International Trade and Income Differences

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Abstract

I study the relationship between international trade and a country's standard of living in a quantitative general equilibrium model of trade. From the model, I derive an analytical decomposition of income per-worker into contributions from capital, productivity, and trade. In a sample of 77 countries, I find the contribution from trade explains little of the variation in income per-worker relative to contributions from productivity or capital. Quantifying the full model to match the pattern of bilateral trade, I find that the model generates cross-country income differences consistent with the data. Through counterfactual experiments, I show reductions in barriers to trade are quantitatively relevant for economic development with cross-country income differences reduced by nearly 50 percent through the reallocation of production across countries.

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What is the relationship between international trade and a country's standard of living? I answer this question by studying the joint relationship between trade and a country's income level in general equilibrium. Focusing on the implications of international trade on income, I argue two points: first, trade is not an important factor in explaining cross-country income differences; productivity differences are the driving force. Second, reductions in barriers to trade allow low productivity countries to gain relative to high productivity countries via comparative advantage.

To argue these points, I construct a multi-country model of trade. In each country, there are two vertically integrated 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 good with a technology common to all countries which is consumed.

To quantify the relationship between international trade and a country's income level, I proceed in two ways. First, 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. Since the contribution from trade is measurable, this procedure allows me to quantify the extra gain in income per-worker each country receives as a result of trade. In accounting for trade's role, I find trade is not quantitatively important in explaining cross-country income differences. In a sample of 77 countries, there is a 25-fold difference in income per-worker across the top 10th percentile and bottom 10th percentile. The contribution from trade varies by a factor of 1.13 across the top 10th percentile and bottom 10th percentile. 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 understand, this result does not imply that trade policies and trade costs are quantitatively irrelevant for economic development. The prior result is only a statement regarding the observed volume of trade, not the gains possible if trade policies or trade costs were changed. To quantitatively asses these possibilities, I parameterize 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 quantitative properties.

The model generates large differences in income per-worker which are consistent with the data. In the data, the ratio of the top 10th percentile to the bottom 10th percentile in income per-worker is 25. In the model, it is 29. Consistent with the accounting exercise, large differences in average efficiency are implied by the pattern of bilateral trade.

However, 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. Since the distribution of income across countries depends on the general equilibrium allocation of production, any distortion to the allocation of production across countries suggests cross-country income differences reflect these distortions. Thus, changes in trade policies and trade costs, which help determine the general equilibrium allocation of production and specialization, provide an avenue for poor countries to gain via comparative advantage. I illustrate this point through counterfactual experiments by studying a world without trade costs, but with the recovered efficiency levels. Through the reallocation of production across countries from the elimination of trade costs, the ratio of the top 10th percentile to the bottom 10th percentile in income per-worker is reduced to 15. That is cross-country income differences are reduced by nearly 50 percent by eliminating barriers to trade.

Building on this latter point, I then explore the welfare implications of the model. I find large welfare gains, especially for poor countries. For example, a 10 percent reduction in trade costs generates an average welfare gain of 3.6 percent across all countries, with the five poorest countries gaining an average of 11.8 percent. Eliminating all trade costs, the average welfare gain is 86 percent, with the five poorest countries gaining an average of 160 percent. Through simple comparative advantage, trade is quantitatively relevant for economic development.

Related to these results is the income accounting literature. The focus in this literature is on two fundamentals in explaining a country's income level—factors of production and total factor productivity. Klenow and Rodriguez-Clare (1997), Hall and Jones (1999), Parente and Prescott (2002), and Caselli (2005) are examples that find cross-country income differences are mostly a result of differences in total factor productivity. Extending these exercises to an open economy framework, I derive an equilibrium relationship with income decomposed into contributions from total factor productivity and capital-output ratios. The key feature is that now total factor productivity is decomposed into two components: an exogenous efficiency level and an endogenous and measurable contribution from trade. As noted, I show that the contribution from trade is not quantitatively important in explaining cross-country income differences—differences in efficiency are the driving force. However, eliminating barriers to trade allows poor countries to gain dramatically.

Most recent studies that do study 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. 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 in 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) as examples. 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 as reduced-form studies 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 policy statements regarding how income or welfare may change given a change in barriers to trade.

In a quantitative general equilibrium model I am able to satisfy both criticisms of these prior approaches. Through the accounting procedure I derive, I am able to explicitly account for the role of international trade on a county's standard of living avoiding the statistical difficulties previous studies have faced. Furthermore, with an explicit model and 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 (2005), this paper is distinguished by studying the implications of trade on a country's level of development. Eaton and Kortum (2002) and Alvarez and Lucas (2005) 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 model's implications for the aggregate volume of trade in a wide cross-section of countries. Furthermore, to aid in answering the question posed, my model includes capital. This feature aids the calibration by adjusting for each country's endowment and provides a straightforward comparison between standard closed economy analysis of cross-country income differences and the open economy analysis I perform.

Another distinction lies in the procedures with which I quantify 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 which are necessary to quantify the whole model. Second, I use equilibrium conditions in the model and data on bilateral trade shares to recover a country's average efficiency level. In this sense, each country's efficiency level is a result from the observed bilateral pattern of trade—disciplining the approach in this paper. In contrast, Alvarez and Lucas (2005) used data on output and relative prices to calibrate a country's efficiency level. Similarly, Eaton and Kortum (2002) use data on wages to recover each country's efficiency level.

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. Unlike traditional "gravity" with symmetric effects, I allow for asymmetric trade costs by estimating a trade cost function assuming a form of export asymmetry. This feature is in contrast to the trade cost function used in Eaton and Kortum (2002) which induces import asymmetry. As discussed in Waugh (2006), the approach here and that of Eaton and Kortum (2002) are indistinguishable in their ability to fit the pattern of trade. However, these two approaches imply fundamentally different quantitative implications for prices and cross-country income differences. Disciplining the approach here is that the model correctly replicates salient features of observed cross-country income differences. Furthermore, this approach is in contrast to the calibration in Alvarez and Lucas (2005) who used simple observed proxies for trade costs.

1 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 with 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.

1.1 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. 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 $m_i(x)$:

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

Power terms α and β control the factor shares.[1] Across goods x, production technologies differ only in their efficiency level $z_i(x)^{-\theta}$. The parameter θ is common to all countries.

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[1] 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.

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.

1.2 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 (2005) and assume that $z_i(x)$ is distributed independently and exponentially with parameter λ_i 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 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.

1.3 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.

1.4 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, so the proper interpretation of τ_{ij} is the cost of international trade *relative* to internal trade.

2 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 3.

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 the aggregate intermediate good are allocated towards the final goods sector, and a fraction $(1 - \gamma)$ is allocated towards the intermediate 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 (2005). 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 (2005). 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 (2005)), 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.

3 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 to serve as a consistency check of the model and for counterfactual exercises. 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 implied cross-country income differences and counterfactual exercises.

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}. Furthermore, manipulation of equation (2) provides a structural equation for the estimation of each country's technology parameter λ_i and trade costs τ_{ij}.

3.1 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:

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

Further rearrangement of (33) 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.[2]

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. 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.

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[2] 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.

