trade by itself raises income. After constructing instruments to control for endogeneity, a moderate positive relationship often remains; see Frankel and Romer (1999) and more recently Noguera and Siscart (2005). Rodriguez and Rodrik (2001), Hallak and Levinsohn (2004), and others have questioned these findings, mostly criticizing the validity of their instruments, leaving the results inconclusive. The second difficulty is that they are reduced-form studies. That is the estimated coefficients in these studies only reflect correlations, not policy statements regarding how income or welfare may change given a change in barriers to trade. In a quantitative general equilibrium model, my accounting procedure explicitly accounts for the role of international trade on a country's standard of living while avoiding the statistical difficulties previous studies have faced. Furthermore, with an explicit model and the quantification of its parameters, I am able to ask and answer how cross-country income differences would change with the removal of barriers to trade.

Relative to recent quantitative models of international trade, such as Eaton and Kortum (2002) and Alvarez and Lucas (2007), the key distinctions are the question and the methods. First, Eaton and Kortum (2002) and Alvarez and Lucas (2007) are principally concerned with the model's implications for trade — with the former studying the bilateral pattern of trade for OECD countries and the latter studying the aggregate volume of trade in a wide cross-section of countries. In contrast, I am principally concerned with the implications of international trade for cross-country income differences.

Another distinction lies in the procedures quantifying the model. First, I derive an accounting procedure allowing me to evaluate the quantitative importance of trade, using only observed measures of trade, without having to make difficult decisions that are necessary to quantify and solve the whole model. Second, disciplining my approach I use equilibrium conditions in the model and data on the pattern of bilateral trade to recover a country's average efficiency level and trade costs jointly. Third, I allow for asymmetries in trade costs and show how my model performs better than alternative approaches at replicating the pattern of bilateral trade, prices, and cross-country income differences.

Because my model is disciplined by the pattern of bilateral trade, my results are fundamentally different relative to Alvarez and Lucas (2007). First, in my model almost all the gains from trade here yet to be realized. Second and more important, the available gains from trade systematically benefit poor countries relative to rich countries reducing cross-country income differences. In contrast, in the appendix I provide a direct comparison of the gains from trade in my model and Alvarez and Lucas (2007) showing that in their calibration the available gains from trade are small and they are allocated symmetrically across countries. These distinctions, i.e. the gains *available* and the *allocation*, are nontrivial. The results of Alvarez and Lucas (2007) suggest that the gains available from trade are small and they will do little to improve the plight of poor countries relative to rich countries. In contrast, my results suggest a completely opposite assessment: The available gains from trade are large and trade has the potential to improve the plight of poor countries relative to rich countries reducing cross-country income differences.

As in Eaton and Kortum (2002), I estimate a structural relationship between observed bilateral trade shares and trade costs resembling a "gravity equation" which has been a foundation of much work in empirical international trade. To estimate these relationships, functional forms must be assumed relating trade costs to observable data. This is restrictive because different functional forms result in different quantitative implications for prices and cross-country income differences. In Waugh (2007), I argue that for structural gravity models to account for both bilateral trade volumes and relative price differences, trade costs must be systematically asymmetric. Given the observed pattern of trade costs in Waugh (2007), I advocated an alternative trade cost specification relative to standard symmetric approaches or that of Eaton and Kortum (2002). In this paper, I employ this trade cost specification and show how my model correctly replicates salient features of both prices and observed cross-country income differences — all while fitting the bilateral trade data equally well or better than alternative approaches.

The resulting trade costs suggests poor countries face systematic difficulties to selling their goods in rich countries markets. This is a fundamentally different view of the impediments present in the pattern of trade relative to models with either symmetric trade costs or the formulation of Eaton and Kortum (2002). Beyond helping the model replicate certain features of the data, a natural counterfactual exercises arises from these results, i.e. if poor countries had equivalent market access to rich countries markets, how would cross-country income differences change? The results suggest that policies which provide equivalent market access for poor countries goods can significantly improve their plight and reduce cross-country income differences.

The paper proceeds as follows: Sections 2 and 3 describe the model and an equilibrium. Section 4 derives the accounting exercise and describes the calibration of the full model in addition to the data used. Section 5, 6, and 7 present the results and section 8 concludes.

2 The Model

Consider a world with N countries. Each country has two sectors, an intermediate goods sector and a final goods sector. Only intermediate goods are traded. Within each country i, there is a measure of consumers L_i. Each consumer has one unit of time supplied inelastically in the domestic labor market and are endowed with capital supplied to the domestic capital market. Furthermore, each consumer has preferences only over the final good which is non-traded. In the following, all variables are normalized relative to the work force in country i.

2.1 Intermediate Goods Sector

As in Dornbusch, Fischer, and Samuelson (1977) there is a continuum of goods indexed by $x \in [0, 1]$ produced and traded. [1] In country i, capital k_i, labor n_i, and the aggregate intermediate good q_i are combined by the following nested Cobb-Douglas production function to produce quantity $m_i(x)$:

$$m_i(x) = z_i(x)^{-\theta}[k_i^{\alpha} n_i^{1-\alpha}]^{\beta} q_i^{1-\beta}.$$

[1] A Ricardian model is a natural starting point for several reasons. First, differences in technology are the source of comparative advantage in contrast to Heckscher-Ohlin models which emphasize differences in factor endowments. Given the importance of technology differences relative to endowments in understanding cross-country income differences, a Ricardian model is more suited to the question in this paper. Second, Ricardian models with a continuum of goods have a prominent extensive margin. Hummels and Klenow (2005) and Kehoe and Ruhl (2003) document the quantitative importance of the extensive margin in explaining trade flows and trade liberalizations. "New trade theory" models were designed to explain trade between similar countries and have no extensive margin, hence they seem less appropriate for the question in this paper.

Power terms α and β control the factor shares.[2] Across goods x, production technologies differ only in their efficiency level $z_i(x)^{-\theta}$. The parameter θ is common to all countries.

The representative firm's problem in country i is to minimize the cost of supplying $m_i(x)$ by choosing capital, labor, and the aggregate intermediate good, given factor prices, r_i, w_i, and p_i^q. All firms in country i have access to the technology for any good x with the efficiency level $z_i(x)^{-\theta}$. Hence, in equilibrium k_i, n_i, and q_i are allocated so that marginal products are equalized across firms and goods are priced at unit cost.

In each country i, individual intermediate goods are aggregated according to a standard symmetric Dixit-Stiglitz technology producing the aggregate intermediate good with elasticity of substitution $\eta > 0$, specified in the next section.

2.2 Distribution of Efficiency Levels

Following Eaton and Kortum (2002), I parameterize the model by treating $z_i(x)$ as an idiosyncratic random variable. In the setup above, I follow Alvarez and Lucas (2007) and assume that $z_i(x)$ is distributed independently and exponentially with parameter λ_i differing across countries. This is analogous to a Type II extreme value distribution or Fréchet distribution as in Eaton and Kortum (2002).

In the production of intermediate goods, each country's λ_i governs its average level of efficiency. A country with a relatively larger λ_i is, on average, more efficient. Given a draw $z(x)$, it is taken to the power $-\theta$ and yields good x's efficiency level. θ controls the dispersion of efficiency levels. Specifically, the coefficient of variation for each country's distribution of efficiency levels is controlled only by θ. A larger θ yields more variation in efficiency levels relative to the mean. In this sense θ controls the degree of comparative advantage and a country's λ_i determines its absolute advantage.

Relabeling each good x by its efficiency level z, the production of the aggregate intermediate good is

$$q_i = \left[\int_0^\infty m(z)^{\frac{\eta-1}{\eta}} \pi(z) dz \right]^{\frac{\eta}{\eta-1}}.$$

Where $\pi(z)$ is

$$\pi(z) = \left(\prod_{i=1}^N \lambda_i \right) \exp \left(- \sum_{i=1}^N \lambda_i z_i \right).$$

In country i, firms producing the aggregate intermediate good face the problem of minimizing the cost of producing q_i. The solution to this problem yields the following price of the aggregate

[2] It is worthwhile to contrast the use of intermediate goods here with the model of Yi (2003) in which there are two stages of production, with individual goods x in the first stage of production are used directly in the second stage of production and then aggregated. It is this mechanism that is important for quantitatively explaining the growth in world trade.

intermediate good:

$$p_i^q = \left[\int_0^\infty p_i(z)^{1-\eta} \pi(z) dz \right]^{\frac{1}{1-\eta}}$$

in which $p_i(z) = \min[p_{i1}(z), ..., p_{iN}(z)]$. $p_{ij}(z)$ is the price country i can purchase intermediate good z from country j including costs to trade.

2.3 Final Goods Sector

In each country, a representative firm produces a homogenous good which is non-traded. Each firm has access to the following nested Cobb-Douglas production function combining capital, labor, and the aggregate intermediate good:

$$y_i = [k_i^\alpha n_i^{1-\alpha}]^\gamma q_i^{1-\gamma}.$$

Factor shares, α and γ, are the same across countries.

The representative firm's problem is to minimize the cost of producing y_i, at price p_i^y, by selecting the amount of capital, labor, and aggregate intermediate good, taking prices as given.

2.4 Trade Costs

To model trade costs, the standard iceberg assumption is made, i.e. $\tau_{ij} > 1$ of good z must be shipped from country j for one unit to arrive in country i in which $(\tau_{ij} - 1)$ "melts away" in transit. Trade costs τ_{ij} are thought to be composed of both policy and non-policy related barriers. In addition, τ_{ii} is normalized to equal one for each country.

3 Equilibrium

The goal is to find allocation rules, prices, and trade shares to construct an equilibrium. Specifically, the functions determining wages, the price of intermediate goods, and trade shares are the most important objects. First, they determine all other equilibrium prices and quantities. Second, these functions provide the basis for the calibration in section 4.

Allocation rules: Allocation rules for capital, labor, and the aggregate intermediate good are easy to compute. Given the production technologies, it is straightforward to show a fraction γ of capital, labor, and β of the aggregate intermediate good are allocated towards the final goods sector.

Price Index: I show in the appendix that each country faces the following price of intermediate goods for each country i:

$$p_i^q \quad = \quad k_i^{-\alpha\beta} \Upsilon \left\{ \sum_{j=1}^{N} \left[w_j^{\beta} p_j^{q(1-\beta)} \tau_{ij} \right]^{\frac{-1}{\theta}} \left(\frac{k_j}{k_i} \right)^{\frac{\alpha\beta}{\theta}} \lambda_j \right\}^{-\theta} \tag{1}$$

where Υ is a collection of constants. This expression is similar to those in Eaton and Kortum (2002) or Alvarez and Lucas (2007). A difference is in how each country's capital-labor ratio relative to country i "weights" the importance of other countries in the determination of country i's price of intermediate goods. If country j has a relatively larger stock of capital, then its weight on the sum will be higher in contrast to a country with a relatively small stock of capital.

Trade Shares: M_{ij} is the fraction of all goods country i imports from country j. Since there is a continuum of goods, computing this fraction boils down to finding the probability that country j is the low-cost supplier to country i given the joint distribution of efficiency levels, prices, and trade costs for any good z. In the appendix, I provide the details which follow the approach in Alvarez and Lucas (2007). The result is the following expression for trade shares:

$$M_{ij} \quad = \quad \frac{\left[k_j^{-\alpha\beta} w_j^{\beta} p_j^{q(1-\beta)} \tau_{ij} \right]^{\frac{-1}{\theta}} \lambda_j}{\sum_{\ell=1}^{N} \left[k_\ell^{-\alpha\beta} w_\ell^{\beta} p_\ell^{q(1-\beta)} \tau_{i\ell} \right]^{\frac{-1}{\theta}} \lambda_\ell}. \tag{2}$$

Note that the sum across j for a fixed i must add up to one. Furthermore, with no barriers to trade this relationship is independent of the importer i which implies that all countries purchase the same fraction of goods from the same source.

Wage Function: An equilibrium wage vector is computed given trade shares and imposing balanced trade. Imports are defined as

$$\text{Imports} = L_i p_i^q q_i \sum_{j \neq i}^{N} M_{ij},$$

which is the total value of all goods country i consumes from abroad. Similarly, exports are defined as

$$\text{Exports} = \sum_{j \neq i}^{N} M_{ji} L_j p_j^q q_j,$$

which is the total value of all goods countries abroad purchase from country i.

Imposing balanced trade and including each country i's consumption of goods produced at home implies the following relationship must hold:

$$L_i p_i^q q_i \sum_{j=1}^{N} M_{ij} = \sum_{j=1}^{N} L_j p_j^q q_j M_{ji}.$$

which says the aggregate value of intermediate goods purchased by country i is to equal the value of intermediate goods all N countries purchase from country i.

Using the observation that each country allocates $(1-\gamma)$ of capital and labor to the production of the intermediate goods sector and the relationship between factor payments and total revenue (see Alvarez and Lucas (2007)), the equilibrium wage rate for each country i is:

$$w_i = \sum_{j=1}^{N} \frac{L_j}{L_i} w_j M_{ji}. \tag{3}$$

At this point, the three key pieces of the model have been derived. Equation (1) describes the equilibrium price of intermediate goods, equation (2) describes the fraction of goods countries purchase from each other, and equation (3) describes the equilibrium wage rate for each country. From these functions, all other prices and quantities are determined and an equilibrium constructed.

4 Quantification

To quantify the relationship between international trade and cross-country income differences, I outline two methods.

The first is an accounting exercise analogous to standard income accounting procedures as in Klenow and Rodriguez-Clare (1997) or Hall and Jones (1999). Below, I derive an equilibrium relationship with income decomposed into a contribution from total factor productivity and capital-output ratios. The key feature is that total factor productivity is now endogenous and is an analytical function of how much each country trades. Given data on income per worker and trade, I can account for the contribution of trade per-se to cross-country income differences.

The second is a calibration/estimation exercise enabling a deeper analysis of the model. Similar to Eaton and Kortum (2002), I derive and estimate a structural relationship between bilateral trade, technology parameters, and trade costs. With the recovered technology parameters and trade costs, I can compute the cross-country income differences implied by the pattern of bilateral trade and study the response of the economy given changes in costs to trade.

In both exercises, the model's trade shares provide a convenient starting point as I can construct an empirical counterpart X_{ij} to the theoretical trade share M_{ij}.

