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International trade and cross-country capital composition

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INTERNATIONAL TRADE AND CROSS-COUNTRY CAPITAL COMPOSITION

by

Piyusha Mutreja

An Abstract

Of a thesis submitted in partial fulfillment of the
requirements for the Doctor of Philosophy
degree in Economics
in the Graduate College of
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Thesis Supervisor: Professor B. Ravikumar

ABSTRACT

Most of the world's equipment is produced in a small number of rich countries. In 1996, countries in the top decile of cross-country income distribution produced 61% of world equipment and countries in the bottom decile produced only 0.2%. Rich and poor countries also differ in their dependence on imports for equipment. In 1996, poor countries imported more than half of their equipment. Structures, on the other hand, are largely domestically produced. World pattern of production and trade in equipment and structures is potentially an important determinant of composition of capital across countries.

The composition of capital differs significantly across rich and poor countries. In 1996, equipment constituted over 21% of the capital in 5 richest countries and only 8% in 5 poorest countries. While equipment capital-output ratio was a factor of more than 6 between rich and poor countries, structures capital-output ratio was less than a factor of 2. In this dissertation, I determine the quantitative relationship between international trade and cross-country capital composition. I, then, utilize the results on this relationship to examine the implications for economic development.

The starting point of my analysis is a multi-country model of trade in capital goods. There are three tradable sectors: equipment, structures and intermediate goods. Countries differ in their average level of productivity in each of the tradable sectors. International trade is subject to bilateral iceberg costs, which comprise of tariff and non-tariff barriers to trade. The theoretical model implies that the composition of capital is a function of country-specific productivity parameters and bilateral trade costs. I structurally estimate these parameters to match the pattern of bilateral trade in a sample of 76 countries.

Equipped with country specific productivity parameters and trade costs, I determine the quantitative relationship between international trade and cross-country capital composition. The calibrated model generates capital composition differences consistent with the data. Variation in log equipment to output ratio is 1.09 in data and 1.26 in the model. The model also generates cross-country differences in investment rate, income per worker and prices consistent with the data.

Through counterfactual exercises, I study the gains associated with reductions in trade costs. If all trade costs are eliminated, poor countries' welfare would increase by 39% and rich countries' welfare would increase by only 8%. If barriers only to equipment trade are eliminated, poor countries' welfare gain would be 9% and rich countries' welfare gain would be 1.4%. Reductions in barriers to flow of capital goods facilitate a more efficient allocation of the world stock of capital goods across countries and hence, are quantitatively important for economic development.

Abstract Approved: ______________________________

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee for the thesis requirement for the Doctor of Philosophy degree in Economics at the July 2010 graduation.

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To my parents and my husband.
I love you!

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ABSTRACT

Most of the world's equipment is produced in a small number of rich countries. In 1996, countries in the top decile of cross-country income distribution produced 61% of world equipment and countries in the bottom decile produced only 0.2%. Rich and poor countries also differ in their dependence on imports for equipment. In 1996, poor countries imported more than half of their equipment. Structures, on the other hand, are largely domestically produced. World pattern of production and trade in equipment and structures is potentially an important determinant of composition of capital across countries.

The composition of capital differs significantly across rich and poor countries. In 1996, equipment constituted over 21% of the capital in 5 richest countries and only 8% in 5 poorest countries. While equipment capital-output ratio was a factor of more than 6 between rich and poor countries, structures capital-output ratio was less than a factor of 2. In this dissertation, I determine the quantitative relationship between international trade and cross-country capital composition. I, then, utilize the results on this relationship to examine the implications for economic development.

The starting point of my analysis is a multi-country model of trade in capital goods. There are three tradable sectors: equipment, structures and intermediate goods. Countries differ in their average level of productivity in each of the tradable sectors. International trade is subject to bilateral iceberg costs, which comprise of tariff and non-tariff barriers to trade. The theoretical model implies that the composition of capital is a function of country-specific productivity parameters and bilateral

trade costs. I structurally estimate these parameters to match the pattern of bilateral trade in a sample of 76 countries.