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 factor:

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

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

Given this representation, each country's gain from trade, in the form of increased total factor productivity, is $\left(\frac{X_{ii}}{X_{us,us}}\right)^{\frac{-\theta(1-\gamma)}{\beta}}$ and termed the trade factor. Notice that a lower home trade share for country i implies country i imports a larger fraction of goods from the rest of the world. This expression has several straightforward implications. First, if country i has a lower home trade share than the U.S., then country i will gain 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.

Notice, when trade costs are infinite, i.e. when $X_{ii} = 1$, relative income per-worker is:

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

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 $\left(\frac{\lambda_i}{\lambda_{us}}\right)^{\theta}$ to the power $\frac{(1-\gamma)}{\beta}$. This is the second term in brackets in equation (10) and termed the domestic factor.

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 used 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 policy statements regarding how income may change in response to changes in barriers to trade. This criticism is perhaps the most severe because policy statements are the precise motivation of these studies. In contrast, this framework can ask and quantitatively answer these questions. To answer them, however, the full model must be quantified which the next section discusses.

3.2 Recovering Trade Costs and Technology

To study how cross-country income differences respond to changes in barriers to trade, I must recover the unknown technology parameters and trade costs. To recover these parameters, I derive and estimate structural equation which resembles a reduced-form "gravity" equation widely used in empirical international trade.[3]

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 $\log\left(c_i p_i^{q\left(\frac{\beta-1}{\theta}\right)}\right)$.

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[3] 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, however, the appendix details this approach. 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.

To recover the technology parameters and trade costs implied by the pattern of trade, I will estimate equation (14) with the S_is recovered as the coefficients on country specific dummy variables. Unfortunately, to recover trade costs, one must assume a technological relationship between τ_{ij} and observable parameters. I will assume trade costs take one the following 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, 0 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 arrival effect. That is, the estimate of ex_j is the extra cost country j faces to export a good to any country i. This is different from Eaton and Kortum (2002) in which there is an destination effect m_i in its place, with the estimate m_i reflecting the extra cost county i faces to import a good from any country j. As discussed in Waugh (2006), the destination effect of Eaton and Kortum (2002) induces import asymmetry. That is the difference in the average cost to import across countries will differ more than the average cost to export. In contrast, the approach here will induce export asymmetry in trade costs. That is the difference in the average cost to export across countries will differ more than the average cost to import. As discussed in Waugh (2006), both assumption are not innocuous. Though both will fit the trade data equally well, each has distinct implications for prices and cross-country income differences.

Equations (14) and (15) provide the basis for the estimation of trade costs τ_{ij}s and S_is for which I will use ordinary least squares.

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):

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

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—adjusted for endowment differences—providing discipline in recovering these parameters. This in contrast to previous approaches. For example, Alvarez and Lucas (2005) 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 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.

In Eaton and Kortum (2002), they use observed wages. With my focus on income differences, this approach would be problematic. In the structure outlined above, the wage rate used is very important because it induces the recovered λ_is to be higher or lower given that wage rate, holding all else constant. Hence, using observed wages would impose a clear positive correlation structure between income level and λ_is. However, by using the equilibrium wage rates determined from (32) discipline is imposed because, a priori, it is not clear what the correlation structure is between the equilibrium wages from (32) and income level—if any.

3.3 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 4 details the countries considered. 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.[4]

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[4] 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. Many other countries were eliminated because data on gross manufacturing production used in the construction of trade shares was unavailable.

Table 1: Calibration

Parameter	Description	Value
α	k's share	1/3
β	k and n's share in int. goods production	0.43
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

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. 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 4, I present the source for each country's gross manufacturing production data. In table 5, I present trade share's for selected countries.

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.[5] 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 4.

I calibrated parameter values common to all countries as follows. I followed Alvarez and Lucas (2005) 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 exercises in

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

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. Adjusting this value by the fraction of all trade occurring in manufactured goods for OECD countries yields a value of 0.43.

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 (2005) 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.

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 former, I will omit any zero observed trade flows from the estimation of equation (14). This has been a standard approach in the gravity literature. Regarding the later, 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.

4 Results

As discussed in section 3, two methods are used to quantify the relationship between trade and cross-country income differences. The first is an accounting procedure which is only a statement regarding the observed quantities of trade and their quantitative importance in explaining cross-country income differences. The second is the quantification of the full model and considers how cross-country income differences change as barriers to trade change.

4.1 Does Trade Explain Income Differences?

To answer this question, the framework outlined in section 3.1 is useful to understand 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:

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

Figure 1 depicts trade factors versus income per-worker data. If the ordered pairs displayed a positive relationship, then this would imply rich countries have higher incomes relative to poor countries because of trade. As figure 1 illustrates, there is a slight negative relationship. Furthermore, 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 0.005 and the ratio of trade factors for the top 10th percentile and bottom 10th percentile in income per-worker is approximately 1. Recall, the data's variance of log income per-worker is 1.38 and the 90/10 ratio of income per-worker is 25.6.

These results imply that cross-country income differences are entirely explained by each country's average efficiency level $\left(\frac{\lambda_i}{\lambda_{us}}\right)^{\theta}$ and differences in capital-output ratios. Since the calibrated factor shares α, β, γ result in $\frac{(1-\gamma)}{\beta(1-\alpha)} \approx 1$, differences in average efficiency translate directly into differences in income per-worker. For example, the ratio of capital-output ratios to the power $\frac{\alpha}{1-\alpha}$ for the top 10th percentile and bottom 10th percentile in income per-worker is approximately 2. With trade factors contributing next to nothing, this implies the ratio of average efficiency for the top 10th percentile and bottom 10th percentile in income per-worker is approximately 12.5.[6] These two factors account for almost all the variation in income per-worker.

The finding that trade contributes little to explaining cross-country income differences, 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 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. 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 the finding that poor countries seem to gain relatively from trade. 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 countries do not trade enough for trade to have any quantitative meaning.

4.2 Trade Costs, Technology, and Income Differences

The preceding result only says trade is unable to account for the variation in cross-country income differences. It does not say that trade policies and trade costs are irrelevant for economic development. To asses the quantitative importance of trade costs, they first must be determined along with each country's average efficiency level. From the constructed bilateral trade shares, I recovered each country's λ_i and trade costs τ_{ij} as detailed in section 3.2. Table 5 presents some summary statistics. Tables 6 and 7 present the parameter estimates for trade costs and technology parameters.

The parameter estimates themselves are not of interest here, only the reconstructed trade costs and efficiency levels 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). When the set of countries is restricted to only OECD countries, the effect of distance and overall size of trade costs are consistent for a representative developed country as reported in Anderson and van Wincoop (2004).

Second, the arrival effect is negatively correlated with income level. Figure 3 plots each country's arrival effect, expressed in terms of the percent effect on cost, versus income per-worker. The correlation between the arrival effect and log income per-worker is -0.66 and statistically different from zero. As the figure

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[6] This inference on the differences in average efficiency is consistent with the findings from the full calibration exercise where differences in average efficiency are being driven by the observed pattern of bilateral trade. See table 7.

Table 2: Income Per-Worker

	var [log(y)]	y_{90}/y_{10}	Gini
Data	1.38	25.6	0.60
Model	1.36	29.2	0.59

depicts, poor countries appear to have a serious disadvantage at exporting goods relative to rich countries.[7] 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.