4.1 An Accounting Procedure

Suppressing some notation and rearranging the empirical counterpart of (2) and using (1) provides an expression for each country's home trade share:

$$X_{ii} = \frac{\left[k_i^{-\alpha\beta} w_i^{\beta} p_i^{q(1-\beta)}\right]^{\frac{-1}{\theta}} \lambda_i}{p_i^{q\left(\frac{-1}{\theta}\right)} \Psi}. \tag{4}$$

Further rearrangement of (4) provides the expression:

$$\left(\frac{w_i}{p_i^q}\right) = \Psi \left(\frac{\lambda_i}{X_{ii}}\right)^{\frac{\theta}{\beta}} k_i^{\alpha}, \tag{5}$$

in which wages, deflated by the intermediate goods price, are a function of each country's home trade share and its capital-labor ratio.[3]

I define real income per worker as:

$$y_i = \frac{w_i}{p_i^y} + \frac{r_i k_i}{p_i^y}, \tag{6}$$

in which income from wages and capital are deflated by each country's final goods price and balanced trade is imposed.[4] Then using a representative firm's first order conditions determining the rental rate as a function of the wage, I express income per worker as a function of only the wage and the final goods price:

$$y_i = \frac{1}{1-\alpha} \frac{w_i}{p_i^y}. \tag{7}$$

Since my interest is only in relative income differences, constant terms are abstracted from. Combining the expression for the price of final goods and (7), real income per worker is expressed as:

$$y_i = \left(\frac{w_i}{p_i^q}\right)^{1-\gamma} k_i^{\alpha\gamma}. \tag{8}$$

Combining equations (5) and (8), real income per worker is now:

$$y_i = X_{ii}^{\frac{-\theta(1-\gamma)}{\beta}} \lambda_i^{\frac{\theta(1-\gamma)}{\beta}} k_i^{\alpha}. \tag{9}$$

Here real income per worker is only a function of each countries home trade share X_{ii}, its technology parameter λ_i, and its capital-labor ratio.

Finally, I express income per worker relative to the U.S. following Hall and Jones (1999) with income decomposed into terms of total factor productivity and capital-output ratios. But here total factor productivity is decomposed into an endogenous trade factor and an exogenous domestic

[3]For reference, this is analogous to equation (15) in Eaton and Kortum (2002). I have to thank Sam Kortum for directing my attention to this equation.

[4]This is the proper definition to compare the model to data on income per worker from the Penn World Table. The key reason is that in benchmark years the Penn World Table deflates net-trade balance with the same deflator for exports and imports in contrast to alternative approaches to computing real GDP; see Feenstra, Heston, Timmer, and Deng (2004) for a discussion.

factor:

$$\frac{y_i}{y_{us}} = \left(\frac{A_i}{A_{us}}\right)^{\frac{1}{1-\alpha}} \left(\frac{k_i/y_i}{k_{us}/y_{us}}\right)^{\frac{\alpha}{1-\alpha}},$$

$$\frac{A_i}{A_{us}} = \underbrace{\left(\frac{X_{ii}}{X_{us,us}}\right)^{\frac{-\theta(1-\gamma)}{\beta}}}_{trade-factor} \underbrace{\left(\frac{\lambda_i}{\lambda_{us}}\right)^{\frac{\theta(1-\gamma)}{\beta}}}_{domestic-factor}. \tag{10}$$

Closed Economy: When trade costs are infinite, countries are unable to diversify production and must import everything from home. Hence, $X_{ii} = 1$ and relative income per worker is then:

$$\frac{y_i^{closed}}{y_{us}^{closed}} = \left(\frac{\lambda_i}{\lambda_{us}}\right)^{\frac{\theta(1-\gamma)}{\beta}} \left(\frac{k_i}{k_{us}}\right)^{\alpha}.$$

Given how efficiency levels are distributed in the production of intermediate goods, each country's average efficiency level relative to the U.S. is $\left(\frac{\lambda_i}{\lambda_{us}}\right)^{\theta}$. Thus, each country's closed-economy total factor productivity is its average efficiency level to the power $\frac{(1-\gamma)}{\beta}$. Hence, in equation (10), the second term in brackets is termed the domestic factor.

Open Economy: When trade costs are finite, countries are able to diversify production and import some goods from relatively more efficient producers. Hence, $X_{ii} < 1$ and each country's gain from trade, in the form of increased total factor productivity relative to the U.S., is $\left(\frac{X_{ii}}{X_{us,us}}\right)^{\frac{-\theta(1-\gamma)}{\beta}}$ and termed the trade factor. This expression has several straightforward implications. First, if country i has a smaller home trade share than the U.S., then country i gains relatively more from trade. Second, the higher the share of intermediate goods in either sector results in a larger gain from trade than otherwise. Finally, if the world has a larger θ and hence a higher degree of comparative advantage, then trade will matter more than otherwise. Note as well, only through importing does trade benefit a county. A country's exporting behavior is principally determined by its technology parameter λ and trade costs.

This accounting procedure is a step forward relative to recent studies concerning the relationship between international trade and a country's standard of living. The principal focus of these studies have been on the statistical relationship between the aggregate volume of trade and income level. These studies face two difficulties. The first difficulty is that both trade and income are endogenous. To avoid this difficulty, Frankel and Romer (1999) and other authors have proposed instruments to correct for these problems. However, as outlined in Rodriguez and Rodrik (2001), there is some debate surrounding the validity of the instruments leaving the results inconclusive. In contrast to these approaches, the derived accounting relationship in (10)—in conjunction with careful measurement—allow for the quantification of the relationship between trade and income without dealing with these statistical issues.

The second difficulty behind these prior studies is that as reduced-form frameworks they are unable to quantify the response from changes in fundamentals on income and trade. That is the estimated coefficients in these studies only reflect correlations, not statements regarding how income may change in response to changes in barriers to trade. In contrast, this framework can ask and quantitatively answer these questions. Depending on the question, however, the full model must be quantified which the next section discusses.

4.2 Recovering Trade Costs and Technology

To further understand cross-country income differences, I want to understand the pattern of trade and its implications for cross-country income differences. To do so, I will proceed in a second direction and recover the unknown technology parameters and trade costs from the pattern of trade. To recover these parameters, I derive and estimate structural equation which resembles a reduced-form "gravity" equation widely used in empirical international trade.[5]

To derive the gravity equation, rearrange the empirical counterpart of (2), using (1) and then for convenience define $c_i = k_i^{\frac{\alpha\beta}{\theta}} w_i^{\frac{-\beta}{\theta}} \lambda_i$, yielding following expression:

$$X_{ii} = \Psi^{-1} c_i p_i^{q\left(\frac{\beta}{\theta}\right)}, \tag{11}$$

$$X_{ij} = \frac{c_j p_j^{q\left(\frac{\beta-1}{\theta}\right)} \tau_{ij}^{\frac{-1}{\theta}}}{p_i^{q\left(\frac{-1}{\theta}\right)} \Psi}, \tag{12}$$

As discussed in Eaton and Kortum (2002), the framework here nests a log-linear "gravity equation" relationship. To derive this, divide each country i's trade share from country j in (12) by country i's home trade share (11) yielding $N-1$ equations for each country i:

$$\left(\frac{X_{ij}}{X_{ii}}\right) = \frac{c_j p_j^{q\left(\frac{\beta-1}{\theta}\right)} \tau_{ij}^{\frac{-1}{\theta}}}{c_i p_i^{q\left(\frac{\beta-1}{\theta}\right)}}. \tag{13}$$

Taking logs yields the following linear relationship ready for estimation:

$$\log\left(\frac{X_{ij}}{X_{ii}}\right) = S_j - S_i - \frac{1}{\theta}\log\tau_{ij}, \tag{14}$$

in which S_i is defined as $\log\left[c_i p_i^{q\left(\frac{\beta-1}{\theta}\right)}\right]$.

To recover the technology parameters and trade costs, I estimate equation (14) with the S_is recovered as the coefficients on country specific dummy variables. Unfortunately, to recover trade

[5] In previous versions of this paper, I used an alternative approach to calibrate each country's technology level and trade costs by constructing an algorithm to recover the values that fit the trade data in an exact manner. I have deviated from this approach though an appendix is available upon request. The approach here has the benefit of being dramatically more transparent, easier to replicate, and quantifies the effect of distance—all while yielding essentially the same results.

costs, I must assume a technological relationship between τ_{ij} and observable data. I assume trade costs take the functional form:

$$\log(\tau_{ij}) = d_k + b_{ij} + ex_j + \epsilon_{ij}. \tag{15}$$

Here trade costs are a logarithmic function of distance where d_k with $k = 1, 2, ...6$ is the effect of distance between country i and j lying in the kth distance intervals. Intervals are in miles: $[0, 375)$; $[375, 750)$; $[750, 1500)$; $[1500, 3000)$; $[3000, 6000)$; and $[6000, \text{maximum}]$. b_{ij} is the effect of a shared border in which $b_{ij} = 1$, if country i and j share a border, zero otherwise. For estimation purposes, I assume ϵ_{ij} reflects barriers to trade arising from all other factors and is orthogonal to the regressors. These features of the trade cost function are the same as in Eaton and Kortum (2002).

An important difference lies in the term ex_j which is an exporter fixed effect. That is, the estimate of ex_j is the extra cost country j faces to export a good to any country i. In Waugh (2007), I argued that for structural gravity models to account for bilateral trade volumes and data analogs to p_i^q, costs to trade must be systematically asymmetric with poor countries facing higher costs to export relative to rich countries. And I showed in an equilibrium decomposition exercise systematic asymmetry is quantitatively important accounting for at least a third of the variation in bilateral trade. Relative to distance and other symmetric relationships typically considered, systematic asymmetry is quantitatively on par or more important in accusing for the pattern of bilateral trade. With these observations, I then advocated a trade costs specification—described above with an exporter fixed effect—that can improve the equilibrium model's fit and result in prices consistent with those observed.

In contrast, Eaton and Kortum (2002) employ a importer fixed effect m_i in which the estimate m_i reflects the extra cost county i faces to import a good from any country j. As I show in this paper and in Waugh (2007), when the model is estimated with a importer fixed effect, the resulting prices are inconsistent with comparable international price indices for tradable goods. Eaton and Kortum (2001) is a example of this outcome. They studied trade flows in investment goods and the model implied prices using an importer fixed effect and they find poor countries face systematically higher prices of investment goods relative to rich countries. This is in contrast to the data with poor countries facing similar prices relative to rich countries. Hsieh and Klenow (2007) revisited the data and argued that because these prices are roughly the same across countries, lower real rates of investment for poor countries are not a result of distortions such as high tax rates and or trade frictions as in Eaton and Kortum (2001). Instead poor countries face difficulties producing investment goods and exportables. Between Eaton and Kortum (2001) and Hsieh and Klenow (2007), the question is: How does one account for trade flows with various trade frictions *and* the fact that there is little variation in comparable price indices across countries? The trade cost specification I advocated in Waugh (2007) and employ here provides an answer to this question.

Equations (14) and (15) provide the basis for the estimation of trade costs τ_{ij}s and S_is for which

I use ordinary least squares.[6]

Recovering the λ_is requires more work. Given the estimated S_is and τ_{ij}s, the price of intermediate goods is then computed as:

$$p_i^q = \Upsilon \left\{ \sum_{j=1}^{N} e^{S_j} \tau_{ij}^{\frac{-1}{\theta}} \right\}^{-\theta} \tag{16}$$

Then given the p_i^qs computed from (16), one can recover c_is from the estimates of S_i.

With c_is, more information is required to recover each country's technology parameter λ_i. To recover the λ_is, I determine wages from observed bilateral trade shares X_{ij}, each country's labor endowment, and the empirical counterpart to equation (3):

$$w_i \;\; = \;\; \left(\sum_{j=1}^{N} \frac{L_j}{L_i} w_j X_{ji} \right). \tag{17}$$

Wages are determined as a function of bilateral trade shares and labor endowments. Then, in combination with aggregate capital-labor ratios, the recovered prices p_i^q, and c_is, each country's technology parameter λ_i is recovered.

Notice the key parameters λ_i and τ_{ij} are being determined primarily as a function of bilateral trade shares. This approache differers substantially relative to Alvarez and Lucas (2007). For example, Alvarez and Lucas (2007) pursue two calibrations and studied the implications of their model for the aggregate volume of trade. Their first calibration assumed that each country's λ_i is proportional to an unobservable endowment L_i. This assumption in combination with balanced trade, output data, and some proxies for trade costs such as average tariff rates allowed them to calibrate each country's λ_i and L_i jointly. Their second calibration built on the former, but incorporated the use of relative price data and dropped the proportionality assumption of λ_i and L_i to identify each separately.

4.3 Data

To implement the accounting exercise and quantification of the full model, I must take a stand on the world economy and how the model corresponds to actual economies.

The model year is 1996 and table 5 details the countries considered.[7] Beginning with the original sample of countries in Parente and Prescott (1994), some countries were eliminated on the basis of data availability. Thus, 77 countries remain and represent over 90 percent of World GDP.[8]

[6] I also experimented with the poisson pseudo maximum-likelihood estimator advocated by Silva and Tenreyro (2006). The next section and footnote 10 contain a discussion.

[7] For the same exact set of countries, I also studied the year 1985. Similar results were obtained.

[8] The most important countries not included are Germany, due to data problems associated with East Germany's reintegration with West Germany, and Taiwan, again due to data problems as a result of political issues. The data constraint is gross manufacturing production data used to construct bilateral trade shares. Hence other countries were eliminated because the necessary data was unavailable.

I assume that the intermediate goods sector corresponds to the manufacturing goods sector. This is a simplification, but since all trade in the model is in intermediate goods and nearly 80 percent of all merchandise trade is in manufactured goods this assumption is reasonable as a first-order approximation to reality. Furthermore, Hummels, Rapoport, and Yi (1998) and Hummels, Ishii, and Yi (2001) are studies that document the importance of trade in intermediate goods. The final goods sector is thought of as the sector producing all final goods and services for each economy.

I constructed trade shares X_{ij} following Bernard, Eaton, Jensen, and Kortum (2003). First, I compiled manufacturing bilateral trade data from Feenstra, Lipsey, and Bowen (1997) for the model 1996. Aggregating across all 34 BEA manufacturing industry codes provides the aggregate value of manufactured goods each country purchases from each other. I then divided the value of country i's imports from country j by gross manufacturing production minus total manufactured exports (for the whole world) plus manufactured imports (for only the sample) yielding bilateral trade shares. Basically, this is just a way to map production and trade data into the unit interval, by dividing inputs from country j used in country i divided by total inputs used in country i. In table 5, I present the source for each country's gross manufacturing production data. In table 6, I present trade share's for selected countries.

One may be concerned with the absence of agriculture. However, the data does include processed agricultural goods. Most of the gross manufacturing data I employ corresponds with manufacturing as defined by ISIC revision 2 and the bilateral trade data is an approximation of this categorization as well. Roughly any agricultural good that is manipulated shows up as manufacturing. For example, code number 1531 which is "Manufacture of grain mill products" is considered an manufactured product. Basically this activity encompasses the process of turning gains and mills into edible and useful products. In contrast, goods not included are items such as code number 0111 or "growing of cereals and other crops n.e.c." This activity basically encompasses only the of growing the grains.