As an 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 4 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 4, the ordered pairs lie just above the 45° line indicating the model is slightly over-predicting relative incomes. For example, the model predicts that Uganda has an income level 1/28 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. Except for the 90/10 ratio, the summary statistics indicate the model slightly under-predicts the variation in cross-country income differences.[8]

The model predicts incorrectly which countries within the rich are the richest. One potential 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 18.

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[7] This finding is in sharp contrast to the destination effect in Eaton and Kortum (2001). With their trade cost function, poor countries appear to have a serious disadvantage at importing goods relative to rich countries resulting in the finding that poor countries face higher prices for machinery and equipment which is inconsistent with the data, see Hsieh and Klenow (2003). As I show here, my approach generates cross-country income difference constant with those observed. Waugh (2006) demonstrates that the model estimated using the trade cost function with destination effects, as in Eaton and Kortum (2001) or Eaton and Kortum (2002), produces cross-country income differences inconsistent with the data.

[8] The results in figure 4 and table 2 are 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 1.30 and the 90/10 ratio is 25.9. For a θ of 0.20 the variance of log income is 1.43 and the 90/10 ratio is 31.8.

Overall, the model is performing well in capturing the variation in income across countries.

Where does this result arise from? It arises from two observations about the bilateral pattern of trade in table 5 and their implication in the model. First, notice poor countries purchase a substantial fraction of their goods from rich countries. Second, rich countries purchase only a small fraction of their goods from poor countries. In the model's equilibrium with balanced trade, these observations imply that rich countries must have higher wages than poor countries which is then mapped into a productivity differential.

To make this claim concrete, consider the expression for income per-worker in (10). It illustrates the necessary components for the model to correctly capture the variation cross-country income differences. Since the impact of trade is small and capital stocks are taken from the data, the recovered λ_i's are the most important component in determining a country's income level.

What drives the variation in λ_is? Assume for simplicity that the world is only composed of two countries and they each have the same S_i and the same price of intermediate goods. Given how λ_is are recovered from S_is and the assumptions made, the relative difference in λ_i between country i and j is given by:

$$\left(\frac{k_j}{k_j}\right)^{\frac{\alpha\beta}{\theta}} \left(\frac{w_i}{w_j}\right)^{\frac{\beta}{\theta}} = \frac{\lambda_i}{\lambda_j} \tag{18}$$

Note that the wage is central to determining λ_is. A larger relative wage between country i and j yields a larger relative λ. Furthermore, capital works in the opposite direction adjusting the productivity differences appropriately.

As discussed in section 3.2, wages are an outcome of the equilibrium relationship in equation (32), labor endowments, and the bilateral pattern of trade. Using equation (32), relative wages between the two countries are:

$$\frac{w_i}{w_j} = \frac{L_j}{L_i}\frac{X_{j,i}}{X_{i,j}}. \tag{19}$$

Then combining (18) and (19) yields:

$$\left(\frac{k_j}{k_j}\right)^{\frac{\alpha\beta}{\theta}} \left(\frac{L_j}{L_i}\right)^{\frac{\beta}{\theta}} \left(\frac{X_{j,i}}{X_{i,j}}\right)^{\frac{\beta}{\theta}} = \frac{\lambda_i}{\lambda_j}. \tag{20}$$

The first and second bracketed terms adjust each country's productivity level for endowment differences. The third bracketed term encompasses the intuition discussed earlier. If the fraction of goods country j purchases from country i is larger than then the fraction of goods country i purchases from country j, i.e. $X_{j,i} > X_{i,j}$, then country i must be more productive then country j.

To illustrate how (20) works, consider the U.S. and Kenya. The fraction of goods Kenya purchases from the U.S. is significantly larger than the purchases of the U.S. from Kenya such that the term $\left(\frac{X_{ken,us}}{X_{us,ken}}\right)^{\beta}$

is a factor of 54. The term $\left(\frac{k_{ken}}{k_{us}}\right)^{\alpha\beta}\left(\frac{L_{ken}}{L_{us}}\right)^{\beta}$ is a factor of 0.2. These two facts imply that the difference in average efficiency, $\left(\frac{\lambda_{us}}{\lambda_{ken}}\right)^{\theta}$ is a factor of 11 which approximates the full calibration result. The bilateral patten of trade drives each country's productivity level which drives the variation in cross-country income differences.

What is driving this result is very much along the lines of Lucas (1990). He asks why is capital allocated across countries such that rich countries have more capital per-worker than poor countries. One answer to his question is that there are differences in efficiency or other complimentary factors to rationalize his observation. The corollary to his question is to ask how is production allocated across countries. Here, I find the pattern of production across countries is distorted in such a way that the only way to reconcile it in the model is with large differences in efficiency.

4.3 Trade and Economic Development

As table 5 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. Thus, trade costs—which along with productivity differences, capital stocks, and labor endowments determine the general equilibrium allocation of production—may play an important role for economic development.

To quantitatively asses these possibilities, consider a world with the estimated efficiency levels and observed capital-labor ratios but no trade costs. In this world, the variation in log income per-worker is only 0.90. The 90/10 percentile ratio of income per-worker in this world is only 15. Recall, in the baseline model, the variation in log income per-worker is 1.37 and the 90/10 percentile ratio is 29.2. Through the elimination of trade costs, cross-country income differences are reduced by nearly 50 percent.

The mechanism behind this result is simple comparative advantage. In the model, each country is very efficient in the production of some set of goods. Without trade costs, countries are able to specialize in a smaller set of goods, trading increased quantities, for export to a larger set of countries. For example, in this world, the fraction of goods the U.S. purchases from home is 14 percent relative to 68 percent in the model with trade costs. The smaller amount of goods purchased from home is offset by larger purchases from other countries, especially the poor. The result is an improvement the terms of trade, especially between rich and poor countries, resulting in lower relative wage differentials. For example, in the world with free trade, the variance in log wages is almost half of the baseline calibration (7.53 versus 4.14). This reduction in variance is partially offset by changes in the price of final goods. Together, the result is a decrease in cross-country

Table 3: Welfare Gains, Percent Change

	Mean	Max	Min	Corr.	var [log(y)]	y_{90}/y_{10}
10%	3.6	27.4 (Niger)	0.36 (Syria)	-0.29	1.33	28.2
100%	85.9	186.9 (Rwanda)	12.9 (Japan)	-0.83	0.90	15.1

income differences.[9]

Reductions in trade costs allow low productivity countries to gain relatively via comparative advantage. As the next section discusses, the welfare possibilities from changes in trade policy and trade costs are large and hard to ignore, especially for poor countries.

4.4 Gains From Trade

To explore the welfare implications of the calibrated model, I study the welfare gains from reductions in trade costs through several exercises. To compute these gains, I computed consumption for the baseline model and then adjusted trade costs and recomputed a new equilibrium. Welfare gains are the percentage increase in consumption across the two equilibria. In table 3, I present some summary statistics of the welfare gains, the correlation between income level and the welfare gain, and statistics reflecting the dispersion in income for a 10 percent reduction and 100 percent reduction. Several points are of interest.