The distance measures used to estimate trade costs are in miles from capital city in country i to capital city in country j calculated by the great circle method.[9] These measures and border data are from from Centre D'Etudes Prospectives Et D'Informations Internationales (http://www.cpeii.fr).

I used aggregate capital-labor ratios from Caselli (2005). They were constructed using the perpetual inventory method using purchasing power parity adjusted investment rates in Heston, Summers, and Aten (2002). I used labor endowments from Caselli (2005) which are from information in Heston, Summers, and Aten (2002) as well. Each country's labor endowment relative to the U.S. is presented in table 5.

I calibrated parameter values common to all countries as follows. I followed Alvarez and Lucas (2007) in selecting the value for η. Other then satisfying the necessary assumptions detailed in the appendix, this value plays no quantitative role.

Given the model's structure resulting in equation (10), I want α to be consistent with the

[9]The great circle method is a way to calculate the shortest distance between two points along the surface of a sphere.

Table 1: Common Parameter Values

Parameter	Description	Value
α	k's share	1/3
β	k and n's share in int. goods production	0.33
γ	k and n's share in final goods production	0.72
η	elasticity of substitution in aggregator	2.0
θ	variation in efficiency levels	0.15

exercises in the income accounting literature. To do so, I set α equal to 1/3. An argument for setting α equal to 1/3 relies on Gollin (2002). He calculated labor's share for a wide cross-section of countries to be around 2/3.

The parameter β controls value added in intermediate goods production. With respect to the data used, β corresponds with value added in the traded manufacturing goods sector. For OECD countries in 1996 (http://www.sourceoecd.org), the average value added in the manufacturing goods sector is 0.33. This is consistent with the value employed in Yi (2003).

The parameter γ controls value added in final goods production. Since all trade is assumed to be in manufactured goods, this implies $(1-\gamma)$ corresponds with traded manufacturing goods value added in total output. Manufacturing's value added as a fraction of GDP averaged across all countries in the sample is 0.17 as found in World Development Indicators (http://www.worldbank.org/data). I adjusted this number by the fraction of all trade occurring in manufactured goods. Averaging across the fraction of manufactured goods trade for the sample yields a value of 0.60. Together, this implies traded manufactured goods share in final goods production is 0.28 implying a value for γ of 0.72.

The parameter θ controls the dispersion in efficiency levels across intermediate goods for all countries. I selected a value of 0.15, which is the value used in Alvarez and Lucas (2007) as a baseline. This value and the distributional assumptions imply a coefficient of variation of approximately 0.22 for each country's efficiency levels. The selected baseline value of θ lies in the middle of empirical estimates. Eaton and Kortum (2002) found a range of 0.078 and 0.28 depending on their approach in estimating θ. Furthermore, Eaton and Kortum (2002) and Anderson and van Wincoop (2004) showed how θ is related to the elasticity of substitution in an Armington aggregator model of international trade. Anderson and van Wincoop (2004) claimed reasonable values for this elasticity are between 5 and 10, which implies a range for θ of 1/9 and 0.25. In the next sections, I discuss the sensitivity of the results for other parameterizations of θ. Furthermore, I am currently pursuing approaches to estimating my own value of θ.

An implication of the Eaton and Kortum (2002) framework is that, in aggregate, every country should purchase some non-zero amount of goods from all other countries. In fact, the bilateral trade matrix has many recorded zeros. For the sample considered there are 5,929 possible trading combinations; 1,610 (27 percent) show no trade at all. This presents both an estimation issue and computational issue.

Regarding the estimation, I will omit any zero observed trade flows from the estimation of equation (14). This has been a standard approach in the empirical trade literature. Silva and Tenreyro (2006) propose a poisson pseudo-maximum-likelihood (PPML) estimator to alleviate any bias from log-linearizing equation (13) in the presence of heteroscedasticity and the omission of zero observed trade flows. I employed their technique estimating equation (13) including zero observed trade flows and I found the quantitative results and counterfactual exercises do not differ dramatically relative to using OLS.[10] Furthermore, Helpman, Melitz, and Rubinstein (2007) build on the model of Melitz (2003) with fixed costs and firm heterogeneity and study similar biases present in the estimation of traditional gravity equations. Their results suggest that any bias arising from the omission zero trade flows is quantitatively small.

Regarding the computation, when computing equilibrium prices and counterfactuals I will set trade costs for the instances in which X_{ij} is zero to an arbitrarily large value to approximate what appears to be a trade cost of infinity. In table 1, I summarize the selected parameter values.

5 Does Trade Explain Income Differences?

To answer this question, I use the framework outlined in section 4.1 to study trade's contribution to relative income differences. As discussed, I can express income per worker relative to the U.S. with income decomposed into terms of capital-output ratios, an endogenous trade factor, and an exogenous domestic factor:

$$
\begin{aligned}
\frac{y_i}{y_{us}} &= \left(\frac{A_i}{A_{us}}\right)^{\frac{1}{1-\alpha}} \left(\frac{k_i/y_i}{k_{us}/y_{us}}\right)^{\frac{\alpha}{1-\alpha}}, \\
\frac{A_i}{A_{us}} &= \underbrace{\left(\frac{X_{ii}}{X_{us,us}}\right)^{\frac{-\theta(1-\gamma)}{\beta}}}_{trade-factor} \underbrace{\left(\frac{\lambda_i}{\lambda_{us}}\right)^{\frac{\theta(1-\gamma)}{\beta}}}_{domestic-factor}.
\end{aligned}
$$

A way to view this this accounting exercise is in the context of Caselli's (2005) article on accounting for cross-country income difference. Throughout his paper he asks the question: "how successful is the factor-only model at explaining cross-country income differences?" That is given observed factors what are the implied cross-country income differences. As mentioned in the introduction, conventional measures of factors are not successful at explaining cross-country income differences.

In my accounting procedure income differences are a result of an observable trade factor, capital-output ratios, and an exogenous TFP term represented by λ_i. Since the contribution from capital-output ratios is well studied, the relevant question is: how successful is my trade factor in explaining

[10] This does not contradict their findings. Consistent with their results, I find that OLS exaggerates the distance elasticity suggesting the bias they emphasize is present. For example using PPML, the percent effect on cost are 129, 140, 141, 177, 223, and 263 percent for each distance category. Compared to table 8, shorter distances are more costly and longer distances are less costly relative to OLS. This is consistent with a lower distance elasticity Silva and Tenreyro (2006) find when using PPML relative to OLS.

cross-country income differences? Figure 1 depicts trade factors versus income per worker data. In figure 1 there is at best a slight negative relationship between trade factors and level of development. This suggests that without trade income differences would actually be *larger* than those observed. Ultimately, the magnitude of this relationship is small and trade factors contribute little to explaining cross-country income differences. For example, the variance of log trade factors is 0.008 and the ratio of trade factors for the top 10th percentile and bottom 10th percentile in income per worker is approximately 1. Recall, in data the variance of log income per worker is 1.38 and the 90/10 ratio of income per worker is 25.6. The success of my trade factor at explaining cross-country income differences is negligible, less than one percent; moreover, this result suggests that if there was *no* trade, then relative incomes would be almost the same.

This finding reflected in figure 1, is insensitive to different values of θ. I performed the same exercise with θ set equal to 0.10 and 0.20 at the low and high end for empirically plausible values. Consistent with the prior results, trade factors showed little variation across income levels. That is, trade per-se plays no quantitative role in explaining cross-country income differences as in the baseline calibration. The reasons are straightforward. Figure 2 plots $\left(\frac{X_{us,us}}{X_{ii}}\right)$ versus income per worker data (note this term is flipped because a smaller X_{ii} implies a larger gain from trade). The correlation between income level and this measure of trade is -0.32 and is statistically different from zero. Hence *any* value of $\theta > 0$ will result in then the implication that without trade income differences would be larger than those observed. Second, though there is substantial variation in $\left(\frac{X_{us,us}}{X_{ii}}\right)$, empirically plausible values for θ are too small and/or trade does not covary systematically enough with level of development to have any quantitative meaning.

Despite the fact that relative incomes would be almost the same if there was no trade, this result does not necessarily imply the world is in autarky. The distinction here is between the level of X_{ii} and how X_{ii} covaries with level of development. For example, imagine a world where for all countries X_{ii} is small implying large volumes of trade. However, if X_{ii} is similar across countries then the same conclusion would be arrived at in this world, i.e. trade per-se plays little role in accounting for cross-country income differences even though volumes of trade are large. Hence the important observation from this exercise is that values of X_{ii} are quite similar across countries.

However, this raises the following question: Rich and poor countries differ in both the technologies and factors, yet why is trade's impact quantitatively similar? For example, consider the simplest Dornbusch, Fischer, and Samuelson (1977) economy with no trade costs. In this economy, a country with an absolute disadvantage (i.e. small λ_i) should import a larger fraction of goods (i.e. X_{ii} should be smaller) relative to a country with an absolute advantage. Figure 2 faintly depicts the intuition of Dornbusch, Fischer, and Samuelson (1977), but figure 1 says the quantitative importance is negligible. However, underlying the pattern of bilateral trade there are distortions and costs to trade affecting the pattern of observed X_{ii}. In the next sections, I argue these distortions affect poor countries differentially relative to rich countries and that cross-country income differences reflect these distortions.

6 Calibration

The prior result is only a statement regarding the *observed* volume of trade, i.e. the volume of trade does not covary systematically enough with level of development to be quantitatively meaningful. To understand why the volume of trade does not covary enough or if it should and to study how cross-country income differences would change if trade policies or trade costs were changed, I employ the calibration procedure as detailed in section 4.2. That is, I recovered each country's λ_i and trade costs τ_{ij} from pattern of bilateral trade. Table 7 presents summary statistics from the estimation of the structural gravity equation. Tables 8 and 9 present the parameter estimates for trade costs and technology parameters.

6.1 Trade Costs and Technology Parameters

Trade Costs: The parameter estimates in table 8 themselves are not of interest here, only the reconstructed trade costs as inputs into the model. However, there are two features to note. Consistent with the gravity literature, distance is an impediment and the estimates reported are consistent with those in Eaton and Kortum (2001) which considers a similar sample of countries. The overall size of the trade costs for a developed country are consistent with those reported in Anderson and van Wincoop (2004). They survey the literature and report that for a representative developed country, trade barriers fall in a range between 40-80 percent depending on the study and elasticities of substitution. I find that the median trade cost between for OECD countries is equivalent to a 90 percent tariff. This is above the upper-range of their survey, but not dramatically so.

Second, the exporter fixed effect is negatively correlated with level of development. Figure 3 plots each country's exporter fixed effect, expressed in terms of the percent effect on cost, versus income per worker data. The correlation between the exporter fixed effect and log income per worker is -0.66 and statistically different from zero. As the figure 3 depicts, poor countries appear to have a serious disadvantage at exporting goods relative to rich countries. For example, a good arriving from the United States costs 55 percent less than the average country. In contrast, a good arriving from Rwanda will cost 130 percent more than the average country.

This is a fundamentally different view of the world relative to standard approaches. For example, most implementations of the gravity model never consider asymmetries in trade costs and completely abstract from this issue. In terms of reconciling the bilateral pattern of trade, this is a non-trivial abstraction. In Waugh (2007) I demonstrate that these asymmetries are quantitatively important accounting for at least a third of the variation in bilateral trade—on par or more important than distance and other symmetric relationships typically considered. As mentioned, an exception is Eaton and Kortum (2001, 2002) which generates asymmetries with an importer fixed effect. As demonstrated here and in Waugh (2007), their procedure results in prices that systematically deviate from the data and result in large cross-country income differences.

There is a simply policy story behind this "asymmetry" in trade costs. The idea is that though rich countries have, on average, low tariff and non-tariff barriers, certain sectors were/are still highly protected and poor countries are the predominant exporters in these sectors.[11] A classic example is the U.S. textile industry. Examining the bilateral trade data sector by sector for several poor countries, a significant fraction of the U.S. imports were in the industry classified as "Apparel and Other Textile Products." Hence it may not be a surprise that the U.S. looks relatively protected towards poor countries. Anderson and van Wincoop (2004) provides some evidence regarding this explanation. More explicit evidence along this front is presented in Kee, Nicita, and Olarreaga (2006). They estimate trade restrictiveness indices from data on both tariff and non-tariff barriers for a large set of countries developed and undeveloped countries. They find that poor countries systematically face the highest trade barriers on their export bundle — similar to the asymmetry in trade costs here. Also relevant to these results, they estimate that non-tariff barriers contribute more than 70 percent to their trade restrictiveness indices. This suggests calibrating trade costs based on average tariff rates are bad approximations of the trade barriers countries actually face.

Technology: Table 9 presents the parameter estimates for the technology parameters. The key observation here is that differences in average efficiency recovered from the pattern of trade are consistent with inferences from the accounting exercise. From equation (10) and employing the requisite data, I can recover values for λ_i with no assumptions regarding trade costs. In this instance, the ratio of average efficiency between the top 10th percentile and bottom 10th percentile is approximately 7.58. Similarly, when estimated from the pattern of bilateral trade, this ratio is 7.96. This an important observation, because two alternative procedures to recovering λ_i provide similar answers suggesting the parameter estimates here are the correct values. Furthermore, the ability of the model to replicate cross-country income differences further reinforces this point as discussed next.

6.2 Prices and Income Differences

Prices: As one assessment of the model, I considered the model's ability to quantitatively replicate data on international prices of tradable goods. Note, that these are *tradable* goods not *traded* goods since in equilibrium some goods may not be traded. To compare the model implied price indices to data, I employed the benchmark price data available at the Penn World Table website (http://pwt.econ.upenn.edu). From the benchmark price data, I constructed the appropriate price indices of tradable goods which best matched the trade data employed; Waugh (2007) provides more details concerning their construction.

Figure 4 plots the data on prices versus income per worker data. As the figure illustrate, poorer countries have slightly lower prices of tradable goods. For the sample considered, the elasticity of the price of tradable goods with respect to income level is 15 percent.[12] These facts are

[11] Of course policies in poor countries could create this effect as well. Export marketing boards are one possible source of this distortion. These boards place a wedge between the price at which producers sell goods and the price at which the good is exported. Export marketing boards are prevalent in African countries.

[12] To contrast this relationship, the elasticity of the price of non-tradable goods with respect to income is 60 percent where non-tradable goods are defined as the compliment of tradable goods.

consistent with Kravis and Lipsey (1988) which documents a similar relationships between the price of tradable goods, price of non-tradeable goods, and level of development. Furthermore, Hsieh and Klenow (2007) study similar price indices for only investment goods and the elasticities I report are consistent with their findings.

Figure 5 plots the prices from the baseline calibration when trade costs are modeled with an exporter fixed effect. The prices from the model with an exporter fixed effect are only slightly higher for poor countries relative to rich countries. The elasticity with respect to income level is approximately -0.04. In contrast, figure 6 plots the prices from a calibration using the trade cost function of Eaton and Kortum (2002) with an importer fixed effect. These prices systematically deviate from the data in a quantitatively important manner with poor countries facing higher prices relative to rich countries. For example, the elasticity with respect to income level is -0.29, seven times larger than my model with an exporter fixed effect. As discussed, this outcome is similar to the results in Eaton and Kortum's (2001) study of investment goods prices estimated from bilateral trade data relative to data on investment goods prices. Using an importer fixed effect they find the estimated prices systematically deviate from the data with poor countries facing higher prices relative to rich countries.

It is important to emphasize that both these two approaches estimate the same number of parameters and fit the data equally well, but my model performs significantly better regarding its implications for price data. In Waugh (2007), I provide a more complete discussion of structural gravity models and their implications for price differences across countries.

Income Differences: As another assessment of the model, I considered the model's ability to quantitatively replicate the cross-country income differences seen in the data. With the λ_is and τ_{ij}s recovered from the pattern of bilateral trade, I computed an equilibrium and each country's income per worker as defined in equation (6). Given this definition of income, the natural empirical analog for comparison is purchasing power parity adjusted income per worker taken from Heston, Summers, and Aten (2002).

Figure 7 depicts the model's income levels versus the data relative to the U.S. along with the 45° line. If the model's relative income per worker is the same as the data, then the ordered pairs would map out the 45° line. In figure 7, the ordered pairs lie around the 45° line. For example, the model predicts that Uganda has an income level 1/30 the U.S. level. In the data, Uganda has an income level 1/32 the U.S. level. Table 2 provides some summary statistics: the variance of log income, the 90/10 percentile ratio, and the Gini index.[13] Except for the the Gini index, the summary statistics indicate the model slightly over-predicts the variation in cross-country income differences.

The model predicts incorrectly which countries within the rich are the richest. One potential

[13] For the year 1985, results in figure 7 and table 2 are similar. For the model calibrated using 1985 data but the same common parameter values calibrated to 1996 data, the variance of log income is 1.25, in the data it is 1.11. The results in figure 7 and table 2 are also insensitive to different values of θ. I calibrated the model with θ set equal to 0.10 and 0.20 which are at the low and high end for empirically plausible values of θ. For a θ of 0.10, the variance of log income is 1.38. For a θ of 0.20 the variance of log income is 1.34. Overall, the model performs well in capturing the variation in income across countries for different years and values of θ.

Table 2: **Income per worker**

	var [log(y)]	y_{90}/y_{10}	Gini
Data	1.38	25.6	0.60
Model	1.43	31.9	0.59

reason is the absence of Germany. Inclusion of Germany would make European countries look a bit less productive and reduce their income levels relative to the U.S. The model also misses on Zaire (the Democratic Republic of the Congo) by a wide margin. In the data, the U.S. is richer by a factor of 90, in the model it is 19.7. Overall, the model accurately captures the variation in income across countries.

In the denominator of the bilateral trade shares there is data on domestic absorbtion, however, this result is not by construction. The domestic absorbtion data does correlate strongly with purchasing power parity GDP per worker data, but of 2.5 times more the variation. In simple examples (like the one below) one can see how a correlation structure between domestic absorbtion data and the resulting wage from balanced trade is possible. In general, the equilibrium wage determined from (17) and how it relates to this piece of data is not clear. Furthermore, real income per worker is not simply the wage but the wage deflated by the price of non-traded goods. The price of non-traded goods depends on many different pieces including how trade costs are modeled and the resulting prices of tradable goods.

For example, had I used a trade cost function with an importer fixed effect instead of the exporter fixed effect, then the variation of log income per worker is 2.60 and 90/10 percentile ratio is 100. One reason why this results in different implications for cross-country income differences relates to the previous results regarding prices. The model with an importer fixed effect results in systematically higher prices p_i^q for poor countries resulting in higher prices of non-traded goods p_i^y. Because real income per worker is deflated by p_i^y, this systematically lowers real income per worker for poor countries resulting in an over prediction of income differences. This suggests that the ability of my model to correctly replicate both prices and the variation in income per worker is an important feature of my model relative alternative approaches to modeling trade patterns.

Where do these result arise from? A three country example. Understanding the features of the data which drive the calibrated parameters and the resulting prices and income differences can be a mystery. To alleviate this mystery, consider the following world with three countries where labor is the only factor of production and labor endowments are the same. Normalize country 1's wage, λ_1, and τ_1 equal one. Finally, assume there is no distance cost and hence τ_j reflects only the exporter fixed effect. Now consider the following trade share matrix

$$\mathbf{X} = \begin{pmatrix} X_{11} & X_{21} & X_{31} \\ X_{12} & X_{22} & 0 \\ X_{13} & 0 & X_{33} \end{pmatrix}$$

in which X_{ij} denotes the fraction of goods country i imports from country j. Hence, rows denote an exporting country and columns denote an importing country.

In this trade share matrix assume that $X_{12} > X_{13}$ but $X_{21} = X_{31}$. Note that this pattern is representative of the bilateral pattern of trade in the following sense; suppose country 1 is the United States, then this says the United States exports similar shares to all countries, yet the U.S. imports different shares across countries depending upon level of development. Furthermore, think of country 2 and country 3 as a middle income and poor country. Normalizing each column in the trade share matrix by X_{ii}, equation (2) implies the following relationship between the model and the data

$$\mathbf{X} \quad = \quad \begin{pmatrix} 1 & \frac{1}{(w_2)^{\frac{-1}{\theta}}\lambda_2} & \frac{1}{(w_3)^{\frac{-1}{\theta}}\lambda_3} \\ \frac{(w_2\tau_2)^{\frac{-1}{\theta}}\lambda_2}{1} & 1 & 0 \\ \frac{(w_3\tau_3)^{\frac{-1}{\theta}}\lambda_3}{1} & 0 & 1 \end{pmatrix}.$$

Given the assumptions made, lets work through a simple example to illustrate how the pattern of trade and the model are informative regarding trade costs, aggregate prices, and technology parameters.

First, notice that from $X_{21} = X_{31}$ then $w_2^{\frac{-1}{\theta}}\lambda_2 = w_3^{\frac{-1}{\theta}}\lambda_3$. Exponentiating both sides by $-\theta$ implies that country 2 and country 3's average unit cost of production are the same. The fact that average unit costs are the same, yet country 1 purchases a large share of goods from country 2 relative to country 3 (i.e. $X_{12} > X_{13}$) implies that country 2 must have easier market access to country 1 relative to country 3, $\tau_2 < \tau_3$. Otherwise country 1 should purchase the same share of goods from both countries because country 2 and country 3 have the same average unit costs of production.

Second, the price indexes in country 2 and country 3 are

$$p_2^q = \Upsilon\left\{w_2^{\frac{-1}{\theta}}\lambda_2 + 1\right\}^{-\theta} \quad \text{and} \quad p_3^q = \Upsilon\left\{w_3^{\frac{-1}{\theta}}\lambda_3 + 1\right\}^{-\theta},$$

which are the same. Basically, this is another expression of the fact that average unit costs between country 2 and 3 are the same. Here modeling trade costs with an exporter fixed effect is critical. If they were modeled with an importer fixed effect, one can show this trade share matrix implies that country 2 has a lower average unit cost relative to country 3. Furthermore, this would imply that the aggregate price index in country 2 is lower relative to country 3 — similar to how prices covary with level of development in figure 6 illustrates when the model is estimated with an importer fixed effect.

At this point, all that is known is that average unit costs are the same between country 2 and country 3. To say more about relative values of λ, one must determine relative wages between country 2 and country 3. In this paper, I use balanced trade and bilateral trade data to determine the wage. Balanced trade implies that:

$$\frac{X_{12}}{X_{21}} = w_2 \quad \text{and} \quad \frac{X_{13}}{X_{31}} = w_3.$$

Given the structure of the trade share matrix with $X_{21} = X_{31}$ and $X_{12} > X_{13}$ then the wage in country 2 is greater than the wage in country 3. Since $w_2^{\frac{-1}{\theta}} \lambda_2 = w_3^{\frac{-1}{\theta}} \lambda_3$, this observation implies that country 2 must be more productive relative to country 3. Average unit costs are the same across countries yet wages are different. Therefore, there must be differences in productivity.

To understand this example relative to the data revisit table 6. Think of the U.S. as country 1, Japan as country 2, and Senegal as country 3. Notice that Japan and Senegal import similar shares of goods from the U.S. But the U.S. imports a larger share of goods from Japan than from Senegal. Ignoring the role of the diagonal, the fact the U.S. row does not vary between Japan and Senegal implies unit costs are similar. Yet, the fact that the U.S. column does vary between Japan and Senegal implies that Senegal faces higher barriers to export to the U.S. relative to Japan. With balanced trade, the only way for unit costs to be similar across countries is for Senegal to be less productive relative to Japan offsetting the fact that wages are lower in Senegal.

7 How Do Trade Costs Influence Cross-Country Income Differences?

As table 8 illustrates, there are significant distortions present in the pattern of trade. Since the distribution of income across countries depends on the general equilibrium allocation of production, any distortion to the allocation of production suggests cross-country income differences reflect these distortions. For example, trade costs may allow production of a good to exist in a country which otherwise may have been imported. Reducing trade costs shuts down the production of goods a country is relatively inefficiently at producing and these goods are now imported. As a result, domestic resources are reallocated toward the production of goods that the country has a comparative advantage in increasing output per worker. Thus, trade costs through the reallocation of production both within and across countries may play an important role for economic development. To quantify these possibilities, I performed two counterfactual exercises modifying trade costs while fixing the estimated efficiency levels and observed capital-labor ratios.

In the first exercise, I adjusted trade costs so the new costs to trade between two countries are $\hat{\tau}_{ij} = \min(\tau_{ij}, \tau_{ji})$. The premise is that costs above this minimum reflect some extra distortion one country faces while the other does not. Hence, the exercise is to remove these additional distortions to trade. As discussed, a simply policy story lies behind this asymmetry in trade costs. The idea is that rich countries are systematically protected in certain sectors and poor countries are the predominant exporters in these sectors. Under this interpretation, this counterfactual exercise is to provide poor countries with equivalent market access to rich countries markets. Furthermore this issue, i.e. market access for poor countries goods, has been at the center of both past and recent

Table 3: **Income Differences and Welfare Gains, Percent Change**

	var [log(y)]	y_{90}/y_{10}	Mean	Max	Min	Corr.
Baseline	1.43	31.9	—	—	—	—
$\min(\tau_{ij}, \tau_{ji})$	1.18	21.3	22.9	70.3 (Mali)	0.56 (Japan)	-0.69
$\tau_{ij} = 1$	0.87	13.9	118.2	267.8 (Rwanda)	16.8 (Belgium)	-0.83

multilateral trade negotiations.

With the new trade costs, the variation in log income per worker declines to 1.18 and the 90/10 percentile ratio of income per worker is only 21.3. Cross-country income differences decline by up to 33 percent relative to the baseline model. Note that in this exercise trade costs are still large. For example, distance is still an impediment to trade and the median trade cost is 142 percent for all countries. This is significantly larger than the value reported in Anderson and van Wincoop (2004) for a developed country. Table 3 also reports the welfare gains and associated summary statistics.[14] Note, all countries gain—but poor countries gain relatively more than rich countries.

As a more extreme example, consider a world with no trade costs. In this world, the variation in log income per worker is only 0.87. The 90/10 percentile ratio of income per worker in this world is only 13.9. Recall, in the baseline model, the variation in log income per worker is 1.43 and the 90/10 percentile ratio is 31.9. Eliminating all trade costs reduces cross-country income differences by up to 56 percent. Again, table 3 reports the welfare gains showing all countries gain and poor countries gaining relatively more.[15]

Admittedly, this is an extreme exercise. However, it is a quantitative measure of trade's *potential* to eliminate cross-country income differences. For example, even if one takes the position that much of the distortions to trade are outside of the policy realm, this result says that non-policy related changes such as technological improvements in shipping, infrastructure, and communications are quantitatively important to reducing cross-country income differences.

The Allocation of the Gains From Trade: The reason behind the reductions in cross-country income differences results from the *allocation* of the gains from trade.[16] Many models can generate large welfare gains for all countries symmetrically. However, the results here show that reductions in barriers to trade systematically benefit poor countries more *relative* to rich countries — reducing cross-country income differences.

[14] Welfare gains are defined as the percentage increase in consumption across the two equilibria. If one assumes a utility function with diminishing marginal returns, then poor countries gain even more relative to rich countries.

[15] In the two exercises with θ set to 0.20, the variance of log income declines to 1.05 and 0.80 and the average welfare gain is 30 and 136 percent. With θ set to 0.10 the response is smaller. The variance of log income declines to 1.32 and 0.95 and the average welfare gain is 7.78 and 76.9 percent.

[16] This feature is the most relevant distinction between the gains from trade in this paper and in Alvarez and Lucas (2007). Overall the key differences in the welfare gains are: (i) The welfare gains here are larger, (ii) almost all the welfare gains here have yet to be realized, and (iii) the available welfare gains here are correlated with level of development. The appendix provides a discussion.

Two reasons drive the reduction in cross-country income differences. First, section 5 shows that based on observed volumes of trade, trade's contribution to cross-country income differences is negligible. That is, X_{ii} are similar across countries so the current gains from trade are similar. Second, the *available* gains are systematically allocated towards poor countries precisely because of the reasons they are poor. To demonstrate this last point, consider each country's trade share X_i in frictionless trade

$$X_i = K_i^{\frac{\alpha\beta}{\theta+\beta}} L_i^{\frac{(1-\alpha)\beta}{\theta+\beta}} \lambda_i^{\frac{\theta}{\theta+\beta}} \left(\sum_{\ell=1}^{N} K_\ell^{\frac{\alpha\beta}{\theta+\beta}} L_\ell^{\frac{(1-\alpha)\beta}{\theta+\beta}} \lambda_\ell^{\frac{\theta}{\theta+\beta}} \right)^{-1}, \tag{18}$$

where K_i is the total stock of capital in country i. Note that with no trade costs, all countries purchase the same fraction of goods from country i and hence $X_i = X_{ii} = X_{ij}, \forall j$. Equation (18) says that in frictionless trade, countries with larger endowments or efficiency levels produce a larger share of goods relative to countries with smaller endowments or are less productive.