First, the welfare gains are large for all countries. For example, a 10 percent reduction in trade costs yields an an average gain of 3.6 percent. Relative to the welfare gains discussed throughout economics in general, this is not a trivial amount. For example, Lucas (2003) estimates the welfare gain from removing consumption risk in the U.S. economy to be 0.0005 percent.

Second, even more dramatic gains are possible, especially for poor countries. For example, the average welfare gain is 86 percent. The correlation between initial income level and welfare gain is -0.83 showing poor countries are gaining relatively more than rich countries. Ultimately, the gains from a 100 percent reduction in trade costs are large and hard to comprehend. However, they are a quantitative measure of the magnitude in which the allocation of production across countries is distorted.[10]

Some caveats are in order. Here, trade costs are modeled as “iceberg” costs to trade, not as tariffs

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[9] These effects can be seen in equation (10) as well. With no trade costs, low productivity countries specialize in a smaller set of goods for export relative to high productivity countries. Furthermore, with no trade costs, all countries purchases the same fraction of goods from each country. This implies that the fraction of goods purchased from home X_{ii} is smaller for low productivity countries relative to high productivity countries resulting in a decrease in cross-country income differences.

[10] At my web site http://myweb.uiowa.edu/mwaugh/Acoolmovie.htm, a graphical representation depicting how the pattern of trade changes when trade costs are removed, illustrates this point.

with income being rebated to agents in each country. Alvarez and Lucas (2005) considered the welfare implications when revenue from tariffs are rebated. In their calibration, they assumed the calibrated trade costs are multiplicative in each country's observed average tariff rate t_i and other barriers to trade b_{ij}, i.e. $\tau_{ij} = (1 + t_i)b_{ij}$. Setting $b_{ij} = 1.33$ for all countries, they removed the policy component and computed the average welfare gain to be 1.1%. Incorporating these effects in the model will dampen the welfare gains here as countries experience a loss in tariff revenue. However, the reduction in my calibration is starting from a point further away from free trade and there are more sources of heterogeneity across countries (in factors, technology, and trade costs). Both of these factors suggest the gains here should be larger than in Alvarez and Lucas (2005). Furthermore, though their results suggests a majority of the gains are outside of the policy realm, tariffs are not the only policy barriers restricting trade (see Anderson and van Wincoop (2004)) and this does not imply they are not achievable. Technological improvements in transportation, infrastructure, communication, etc. provide an avenue for their realization.

This observation may suggest the gains here are an upper bound, but there are other aspects not modeled which suggest the contrary. For example, I assumed final goods are not traded. Relaxing this assumption and allowing for trade in final goods should increase the gains by allowing countries more opportunities for specialization. An example of the additional welfare possibilities is Castro (2006). He studied this type of trade liberalization in a two good model with a large number of small open economies and found large average welfare gains.

A second point relates to factors. Allowing for changes in factors such as capital would enhance the analysis of these gains. Allowing for endogenous capital accumulation and analyzing the welfare gains across steady states is possible and was performed in previous versions of this paper.[11] However, incorporating the transition costs is necessary to tell the whole story, yet computational obstacles prevent the telling of it.

Though total factor productivity is endogenous, each country's average efficiency level was treated as invariant to changes in trade costs. In theory, there are a variety of ways that each country's average efficiency level may change in response to reductions in trade costs—either through the diffusion of technology as in Kortum (1997) and Eaton and Kortum (1999), the influence of increased competition on domestic producers as in Parente and Prescott (2002), or industry reallocations as in Melitz (2003). Future quantitative research along these lines will help clarify the most relevant channels through which countries gain from trade. However, the results here suggest large gains are available *only* from the simple reallocation of production across countries.

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[11] Depending on the size of the reduction, endogenous capital accumulation increased the welfare gains by 40 to 70 percent.

5 Conclusion

In a quantitative general equilibrium model of trade, I argued two 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. Second, by recovering efficiency differences and trade costs from the pattern of trade, I showed trade polices and trade costs are important for economic development as they distort the allocation of production across countries in a quantitatively meaningful way. Reductions in trade costs alleviate these distortions and allow poor countries to gain relatively via comparative advantage.

As the analysis here suggests, understanding how countries are quantitatively interrelated via trade is an important topic for continued research. First, understanding why poor countries do not take advantage of trade as a solution to their plight is an important question. Second, since the distribution of income depends on the general equilibrium allocation of production, understanding how capital is allocated across countries takes on a new dimension relative to closed-economy models. Understanding capital flows in a multi-country framework is an important topic for future quantitative models of international trade to take on. Finally, the results emphasize the need to understand cross-country differences in productivity. As the analysis here suggests, not only are they important to understanding income differences, but they are an important feature to understanding the pattern of trade.

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6 Appendix A: 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 (2005).

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

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

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:

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

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

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:

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

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

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

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 the each 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:

$$\begin{aligned} p_i^q &= \Upsilon \left\{ \sum_{j=1}^{N} [k_j^{-\alpha\beta} w_j^{\beta} (p_j^q)^{(1-\beta)} \tau_{ij}]^{\frac{-1}{\theta}} \lambda_j \right\}^{-\theta}, & (27) \\ \Upsilon &= \Omega S(\theta, \eta)^{\frac{1}{1-\eta}} \left(\frac{\alpha}{1-\alpha} \right)^{\alpha\beta}. & (28) \end{aligned}$$

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

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

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

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

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

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

7 Appendix B: Calibrating Technology and Trade Costs

In previous versions of this paper, I approached the recovery of each country's technology parameter and trade costs in a different manner described in this version. Specifically, I constructed and implemented an algorithm to select each country's technology parameter and trade costs for every country pair. Below, I describe the algorithm and then discusses issues and how the results compare with those in the paper.

7.1 Algorithm

The model's trade shares provide a convenient starting point: first, I can construct an empirical counterpart X_{ij} to the theoretical trade share M_{ij}. Second, equation (2) provides a mapping from observed trade shares to each country's technology parameter λ_i and trade costs τ_{ij} .

To illustrate this mapping, I first determine wages from observed bilateral trade shares X_{ij}, each country's labor endowment, and the empirical counterpart to equation (3):

$$w_i \quad = \quad \left(\sum_{j=1}^{N} \frac{L_j}{L_i} w_j X_{ji} \right) \quad \text{or} \quad g(w; \mathbf{X}) = w, \tag{32}$$

in which expression (32) is written parsimoniously as a fixed-point problem conditioned on the observed bilateral trade share matrix denoted as $\mathbf{X}$. Wages, in combination with aggregate capital to labor ratios, pin down each country's cost structure.

The remaining unknown parameters are N λ_is and $(N^2 - N)$ τ_{ij}s (since $\tau_{ii} = 1$) that yield N^2 trade shares from the model, M_{ij}, consistent with the data, X_{ij}. With a large number of countries, this seems to be a daunting task requiring a solution to a system of N^2 non-linear equations for N^2 unknowns. However, with some manipulation of (2), this reduces to solving a large fixed-point problem.