Equations (10) and (18) together provide an expression for a country's welfare gain when moving from autarky to frictionless trade:

$$W_i = \frac{-\theta(1-\gamma)}{\beta} \log\left(X_i\right), \tag{19}$$

where W_i is the welfare gain and equation (18) defines X_i. Now compare the welfare gains between a representative rich and poor country assuming they have the same labor endowments. From (19) and (18) the *relative* welfare gain is

$$\frac{W_p}{W_r} = \frac{\theta(1-\gamma)}{(\theta+\beta)} \log\left(\frac{k_r^\alpha}{k_p^\alpha}\right) + \frac{\theta}{(\theta+\beta)} \log\left(\frac{\lambda_r^{\frac{\theta(1-\gamma)}{\beta}}}{\lambda_p^{\frac{\theta(1-\gamma)}{\beta}}}\right). \tag{20}$$

Equation (20) says differences in capital-labor ratios to the power α and closed-economy total factor productivity, $\lambda^{\frac{\theta(1-\gamma)}{\beta}}$, determine the *relative* gains. Poor countries have both lower capital-labor ratios and λs relative to rich countries. Poor countries are poor because of these facts. Thus equation (20) says that the poorer a country is the more it has to gain from trade *relative* to rich countries.[17]

In section 5, observed relative volumes of trade and equation (10) show the current gains from trade are quite similar across countries. Yet equation (20) shows poor countries have systematically more to gain from trade than rich countries. These two observations imply that reductions in barriers to trade not only deliver welfare gains but are an important force for reducing cross-

[17] There is a second feature that is more subtle — why poor countries are poor matters as well. Consider a simple thought experiment, suppose cross-country income differences are entirely explained by capital-labor ratios to the power α. Equation (20) implies a poor country in the 10 the percentile will gain 28 percent more relative to a rich country in the 90th percentile. In contrast, suppose cross-country income differences are entirely explained by $\lambda^{\frac{\theta(1-\gamma)}{\beta}}$. In this case, a poor country in the 10 the percentile will gain 100 percent more relative to a rich country in the 90th percentile.

country income differences. Furthermore, the quantitative importance of this force is a function of the variation in cross-country income differences.

8 Conclusion

In a quantitative general equilibrium model of trade, I argued three points. Decomposing income per worker into components arising from trade, capital, and efficiency, I showed the contribution from trade is not quantitatively important in explaining cross-country income differences. However, preventing trade from playing any role are differences in the barriers to trade poor countries face relative to rich countries. Eliminating these differences allows poor countries to gain relative to rich countries reducing cross-country income differences through the reallocation of production both within and across countries.

As the analysis here suggests, understanding how countries are quantitatively interrelated via trade is an important topic for continued research. Fundamentally, cross-country income differences *and* the bilateral of pattern of trade can be viewed as a function of differences in endowments, an exogenous TFP term, and trade costs. Thus, understanding productivity differences takes on a larger role in the sense that they are an important feature to understanding the bilateral pattern of trade. Furthermore, understanding trade costs takes on a larger role in the sense that they are an important feature to understanding cross-country income differences.

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9 Appendix: Derivation of Price Indices and Trade Shares

In this section, I provide some details concerning the derivation of equations which describe the the price index for intermediate goods and the share of goods purchased from each country. The approach followed here largely follows Alvarez and Lucas (2007).

Rewrite the price of each good $p_i(z)$ as:

$$p_i(z)^{\frac{1}{\theta}} = \Omega^{\frac{1}{\theta}} \min_j \left[(r_j^a w_j^b (p^q)_j^c \tau_{ij})^{\frac{1}{\theta}} z_j \right]. \tag{21}$$

Where $a = \alpha\beta$, $b = (1-\alpha)\beta$, and $c = (1-\beta)$. Note the following facts about the exponential distribution:

- if $z \sim \exp(\lambda)$, $\kappa > 0$, $\Rightarrow \kappa z \sim \exp(\frac{\lambda}{\kappa})$.
- if $z = \min(x, y)$, $y \sim \exp(\mu)$ and $x \sim \exp(\xi) \Rightarrow z \sim \exp(\mu + \xi)$.

This implies that each country i faces the following distribution for prices:

$$p_i(z)^{\frac{1}{\theta}} \sim \exp(\mu_i) \tag{22}$$

$$\text{where} \quad \mu_i = \Omega^{\frac{-1}{\theta}} \sum_{j=1}^{N} [r_j^a w_j^b (p_j^q)^c \tau_{ij}]^{\frac{-1}{\theta}} \lambda_j. \tag{23}$$

This implies the price index for the representative country i is

$$(p_i^q)^{1-\eta} = \left\{ \int_0^\infty \mu_i p_i(z)^{(1-\eta)} \exp[-\mu_i p_i(z)^{\frac{1}{\theta}}] dp_i^{\frac{1}{\theta}} \right\}. \tag{24}$$

Employing a change of variables by setting $s = \mu_i p_i(z)^{\frac{1}{\theta}}$, the expression for (24) may be computed as:

$$(p_i^q)^{1-\eta} = \mu_i^{-(1-\eta)\theta} \int_0^\infty s^{\theta(1-\eta)} \exp(-s) ds, \tag{25}$$

where the integral is the gamma function. Expanding what we have is:

$$p_i^q = \Omega S(\theta, \eta)^{\frac{1}{1-\eta}} \left\{ \sum_{j=1}^{N} [r_j^a w_j^b (p_j^q)^c \tau_{ij}]^{\frac{-1}{\theta}} \lambda_j \right\}^{-\theta}, \tag{26}$$

providing a more useful expression for the price index. $S(\theta, \eta)$ is the gamma function evaluated at $[1 + \theta(1-\eta)]$. For $S(\theta, \eta)$ to exist, $1 > \theta(\eta - 1)$ must hold which is assumed throughout. Finally, to arrive at (1), note that from a representative firm's first order condition the following relationship must hold:

$$r_i = \frac{\alpha}{1-\alpha} w_i k_i^{-1}.$$

This implies the following expression for each countries price of intermediate goods:

$$p_i^q = \Upsilon \left\{ \sum_{j=1}^{N} [k_j^{-\alpha\beta} w_j^{\beta} (p_j^q)^{(1-\beta)} \tau_{ij}]^{\frac{-1}{\theta}} \lambda_j \right\}^{-\theta}, \tag{27}$$

$$\Upsilon = \Omega S(\theta, \eta)^{\frac{1}{1-\eta}} \left(\frac{\alpha}{1-\alpha} \right)^{\alpha\beta}. \tag{28}$$

From here, one can rearrange (27) as found in the paper:

$$p_i^q = k_i^{-\alpha\beta} \Upsilon \left\{ \sum_{j=1}^{N} \left[w_j^{\beta} (p_j^q)^{(1-\beta)} \tau_{ij} \right]^{\frac{-1}{\theta}} \left(\frac{k_j}{k_i} \right)^{\frac{\alpha\beta}{\theta}} \lambda_j \right\}^{-\theta}. \tag{29}$$

To compute the the probability some country j is the low cost supplier for some good to country i, just a couple more facts about the exponential distribution and order statistics are required:

- if z and y are independent and $z \sim \exp(\xi)$, $y \sim \exp(\mu)$, $\Rightarrow \text{prob}\{z \leq y\} = \frac{\xi}{\mu+\xi}$.

Then note the following observation that

$$\text{Prob} \left\{ p_j(z) \leq \min_{j \neq s} [p_s(z)] \right\} = \text{Prob} \left\{ p_j(z)^{\frac{1}{\theta}} \leq \min_{j \neq s} [p_s(z)^{\frac{1}{\theta}}] \right\}, \tag{30}$$

then denoting M_{ij} as the probability country j is the low cost supplier to country i, one may express M_{ij} as:

$$M_{ij} = \frac{\left[k_j^{-\alpha\beta} w_j^{\beta} (p_j^q)^{(1-\beta)} \tau_{ij} \right]^{\frac{-1}{\theta}} \lambda_j}{\sum_{\ell=1}^{N} \left[k_\ell^{-\alpha\beta} w_\ell^{\beta} (p_\ell^q)^{(1-\beta)} \tau_{i\ell} \right]^{\frac{-1}{\theta}} \lambda_\ell}. \tag{31}$$

10 Appendix: Discussion of Alvarez and Lucas (2007)

The model in this paper is a variant of Alvarez and Lucas (2007) which in turn in a reformulation of Eaton and Kortum (2002). The key distinctions here between my model and Alvarez and Lucas (2007) lie in the calibration and the resulting welfare gains: (i) The gains here are larger, (ii) almost all the gains here have yet to be realized, and (iii) the available gains here are correlated with level of development. Below is a brief description of their calibration and then direct comparisons between the welfare gains from my approach and Alvarez and Lucas (2007) are made.

In the calibration of Alvarez and Lucas (2007), λ and L are the unknown parameters of interest and L is the number of effective labor units in the economy. They do not calibrate trade costs and instead construct them from data on average tariff rates and a simple formulation of transportation costs. They pursue two approaches to calibrating λ and L. First, they assume that λ is proportional to L and calibrate both to match a countries share of nominal World GDP. The second approach incorporates relative price data and allows them to calibrate each separately. To contrast the results between this paper and Alvarez and Lucas (2007), I used their second calibration and recalibrated my model with their values of β and γ — so the only difference in welfare gains arises from differences in λ, L, and τ.[18] The sample of countries between this paper and Alvarez and Lucas (2007) are different, however the assumption is that this margin is not quantitatively important.

Table 4 compares the welfare gains under two counterfactual exercises. The first counterfactual exercise is a move from the calibrated economy to frictionless trade and the first two rows of table 4 present the results. In Alvarez and Lucas's (2007) calibration the average welfare gain is only 16.5 percent. In this paper the average welfare gain is 61 percent — 270 percent larger. The second column and third column report the slope coefficient and standard error from a regression of the welfare gains on log income per worker for each country in 1996. For Alvarez and Lucas (2007), the slope coefficient is effectively zero. In my model, slope coefficient implies that poor countries gain systematically more relative to rich countries. For example, a country with income per worker in the 10 percentile of the sample will experience a welfare gain 225 percent larger than a country in the 90th percentile of the sample. Figure 8 plots the welfare gain versus income per worker data summarizing these results — the gains from trade are larger and more correlated with a countries level development. This means that in Alvarez and Lucas (2007) any potential gains from trade are allocated the same across countries independent of a country's level of development and hence the gains from trade do nothing to reduce cross-country income differences.

The third distinction between the welfare gains regards the realization of the gains. In Alvarez and Lucas (2007) almost all the gains are realized. A second counterfactual exercise illustrates this point by computing the welfare gains for a move from autarky to frictionless trade given the parameters L and λ.

The bottom two rows in table 4 compare the welfare gains for a move from autarky to frictionless

[18] They find that the implications for the volume of trade and welfare gains are quite similar across the two calibrations. To compute the gains, I used their programs which are available at Fernando Alvarez's website at: http://home.uchicago.edu/ falvare/workingp.html. The specific program used is welfare1.m

Table 4: Welfare Gain Comparison

Calibrated Model to Frictionless Trade	$\mu(W_i)$	$\hat{\beta}$	s.e.$\left(\hat{\beta}\right)$	# Obs.
Alvarez and Lucas (2007)	16.5	-0.009	.0001	60
My Model	60.9	-0.21	.0006	77
Autarky to Frictionless Trade				
Alvarez and Lucas (2007)	47.8	-0.08	.0002	60
My Model	67.2	-0.21	.0002	77

trade. For Alvarez and Lucas (2007), the gains are substantially larger relative to those moving from the calibrated model to frictionless trade. For example, the mean value is 47.8 percent for a move from autarky to frictionless trade while the mean value moving from the calibrated model to frictionless trade is only 16.5 percent. In terms of welfare gains, the world of Alvarez and Lucas (2007) is only 35 percent away from frictionless trade. In contrast, the final row in table 4 presents the welfare gains in this paper. These welfare gains are quite similar to those for a move from the calibrated model to frictionless trade. In terms of welfare gains, the world in this paper is 90 percent away from frictionless trade.

The distinctions highlighted here, i.e. the gains *available* and how the welfare gains are *allocated*, are nontrivial. Regarding the gains available, the results in Alvarez and Lucas (2007) suggest that further removal of existing trade barriers are small relative to those gains already achieved. Even if one takes the position that much of the distortions to trade are outside of the policy realm, this result says that any non-policy related changes such as technological improvements in shipping, infrastructure, communication are of little consequence to those gains already achieved. Regarding the allocations of the gains, the results in Alvarez and Lucas (2007) suggest they will do little to improve the plight of poor countries relative to rich countries. In contrast, the calculations from this paper suggest a completely opposite assessment: The available gains from trade are large and trade has the potential to improve the plight of poor countries relative to rich countries reducing cross-country income differences.

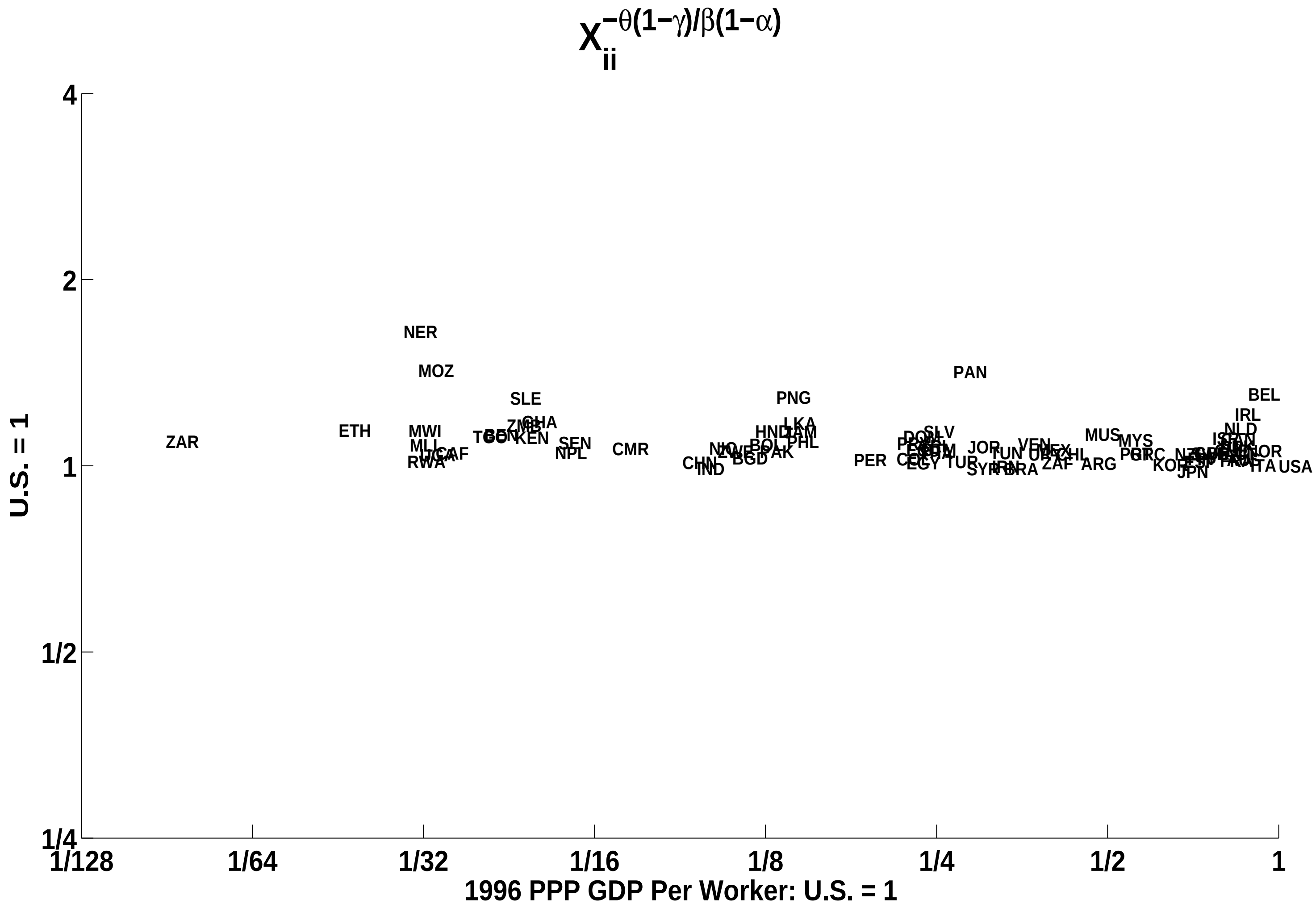

Figure 1: Trade Factors versus Income Data

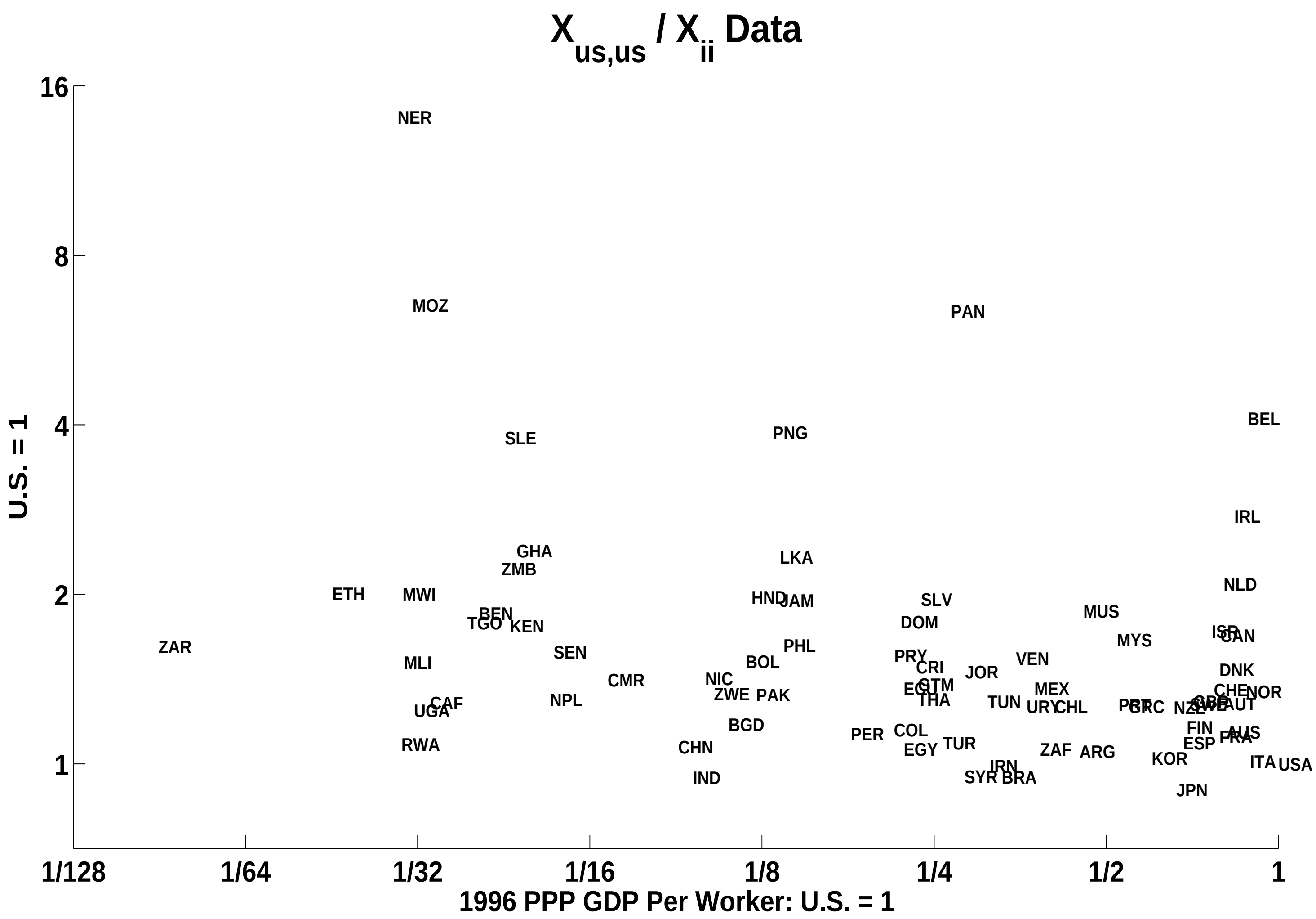

Figure 2: Home Trade Shares versus Income Data

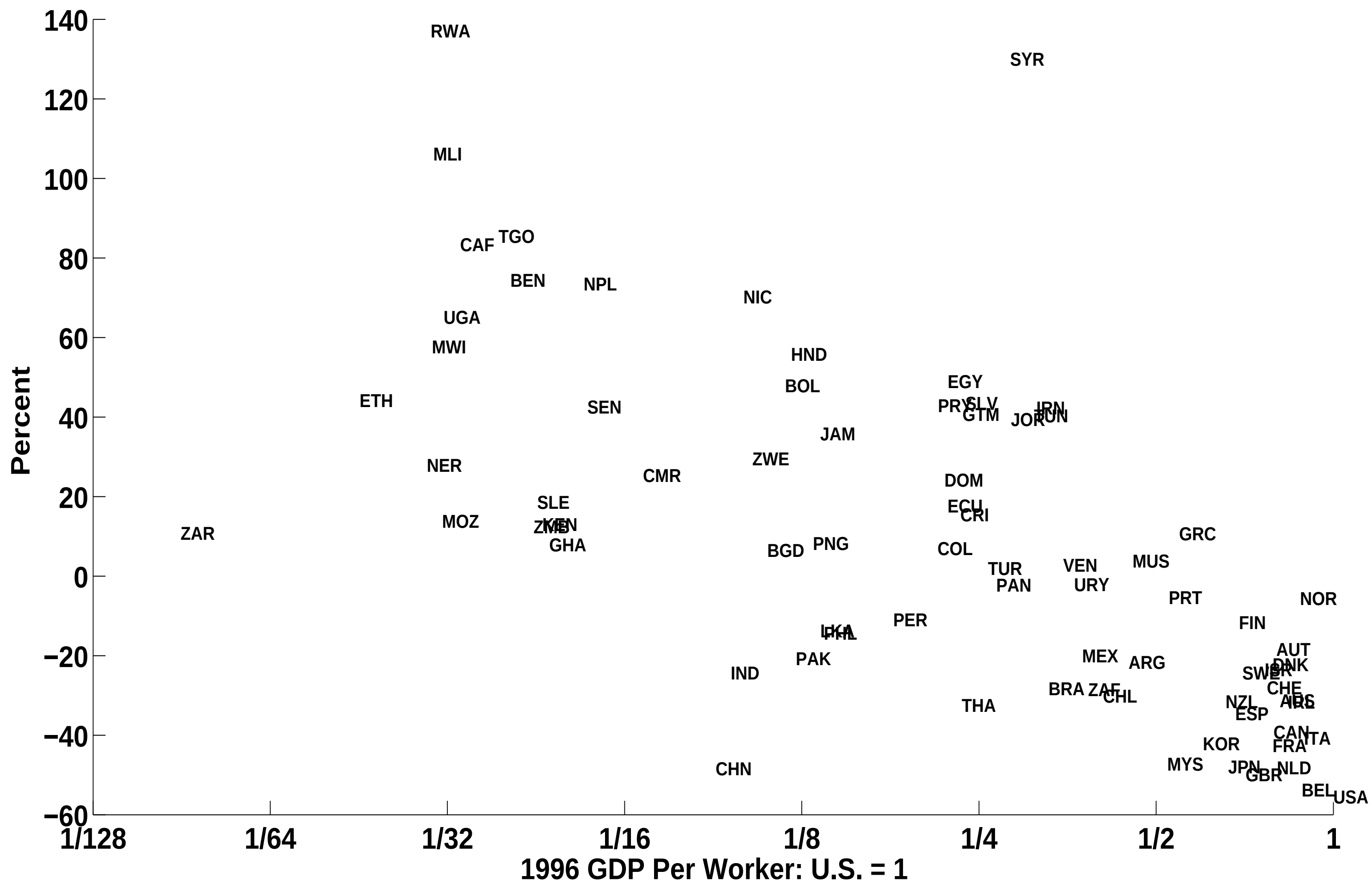

Figure 3: Exporter fixed effect, Percent Effect on Cost