Re-arranging the empirical counterpart of (2) and using (1) yields:

$$X_{ii} \quad = \quad \frac{\left[k_i^{-\alpha\beta} w_i(\mathbf{X})^{\beta} p_i^q(\lambda, \tau; \mathbf{X}, k)^{(1-\beta)} \right]^{\frac{-1}{\theta}} \lambda_i}{p_i^q(\lambda, \tau; \mathbf{X}, k)^{\frac{-1}{\theta}} \Psi}, \tag{33}$$

$$X_{ij} \quad = \quad \frac{\left[k_j^{-\alpha\beta} w_j(\mathbf{X})^{\beta} p_j^q(\lambda, \tau; \mathbf{X}, k)^{(1-\beta)} \tau_{ij} \right]^{\frac{-1}{\theta}} \lambda_j}{p_i^q(\lambda, \tau; \mathbf{X}, k)^{\frac{-1}{\theta}} \Psi}, \tag{34}$$

in which wages, w_i, depend only on $\mathbf{X}$ and p_i^q's dependence on λ, τ, given $\mathbf{X}$ and k is noted. Ψ is a collection of constants. Further manipulation of (33) and (34) yields the following system of equations:

$$X_{ii} \left[\frac{k_i^{-\alpha} w_i(\mathbf{X})}{p_i^q(\lambda, \tau; \mathbf{X}, k)} \right]^{\frac{\beta}{\theta}} \Psi = \lambda_i, \quad \forall i = 1...N, \tag{35}$$

$$X_{ij}^{-\theta} \left[\frac{k_j^{-\alpha\beta} w_j(\mathbf{X})^{\beta} p_j^q(\lambda, \tau; \mathbf{X}, k)^{1-\beta}}{p_i^q(\lambda, \tau; \mathbf{X}, k)} \right]^{-1} \Psi^{-\theta} \lambda_j^{\theta} = \tau_{ij}, \quad \forall i, j; j \neq i. \tag{36}$$

The system expressed as a fixed-point problem is:

$$f(\lambda, \tau; \mathbf{X}, k) = \lambda, \tag{37}$$

$$h(\lambda, \tau; \mathbf{X}, k) = \tau. \tag{38}$$

The theoretical model presented in section 1 is now expressed as a mapping from the pattern of trade to a country's technology parameter and trade costs. Specifically, with data on bilateral trade shares and labor endowments, I compute an equilibrium wage vector from (32). Then, with aggregate capital to labor ratios, trade shares, and parameters common to all countries, I compute each country's technology level λ_i and trade costs τ_{ij}s by the fixed-point problem implied by (37) and (38).

7.2 Issues and Results Comparisons

As pointed out to me by Sam Kortum, the principal issue with the algorithm outlined above is that the solution it generates it not unique. That is there are other combinations of λ_i and τ_{ij} which can rationalize the bilateral trade data. Hence, all that can be said from these results is that these are the parameters—contingent on the algorithm described above. Other algorithms and other approaches might generate results that fit the bilateral trade data equally well.

However, there are ways to evaluate the parameters the algorithm generates. For instance, in in equation (10) it is clear that different λ_is imply different implications for cross-country income differences in the model. Hence, if the algorithm generates cross-country income differences consistent with the data, then one can conclude that these parameters are reasonable.

In previous versions of this paper, the model was generating cross-county income differences consistent with the data. For example, the variance in log income from the model is 1.16 and the 95/5 percentile ratio 30. In the data, the variance of log income is 1.38 and the 95/5 percentile ratio is 30 as well. On this basis, one can say that the algorithm is generating reasonable parameters.

Ultimately, both the method in the paper and the algorithm are generating similar results. Both replicate cross-country income differences well and generate similar impacts from reductions in barriers to trade on cross-country income differences.