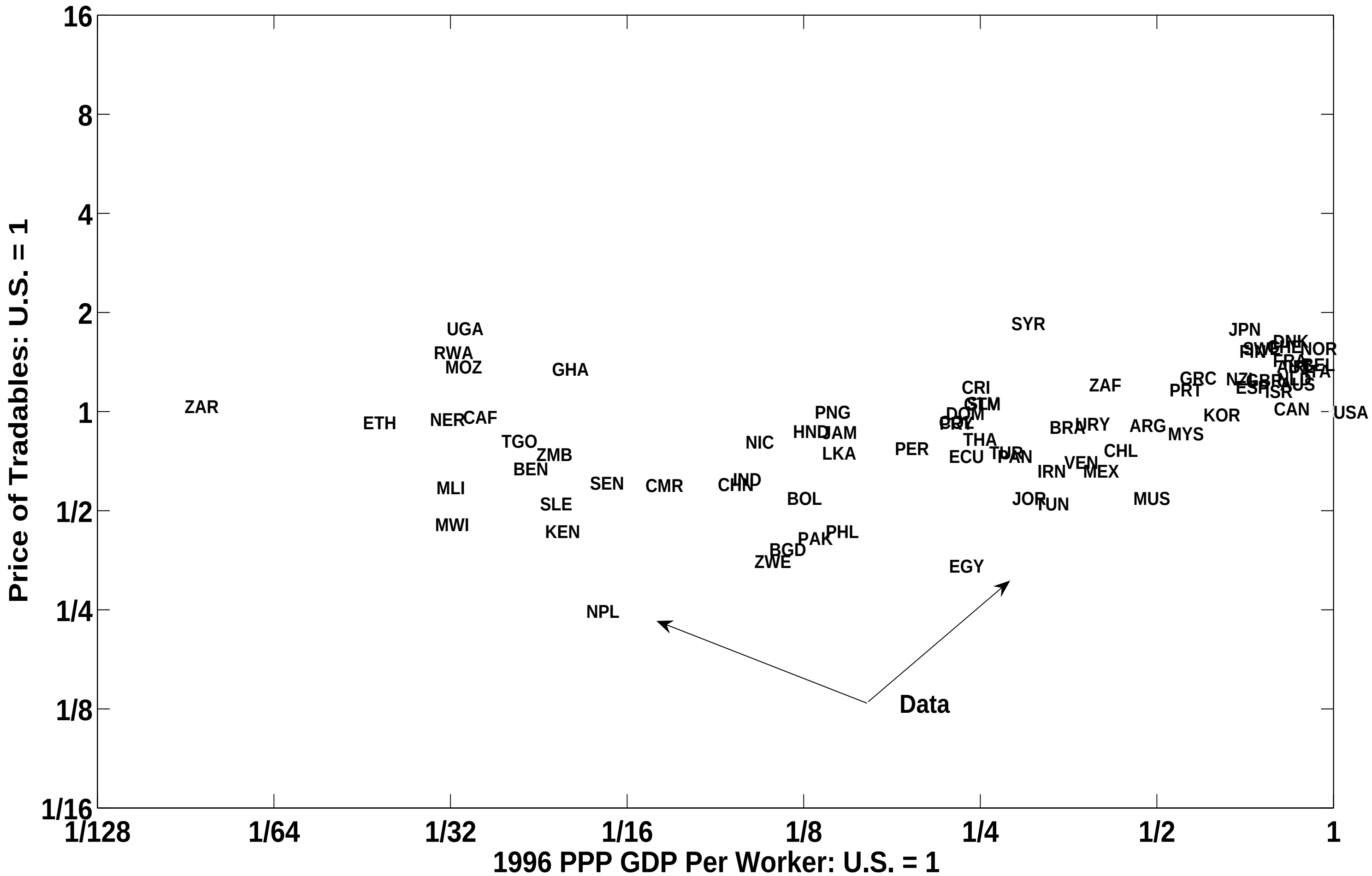

Figure 4: Price Data

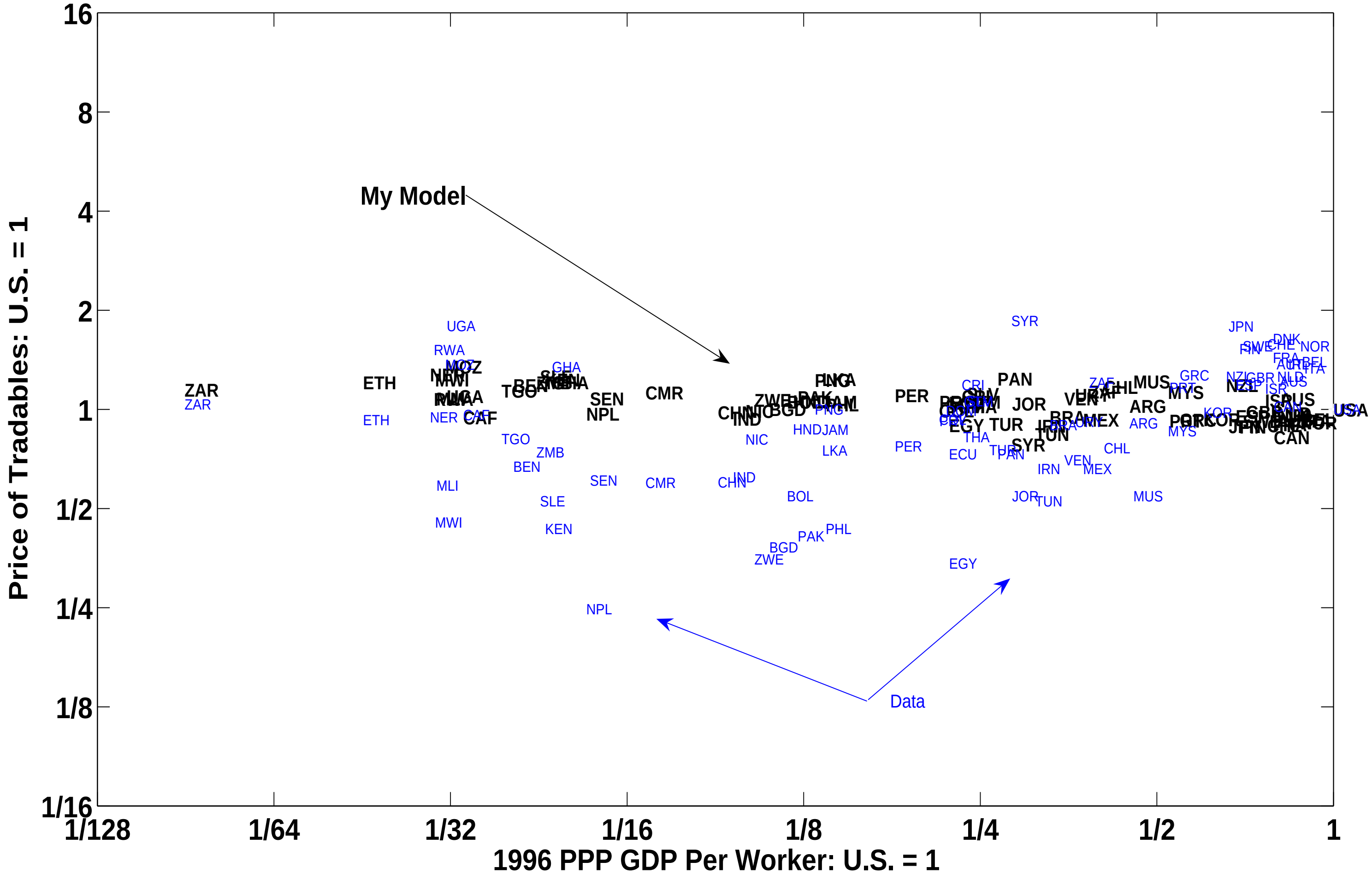

Figure 5: Price Data and My Model

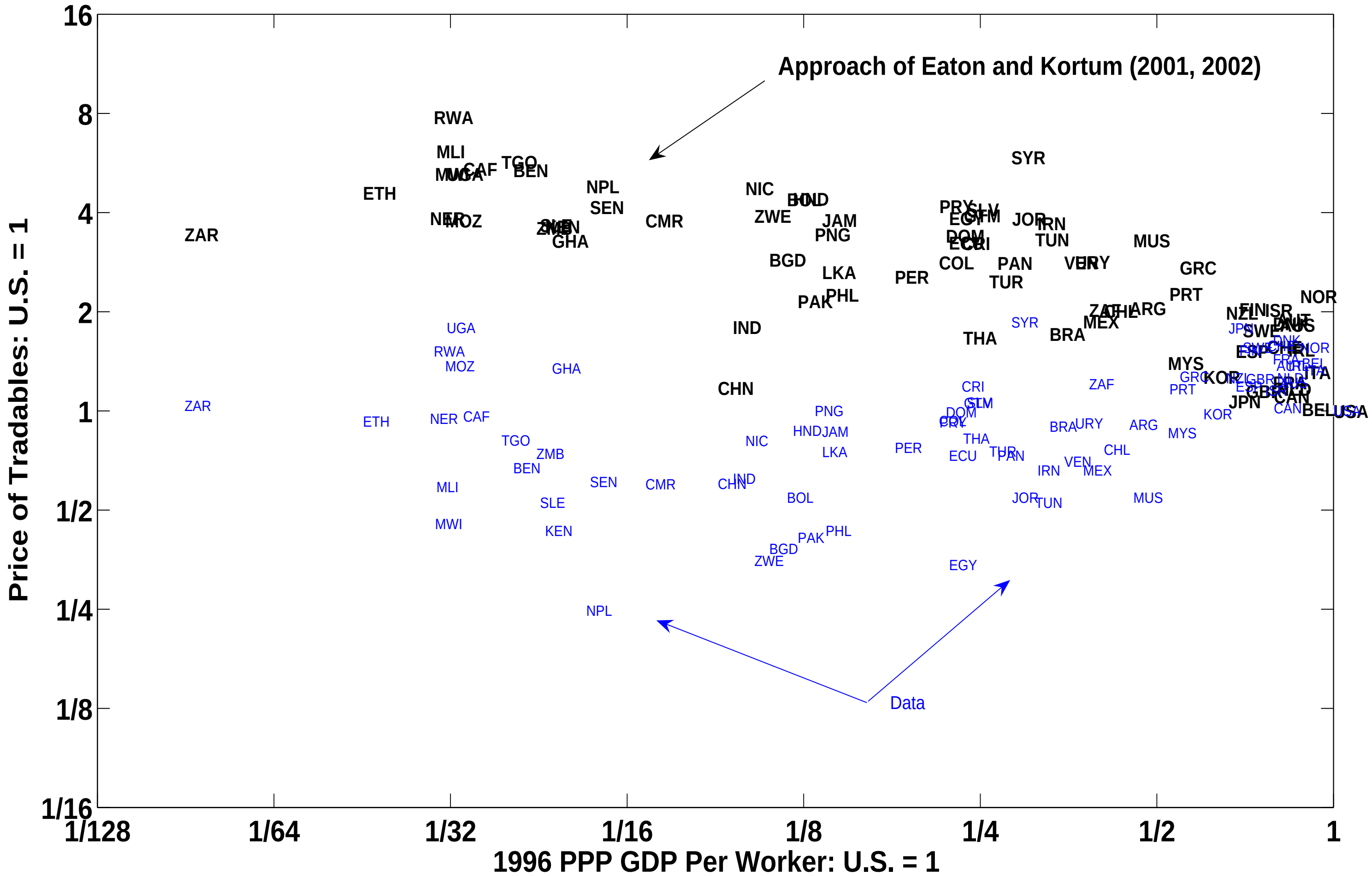

Figure 6: Price Data and Modeling approach of Eaton and Kortum (2002)