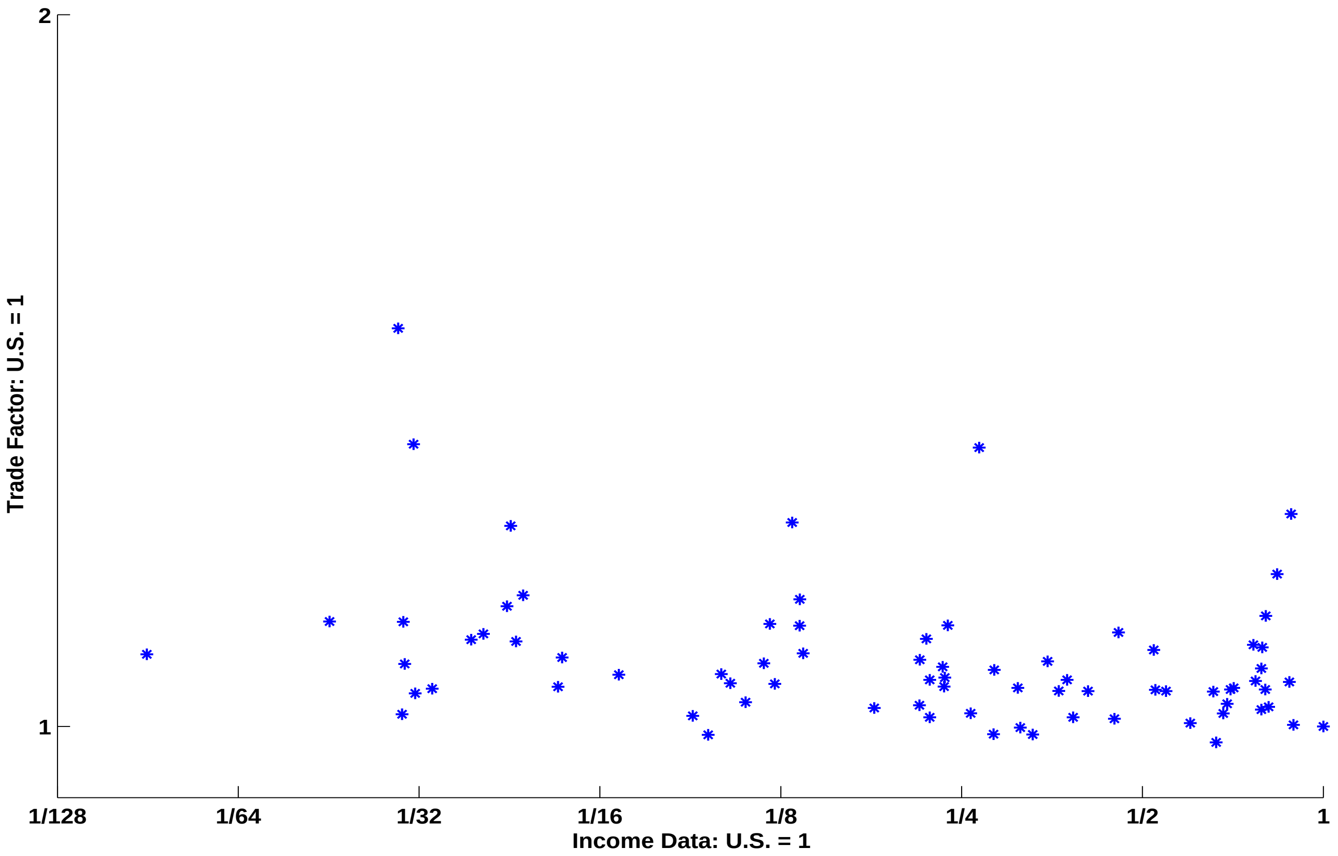

Figure 1: Trade Factors versus Income Data

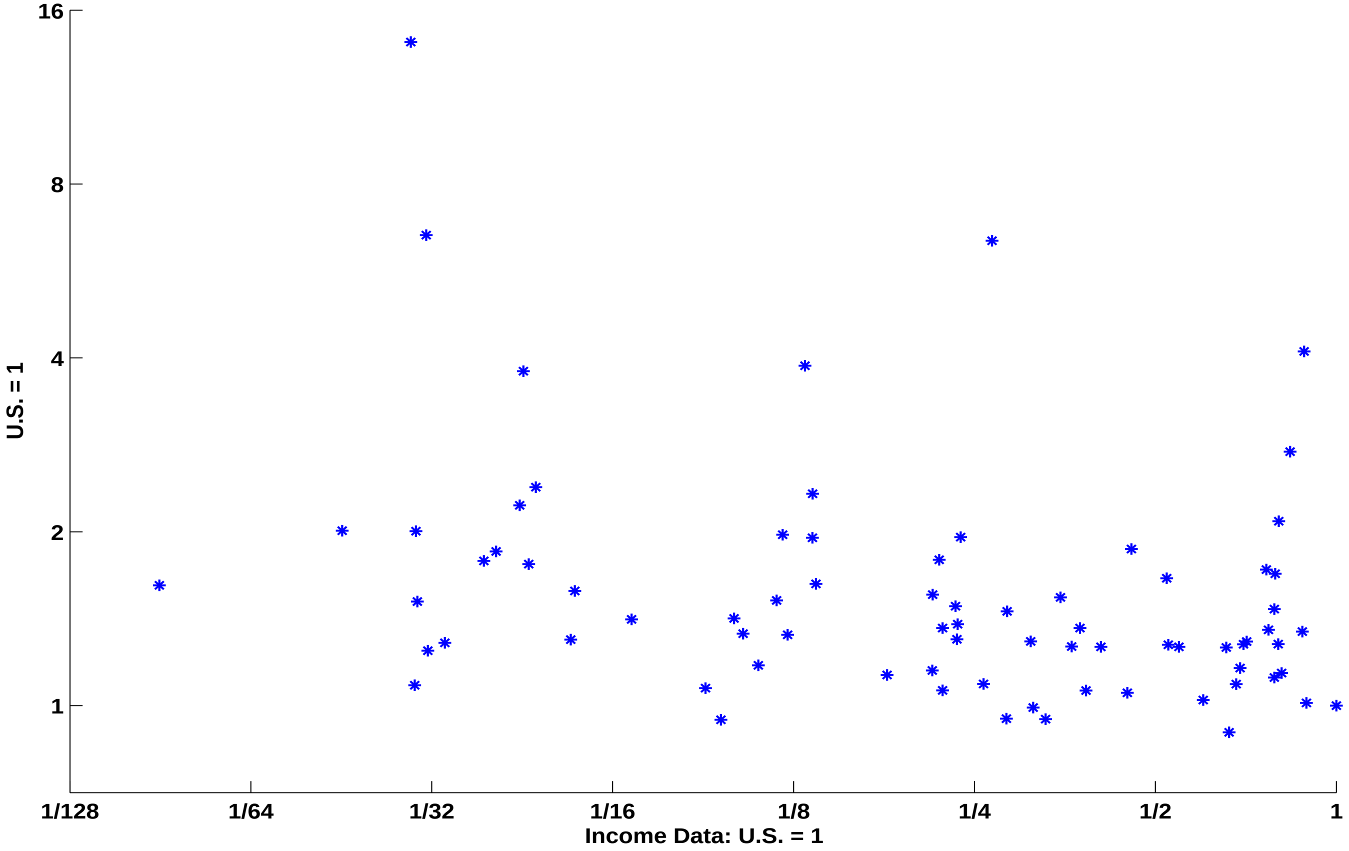

Figure 2: Home Trade Shares versus Income Data

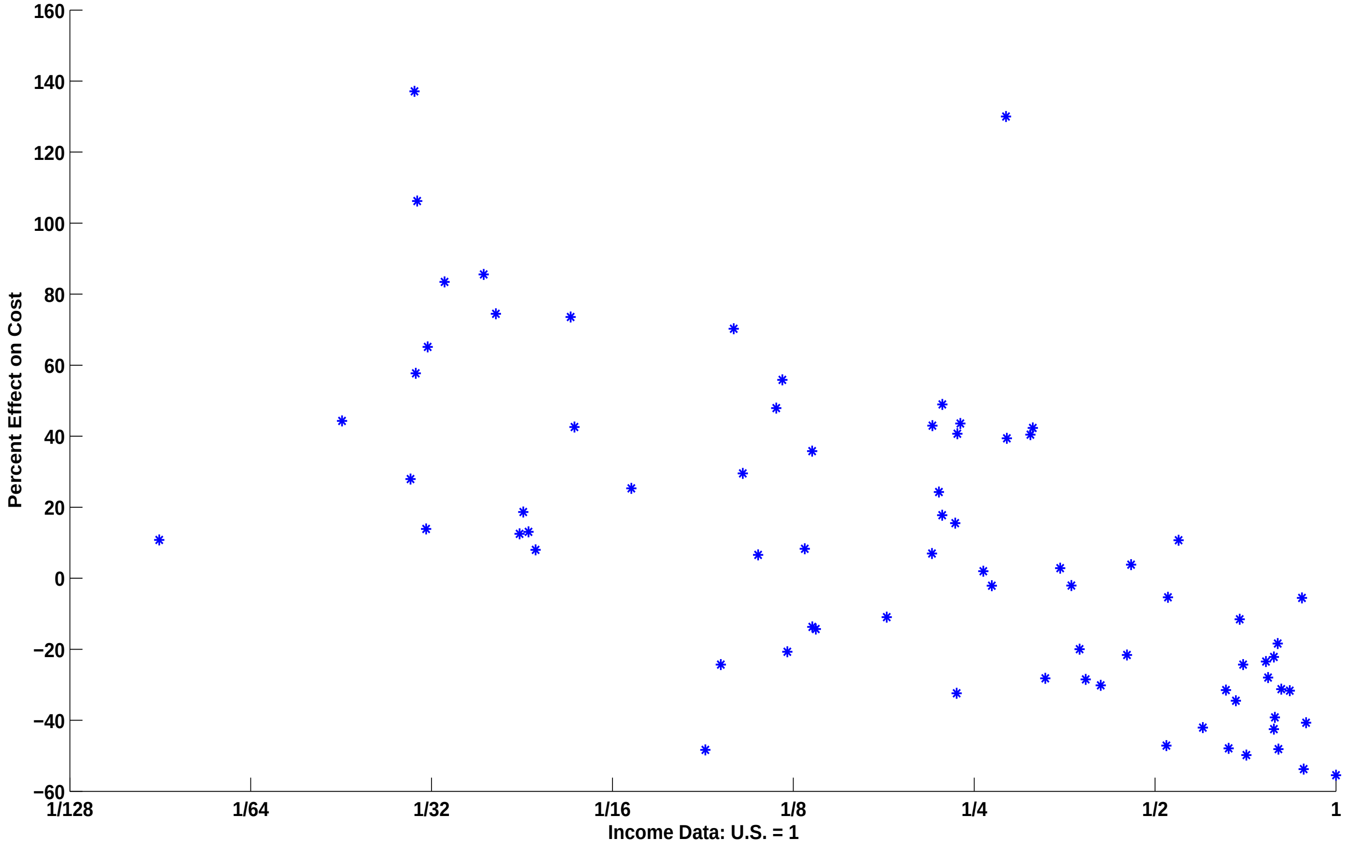

Figure 3: Arrival Effect, Percent Effect on Cost

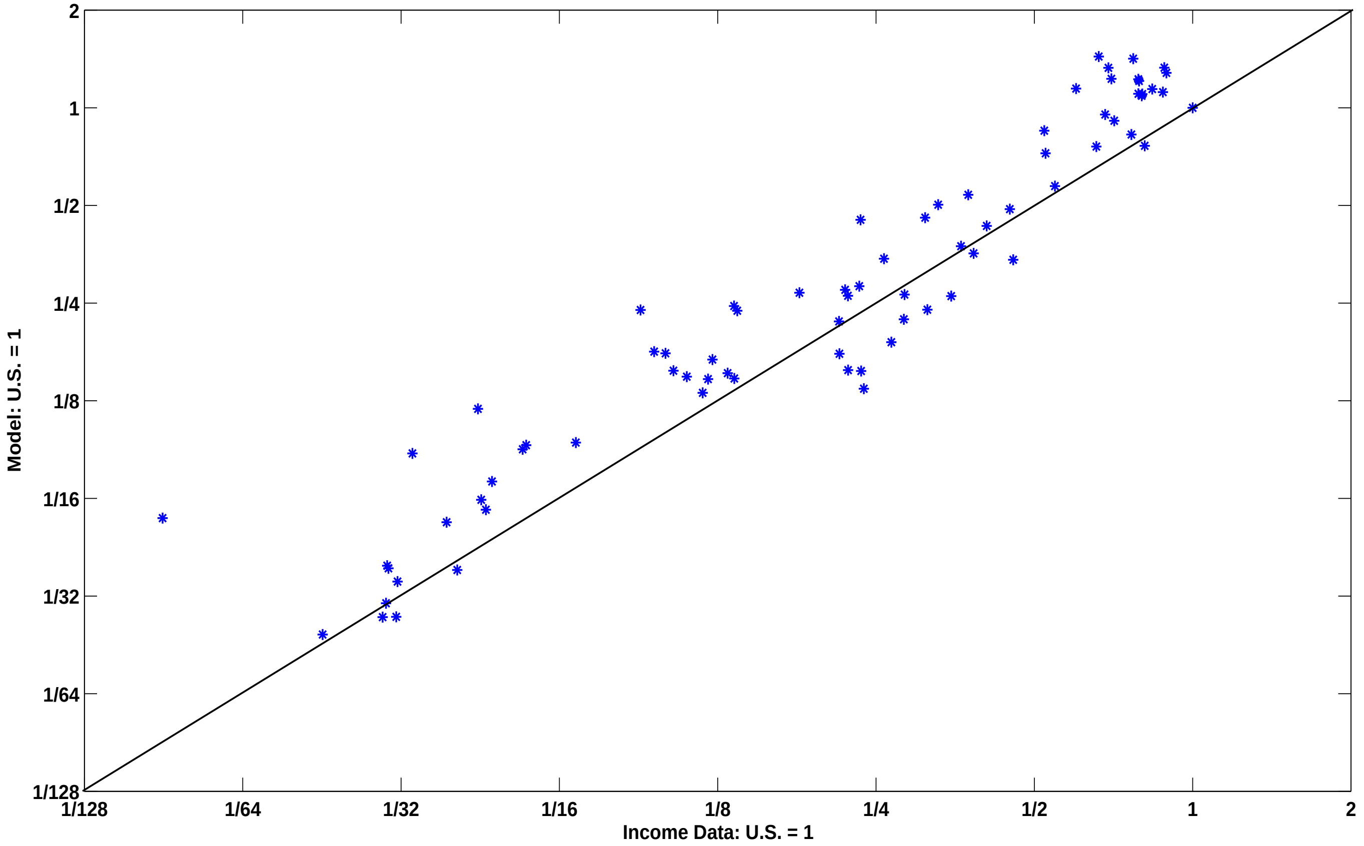

Figure 4: Income: Data and Model

Table 4: 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 4: 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 the U.S. income per-worker relative to country *i*'s income per-worker, the relative labor endowments between country *i* and the U.S., 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 5: Trade Shares X_{ij} for Selected Countries

Country	U.S.	Italy	Can.	Fr.	U.K.	Japan	Arg.	Mexico	India	China	Malawi	Niger	Zaire
U.S.	83.25	1.22	39.73	2.36	5.47	2.27	5.10	31.62	1.61	3.63	1.57	12.03	2.93
Italy	0.51	82.36	0.65	4.28	2.81	0.22	1.56	0.49	0.43	1.08	1.23	2.74	2.28
Canada	3.78	0.13	49.21	0.18	0.44	0.21	0.27	0.72	0.12	0.32	0.67	4.22	0.51
France	0.46	3.76	0.72	74.41	4.49	0.20	1.28	0.50	0.39	0.83	0.71	38.46	2.48
U.K.	0.72	1.96	0.96	3.14	64.47	0.24	0.53	0.32	1.33	0.93	4.49	2.60	1.32
Japan	3.04	0.55	2.01	0.95	2.23	92.56	0.58	1.59	1.19	6.99	2.65	2.83	0.82
Argentina	0.03	0.10	0.03	0.04	0.04	0.01	79.09	0.11	0.11	0.11	0.006	0.003	0.10
Mexico	1.88	0.03	1.33	0.05	0.06	0.02	0.62	61.09	0.02	0.057	0	0	0.007
India	0.16	0.13	0.12	0.10	0.32	0.06	0.07	0.04	88.04	0.32	2.30	3.06	1.65
China	1.78	0.55	1.41	0.71	1.64	1.44	0.79	0.30	0.75	77.61	2.50	6.40	6.81
Malawi	0*	0*	0*	0*	0*	0*	0	0	0	0	41.52	0	0
Niger	0*	0*	0.004	0.001	0*	0*	0	0	0	0	0	5.90	0
Zaire	0.003	0.002	0.005	0.001	0.003	0.003	0.0007	0.0002	0.02	0.0003	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 all manufacturing goods country j purchased from country i.