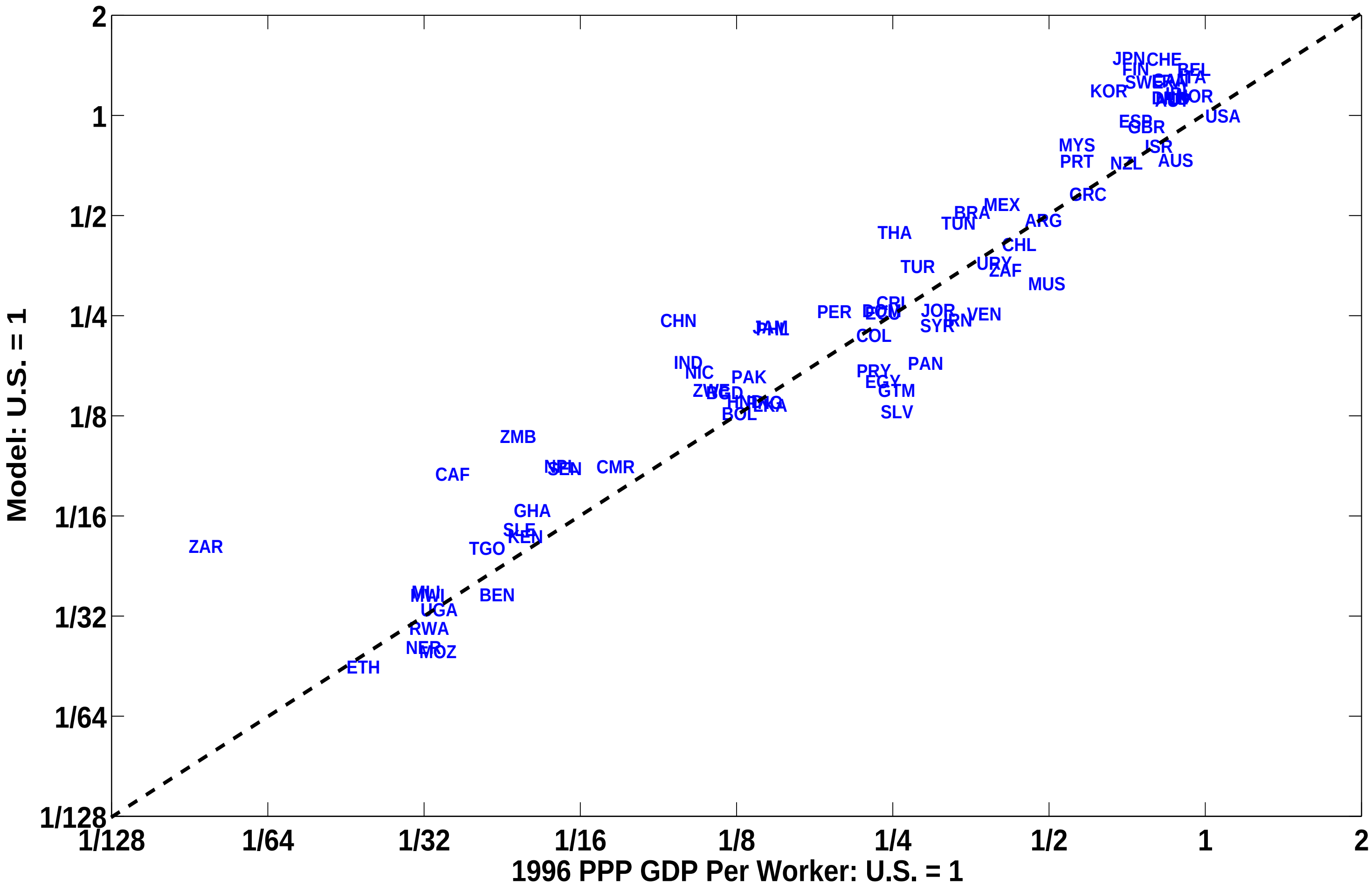

Figure 7: Income Per Worker: Data and Model

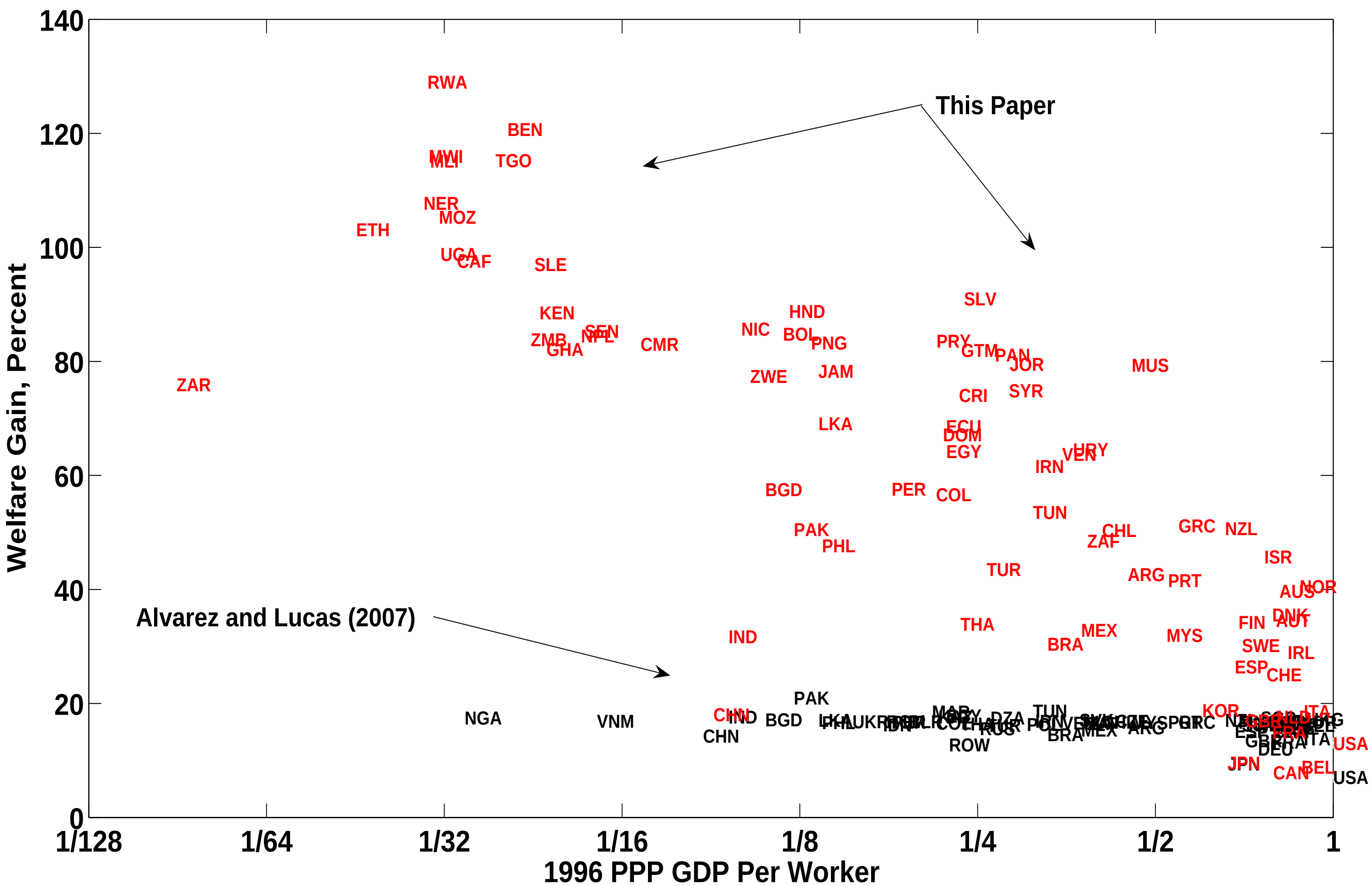

Figure 8: Welfare Gains: Calibrated Model to Frictionless Trade

Table 5: Country Data

Country	$\frac{y_{us}}{y_i}$	$\frac{L_{us}}{L_i}$	k_i/y_i	$\frac{X_{ii}}{X_{us,us}}$	Data Source
United States	1.00	1.00	2.19	1.00	O
Argentina	2.23	9.25	1.91	0.95	I
Australia	1.23	15.0	2.56	0.88	O
Austria	1.25	35.8	2.96	0.78	O
Belgium	1.13	31.9	2.80	0.24	O
Benin	25.0	49.6	0.76	0.54	W
Bangladesh	9.15	4.61	0.97	0.85	I
Bolivia	8.54	45.2	1.06	0.66	I
Brazil	3.05	2.28	2.05	1.06	I
Central African Republic	30.4	84.6	0.93	0.78	W
Canada	1.26	8.94	2.70	0.59	O
Switzerland	1.30	34.5	3.59	0.74	I
Chile	2.46	24.3	1.58	0.79	I
China-Hong Kong	11.2	0.18	1.54	0.93	I
Cameroon	14.9	20.2	0.98	0.71	I
Colombia	4.70	7.58	1.25	0.87	I
Costa Rica	4.30	102	1.74	0.67	O
Denmark	1.27	48.1	2.71	0.68	W
Dominican Republic	4.58	54.0	1.29	0.56	I
Ecuador	4.52	37.8	1.99	0.73	W
Egypt	4.52	7.80	0.63	0.94	I
Spain	1.47	8.65	2.83	0.92	I
Ethiopia	45.1	5.34	0.48	0.50	O
Finland	1.45	53.5	3.13	0.86	O
France	1.27	5.06	2.99	0.89	W
United Kingdom	1.41	4.64	2.16	0.77	O
Ghana	21.5	16.0	0.79	0.42	I
Greece	1.83	31.7	2.81	0.79	W
Guatemala	4.27	46.1	0.83	0.72	I
Honduras	8.34	75.2	1.46	0.51	O
India	10.6	0.37	1.04	1.06	I
Ireland	1.19	96.6	1.77	0.36	I
Iran	3.19	7.58	1.85	1.01	O
Israel	1.31	63.1	2.49	0.58	W
Italy	1.12	5.87	2.72	0.99	I
Jamaica	7.44	108	2.31	0.51	O
Jordan	3.53	135	1.59	0.69	I
Japan	1.51	1.69	3.51	1.11	O
Kenya	22.7	9.85	0.96	0.57	I
Republic of Korea	1.67	7.11	2.86	0.98	O
Sri Lanka	7.44	17.7	1.14	0.43	W
Mexico	2.67	4.26	2.06	0.73	I
Mali	33.8	28.2	0.92	0.66	I
Mozambique	32.7	17.1	0.39	0.15	I
Mauritius	2.19	263	1.14	0.54	I

Table 5: Country Data contd.

Country	$\frac{y_{us}}{y_i}$	$\frac{L_{us}}{L_i}$	k_i/y_i	$\frac{X_{ii}}{X_{us,us}}$	Data Source
Malawi	34.0	31.6	1.06	0.50	I
Malaysia-Singapore	1.91	18.2	2.38	0.60	W
Niger	34.7	29.5	0.86	0.07	O
Nicaragua	10.0	95.4	1.72	0.71	O
Netherlands	1.25	18.6	2.66	0.48	W
Norway	1.14	62.2	3.22	0.74	O
Nepal	18.8	14.8	1.43	0.77	I
New Zealand	1.52	77.1	2.55	0.79	I
Pakistan	8.19	3.86	1.07	0.75	I
Panama	3.74	136	2.05	0.16	I
Peru	5.59	13.0	2.24	0.88	W
Philippines	7.34	4.69	1.66	0.62	O
Papua New Guinea	7.66	65.0	1.20	0.26	W
Portugal	1.90	30.2	2.36	0.78	W
Paraguay	4.69	62.2	1.18	0.64	I
Rwanda	34.2	40.9	0.62	0.92	W
Senegal	18.5	33.1	0.80	0.63	O
Sierra Leone	22.5	80.5	0.53	0.26	O
El Salvador	4.22	74.6	0.85	0.51	O
Sweden	1.43	29.4	2.73	0.78	I
Syrian Arab Republic	3.54	37.9	1.05	1.05	W
Togo	26.2	78.8	0.96	0.56	I
Thailand	4.28	4.25	2.78	0.77	I
Tunisia	3.23	45.2	1.45	0.77	I
Turkey	3.86	4.96	1.71	0.92	W
Uganda	32.5	14.1	0.24	0.80	O
Uruguay	2.76	93.2	1.42	0.79	I
Venezuela	2.88	17.4	1.94	0.65	I
South Africa	2.61	10.0	1.27	0.94	I
Zaire (DRC)	90.9	6.08	1.07	0.62	W
Zambia	22.8	43.8	1.93	0.45	W
Zimbabwe	9.71	24.8	1.82	0.75	W

Note: Column's 2, 3, and 4 are constructed from Heston, Summers, and Aten (2002) describing relative income per worker, relative labor endowments, and each country's capital-output ratio. Column 5 is the relative home trade share for each country—the inverse is depicted in log base 2 scale in figure 2. Column 5 denotes the source of gross manufacturing production data. "O" denotes the OECD. "I" denotes data from the International Yearbook of Industrial Statistics from various years published by the United Nations Industrial Development Organization. "W" denotes the World Bank and gross manufacturing production is computed from value added. China and Hong Kong and Malaysia and Singapore are aggregated together following Bernard, Eaton, Jensen, and Kortum (2003) to avoid problems with entrepot trade.

Table 6: 1996 Trade Shares X_{ij} in Percent

	U.S.	Can.	Japan	Mexico	China	Senegal	Malawi	Zaire
U.S.	83.25	39.73	2.27	31.62	3.63	2.16	1.57	2.93
Can.	3.78	49.21	0.21	0.72	0.32	0.56	0.67	0.51
Japan	3.04	2.01	92.56	1.59	6.99	1.34	2.65	0.82
Mexico	1.88	1.33	0.02	61.09	0.057	0.01	0	0.007
China	1.78	1.41	1.44	0.30	77.61	2.69	2.50	6.81
Senegal	0*	0*	0*	0	0*	52.68	0	0
Malawi	0*	0*	0*	0	0	0	41.52	0
Zaire	0.003	0.005	0.003	0*	0*	0	0	51.53

Note: Zeros with stars indicate the value is less than 10^{-4}. Zeros without stars are recorded zeros in the data. Entry in row i, column j, is the fraction of goods country j imports from country i.

Table 7: Summary Statistics

No. Obs	TSS	SSR	σ_ϵ^2
4242	4924	851	2.08

Table 8: Geographic Barriers, $\theta = 0.15$

Barrier	Parameter Estimate	S.E.	%effect on cost
$[0, 375)$	−4.66	0.60	101.1
$[375, 750)$	−5.60	0.30	131.9
$[750, 1500)$	−6.16	0.17	151.9
$[1500, 3000)$	−7.22	0.12	195.2
$[3000, 6000)$	−8.44	0.09	254.8
$[6000, \text{maximum}]$	−9.37	0.10	308.1
Shared Border	0.69	0.37	−10.8
Arrival Country			
United States	5.40	0.43	−55.5
Argentina	1.62	0.53	−22.0
Australia	2.50	0.53	−31.2
Austria	1.35	0.34	−18.4
Belgium	5.13	0.51	−53.7
Benin	−3.71	0.87	74.5
Bangladesh	−0.43	0.58	6.58
Bolivia	−2.61	0.66	47.9
Brazil	2.21	0.45	−28.2
Central African Republic	−4.04	1.83	83.4
Canada	3.32	0.39	−39.2
Switzerland	2.19	0.44	−28.0
Chile	2.40	0.49	−30.1
China-Hong Kong	4.40	0.39	−48.3
Cameroon	−1.50	0.80	25.3
Colombia	−0.45	0.44	6.97
Costa Rica	−0.96	0.60	15.5
Denmark	1.67	0.40	−22.1
Dominican Republic	−1.45	0.62	24.3
Ecuador	−1.09	0.52	17.7
Egypt	−2.66	0.50	48.9
Spain	2.82	0.38	−34.5
Ethiopia	−2.45	0.63	44.3
Finland	0.82	0.41	−11.5
France	3.69	0.41	−42.5
United Kingdom	4.60	0.42	−49.8
Ghana	−0.51	0.75	8.00
Greece	−0.68	0.41	10.7
Guatemala	−2.28	0.63	40.7
Honduras	−2.96	0.78	55.8
India	1.86	0.49	−24.3

Table 8 Contd.

Arrival Country	Parameter Estimate	S.E.	% effect on cost
Ireland	2.54	0.42	−31.7
Iran	−2.35	0.76	42.3
Israel	1.78	0.51	−23.4
Italy	3.48	0.37	−40.7
Jamaica	−2.04	0.94	35.8
Jordan	−2.22	0.71	39.4
Japan	4.35	0.36	−47.9
Kenya	−0.82	0.65	13.1
Republic of Korea	3.64	0.41	−42.0
Sri Lanka	0.98	0.56	−13.7
Mexico	1.49	0.46	−20.0
Mali	−4.83	0.65	106
Mozambique	−0.87	0.85	13.9
Mauritius	−0.26	0.66	3.84
Malawi	−3.04	0.92	57.7
Malaysia-Singapore	4.25	0.43	−47.1
Niger	−1.64	0.99	27.9
Nicaragua	−3.55	0.86	70.2
Netherlands	4.38	0.39	−48.1
Norway	0.38	0.50	−5.55
Nepal	−3.68	0.68	73.6
New Zealand	2.52	0.51	−31.5
Pakistan	1.55	0.53	−20.7
Panama	0.14	0.63	−2.11
Peru	0.77	0.52	−11.0
Philippines	1.03	0.54	−14.3
Papua New Guinea	−0.53	1.05	8.30
Portugal	0.37	0.40	−5.38
Paraguay	−2.38	0.65	43.0
Rwanda	−5.76	1.01	137
Senegal	−2.37	0.82	42.6
Sierra Leone	−1.14	1.05	18.6
El Salvador	−2.41	0.88	43.6
Sweden	1.86	0.38	−24.3
Syrian Arab Republic	−5.55	0.59	130
Togo	−4.12	0.82	86.5
Thailand	2.61	0.52	−32.4
Tunisia	−2.26	0.60	40.4
Turkey	−0.13	0.39	1.98
Uganda	−3.35	0.81	65.2
Uruguay	0.14	0.47	−2.07
Venezuela	−0.19	0.63	2.82
South Africa	2.24	0.43	−28.5
Zaire (DRC)	−0.68	0.82	10.8
Zambia	−0.79	0.85	12.5
Zimbabwe	−1.73	0.66	29.5

Note: The parameters were estimated by OLS. For an estimated parameter $\hat{b}$, the implied percentage effect on cost is $100 \times (e^{-\theta\hat{b}} - 1)$. Heteroskedasticity-robust standard errors reported

Table 9: Technology, λ_i

Country	$\hat{S}_i$	S.E.	$\left(\frac{\lambda_{us}}{\lambda_i}\right)^\theta$
United States	0.54	0.33	1.00
Argentina	0.69	0.34	1.61
Australia	0.11	0.38	1.38
Austria	0.77	0.26	0.95
Belgium	-1.55	0.45	1.15
Benin	-0.25	0.50	9.98
Bangladesh	0.54	0.43	2.91
Bolivia	-0.09	0.39	3.71
Brazil	1.27	0.38	1.34
Central African Republic	0.33	0.53	3.40
Canada	0.11	0.32	1.00
Switzerland	0.75	0.35	0.77
Chile	-0.39	0.35	1.79
China-Hong Kong	0.76	0.31	1.88
Cameroon	-0.43	0.46	4.52
Colombia	0.63	0.29	2.62
Costa Rica	0.01	0.42	2.44
Denmark	0.81	0.33	0.90
Dominican Republic	-0.49	0.39	2.18
Ecuador	0.06	0.36	2.69
Egypt	1.17	0.29	2.93
Spain	0.53	0.30	1.03
Ethiopia	-1.15	0.42	11.74
Finland	1.39	0.32	0.67
France	0.68	0.32	0.85
United Kingdom	-0.08	0.34	1.10
Ghana	-1.50	0.47	5.47
Greece	0.75	0.29	1.68
Guatemala	-0.03	0.36	3.72
Honduras	-0.46	0.43	3.88
India	1.24	0.42	2.17
Ireland	-0.33	0.35	0.88
Iran	1.20	0.63	3.07
Israel	-0.01	0.37	1.26
Italy	0.85	0.30	0.77
Jamaica	-0.50	0.36	2.63
Jordan	-0.01	0.37	2.74
Japan	1.44	0.31	0.62
Kenya	-0.58	0.39	6.91
Republic of Korea	1.00	0.32	0.78
Sri Lanka	-1.48	0.38	4.03
Mexico	0.76	0.28	1.36
Mali	0.08	0.44	8.93
Mozambique	-2.32	0.54	12.01
Mauritius	-1.04	0.46	2.28

Table 9: Technology, λ_i contd.

Country	$\hat{S}_i$	S.E.	$\left(\frac{\lambda_{us}}{\lambda_i}\right)^{\theta}$
Malawi	-0.71	0.58	9.75
Malaysia-Singapore	-0.33	0.30	1.05
Niger	-2.94	0.52	18.43
Nicaragua	0.09	0.47	2.96
Netherlands	-0.75	0.32	1.14
Norway	0.92	0.39	0.96
Nepal	0.62	0.41	4.69
New Zealand	-0.27	0.32	1.33
Pakistan	-0.01	0.41	2.94
Panama	-1.71	0.42	5.58
Peru	-0.08	0.35	2.53
Philippines	-0.12	0.36	2.36
Papua New Guinea	-1.51	0.55	3.80
Portugal	0.61	0.27	1.18
Paraguay	0.26	0.43	3.48
Rwanda	0.24	0.58	9.96
Senegal	-0.36	0.43	3.87
Sierra Leone	-2.01	0.55	5.67
El Salvador	-0.64	0.46	4.59
Sweden	1.07	0.30	0.73
Syrian Arab Republic	1.75	0.36	2.45
Togo	-0.49	0.43	7.10
Thailand	0.15	0.46	1.67
Tunisia	1.29	0.40	1.28
Turkey	1.23	0.30	1.81
Uganda	-0.27	0.39	6.01
Uruguay	-0.31	0.27	1.96
Venezuela	-0.16	0.36	3.27
South Africa	0.16	0.32	1.93
Zaire (DRC)	-0.57	0.56	4.32
Zambia	-1.05	0.45	3.90
Zimbabwe	0.14	0.40	3.55

Note: Technology parameters, λ_i, are recovered as detailed in section 4.2 and $\theta = 0.15$. Heteroskedasticity-robust standard errors reported