Table 5: Summary Statistics

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

Table 6: Geographic Barriers, $\theta = 0.15$

Barrier	Parameter Estimate	S.E.	%effect on cost
$[0, 375)$	-4.66	0.21	101.1
$[375, 750)$	-5.60	0.13	131.9
$[750, 1500)$	-6.16	0.08	151.9
$[1500, 3000)$	-7.22	0.06	195.2
$[3000, 6000)$	-8.44	0.04	254.8
$[6000, \text{maximum}]$	-9.37	0.04	308.1
Shared Border	0.69	0.16	-10.8
Arrival Country			
United States	5.40	0.23	-55.5
Argentina	1.62	0.25	-22.0
Australia	2.50	0.24	-31.2
Austria	1.35	0.24	-18.4
Belgium	5.13	0.23	-53.7
Benin	-3.71	0.39	74.5
Bangladesh	-0.43	0.26	6.58
Bolivia	-2.61	0.30	47.9
Brazil	2.21	0.25	-28.2
Central African Republic	-4.04	0.50	83.4
Canada	3.32	0.24	-39.2
Switzerland	2.19	0.24	-28.0
Chile	2.40	0.25	-30.1
China-Hong Kong	4.40	0.24	-48.3
Cameroon	-1.50	0.30	25.3
Colombia	-0.45	0.26	6.97
Costa Rica	-0.96	0.29	15.5
Denmark	1.67	0.23	-22.1
Dominican Republic	-1.45	0.28	24.3
Ecuador	-1.09	0.29	17.7
Egypt	-2.66	0.27	48.9
Spain	2.82	0.24	-34.5
Ethiopia	-2.45	0.32	44.3
Finland	0.82	0.24	-11.5
France	3.69	0.24	-42.5
United Kingdom	4.60	0.23	-49.8
Ghana	-0.51	0.33	8.00
Greece	-0.68	0.24	10.7
Guatemala	-2.28	0.29	40.7
Honduras	-2.96	0.33	55.8
India	1.86	0.24	-24.3

Table 6 Contd.

Arrival Country	Parameter Estimate	S.E.	% effect on cost
Ireland	2.54	0.24	−31.7
Iran	−2.35	0.32	42.3
Israel	1.78	0.26	−23.4
Italy	3.48	0.24	−40.7
Jamaica	−2.04	0.31	35.8
Jordan	−2.22	0.32	39.4
Japan	4.35	0.23	−47.9
Kenya	−0.82	0.26	13.1
Republic of Korea	3.64	0.24	−42.0
Sri Lanka	0.98	0.30	−13.7
Mexico	1.49	0.25	−20.0
Mali	−4.83	0.37	106
Mozambique	−0.87	0.36	13.9
Mauritius	−0.26	0.28	3.84
Malawi	−3.04	0.36	57.7
Malaysia-Singapore	4.25	0.24	−47.1
Niger	−1.64	0.38	27.9
Nicaragua	−3.55	0.33	70.2
Netherlands	4.38	0.23	−48.1
Norway	0.38	0.24	−5.55
Nepal	−3.68	0.34	73.6
New Zealand	2.52	0.26	−31.5
Pakistan	1.55	0.23	−20.7
Panama	0.14	0.30	−2.11
Peru	0.77	0.28	−11.0
Philippines	1.03	0.26	−14.3
Papua New Guinea	−0.53	0.37	8.30
Portugal	0.37	0.24	−5.38
Paraguay	−2.38	0.30	43.0
Rwanda	−5.76	0.42	137
Senegal	−2.37	0.33	42.6
Sierra Leone	−1.14	0.38	18.6
El Salvador	−2.41	0.31	43.6
Sweden	1.86	0.24	−24.3
Syrian Arab Republic	−5.55	0.30	130
Togo	−4.12	0.35	86.5
Thailand	2.61	0.26	−32.4
Tunisia	−2.26	0.28	40.4
Turkey	−0.13	0.25	1.98
Uganda	−3.35	0.35	65.2
Uruguay	0.14	0.28	−2.07
Venezuela	−0.19	0.28	2.82
South Africa	2.24	0.25	−28.5
Zaire (DRC)	−0.68	0.33	10.8
Zambia	−0.79	0.34	12.5
Zimbabwe	−1.73	0.28	29.5

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

Table 7: Technology, λ_i

Country	$\hat{S}_i$	S.E.	$\left(\frac{\lambda_{us}}{\lambda_i}\right)^{\theta}$
United States	0.54	0.17	1.00
Argentina	0.69	0.18	1.85
Australia	0.11	0.18	1.45
Austria	0.77	0.17	0.96
Belgium	-1.55	0.17	1.12
Benin	-0.25	0.22	18.20
Bangladesh	0.54	0.21	3.95
Bolivia	-0.09	0.20	5.13
Brazil	1.27	0.18	1.53
Central African Republic	0.33	0.24	4.73
Canada	0.11	0.16	1.04
Switzerland	0.75	0.17	0.74
Chile	-0.39	0.17	1.96
China-Hong Kong	0.76	0.17	2.30
Cameroon	-0.43	0.20	6.44
Colombia	0.63	0.20	3.47
Costa Rica	0.01	0.20	3.01
Denmark	0.81	0.17	0.90
Dominican Republic	-0.49	0.20	2.53
Ecuador	0.06	0.19	3.43
Egypt	1.17	0.18	4.20
Spain	0.53	0.16	1.05
Ethiopia	-1.15	0.22	21.0
Finland	1.39	0.16	0.65
France	0.68	0.16	0.85
United Kingdom	-0.08	0.17	1.11
Ghana	-1.50	0.22	7.69
Greece	0.75	0.17	1.99
Guatemala	-0.03	0.19	5.19
Honduras	-0.46	0.19	5.31
India	1.24	0.18	2.87
Ireland	-0.33	0.17	0.84
Iran	1.20	0.23	4.46
Israel	-0.01	0.20	1.30
Italy	0.85	0.16	0.74
Jamaica	-0.50	0.19	3.22
Jordan	-0.01	0.22	3.53
Japan	1.44	0.17	0.58
Kenya	-0.58	0.18	11.0
Republic of Korea	1.00	0.17	0.77
Sri Lanka	-1.48	0.22	5.18
Mexico	0.76	0.17	1.50
Mali	0.08	0.23	16.1
Mozambique	-2.32	0.23	20.1
Mauritius	-1.04	0.20	2.53

Table 7: Technology, λ_i contd.

Country	$\hat{S}_i$	S.E.	$\left(\frac{\lambda_{us}}{\lambda_i}\right)^{\theta}$
Malawi	-0.71	0.23	16.9
Malaysia-Singapore	-0.33	0.17	1.00
Niger	-2.94	0.23	34.5
Nicaragua	0.09	0.20	3.89
Netherlands	-0.75	0.17	1.13
Norway	0.92	0.17	0.99
Nepal	0.62	0.23	7.38
New Zealand	-0.27	0.19	1.34
Pakistan	-0.01	0.18	3.86
Panama	-1.71	0.20	7.88
Peru	-0.08	0.20	3.13
Philippines	-0.12	0.18	2.88
Papua New Guinea	-1.51	0.24	4.75
Portugal	0.61	0.18	1.26
Paraguay	0.26	0.20	4.86
Rwanda	0.24	0.24	18.7
Senegal	-0.36	0.22	5.33
Sierra Leone	-2.01	0.25	7.83
El Salvador	-0.64	0.20	6.52
Sweden	1.07	0.17	0.69
Syrian Arab Republic	1.75	0.21	3.50
Togo	-0.49	0.22	11.5
Thailand	0.15	0.18	1.90
Tunisia	1.29	0.21	1.47
Turkey	1.23	0.18	2.27
Uganda	-0.27	0.24	9.38
Uruguay	-0.31	0.20	2.23
Venezuela	-0.16	0.19	4.35
South Africa	0.16	0.17	2.23
Zaire (DRC)	-0.57	0.22	5.99
Zambia	-1.05	0.23	5.07
Zimbabwe	0.14	0.19	4.92

Note: Technology parameters, λ_i, are recovered as detailed in section 3.2 and $\theta = 0.15$.