Equipped with country specific productivity parameters and trade costs, I determine the quantitative relationship between international trade and cross-country capital composition. The calibrated model generates capital composition differences consistent with the data. Variation in log equipment to output ratio is 1.09 in data and 1.26 in the model. The model also generates cross-country differences in investment rate, income per worker and prices consistent with the data.

Through counterfactual exercises, I study the gains associated with reductions in trade costs. If all trade costs are eliminated, poor countries' welfare would increase by 39% and rich countries' welfare would increase by only 8%. If barriers only to equipment trade are eliminated, poor countries' welfare gain would be 9% and rich countries' welfare gain would be 1.4%. Reductions in barriers to flow of capital goods facilitate a more efficient allocation of the world stock of capital goods across countries and hence, are quantitatively important for economic development.

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CHAPTER 1
INTRODUCTION

Most of the world's equipment is produced in a small number of rich countries. In 1996, countries in the top decile of cross-country income distribution produced 61.4% of world equipment and countries in the bottom decile produced only 0.2%. Rich and poor countries also differ significantly in their dependence on imports for equipment. In 1996, poor countries imported more than half of their equipment. For instance, Nigeria imported 76% of its equipment and Japan imported less than 6% of its equipment. Moreover, in the same year, the share of equipment in total imports was over 25% for poor countries and 10% for rich countries (see figures A.1 and A.2 in the Appendix). Hence, the composition of poor countries' total imports is also biased towards equipment relative to rich countries. Structures on the other hand, are largely domestically produced. Nigeria and Japan respectively produced 73% and 98% of their structures. World pattern of production and trade in equipment and structures is potentially an important determinant of the composition of capital across countries.

While it has been documented in the literature that aggregate capital-output ratio is positively correlated with economic development (Hall and Jones (1999); Caselli (2005)), the capital composition is also systematically different across countries. The equipment capital-output ratio between rich and poor countries differs by a factor of 6.3 and structures capital-output ratio differs only by a factor of 1.8. Figure A.3 plots equipment share of capital stock with income per worker. Equipment comprises over 21% of the capital in 5 richest countries and only 8% in 5 poorest countries.

According to a standard development accounting exercise, variation in physical capital accounts for approximately 37% of income differences across countries. If we decompose the physical capital into equipment capital and structures capital, and conduct a standard development accounting exercise, equipment capital accounts for 26% of the observed variation in income, while structures capital accounts for 11%.[1] To put it differently, according to this simple accounting exercise, if all countries had the same equipment capital-output ratio as that of the US, the resulting cross-country variation in income would reduce by 22%. If instead all countries had same structures capital-output ratio as the US, cross-country income variation would reduce by only 7%.

In this dissertation, I ask and answer the following questions: What is the quantitative relationship between international trade in capital goods and the cross-country capital composition? What are the resulting quantitative implications for economic development?

To answer these questions, I construct a multi-country model of trade. Each country has three tradable sectors: equipment, structures and intermediate goods, all with constant returns technologies. Each tradable sector has a continuum of goods. Similar to Dornbusch, Fischer, and Samuelson (1977), production technologies differ

[1] For the purpose of this development accounting exercise, I assume a unitary elasticity of substitution between equipment and structures, i.e., $y = Ak_e^{\alpha_e} k_s^{\alpha_s} h^{1-\alpha_e-\alpha_s}$. y is output, A is TFP, k_e is equipment capital, k_s is structures capital and h denotes human capital. All variables are in per-worker terms except TFP. Following Krusell, Ohanian, Rios-Rull and Violante (2000), I set $\alpha_s = 0.117$, so $\alpha_e = 0.216$.

across the continuum in the idiosyncratic productivity level. As in Eaton and Kortum (2002), I parameterize the productivity levels with Type II extreme value distributions, which are independent across countries and across tradable goods. Countries differ in their average level of productivity for each of the tradable goods. International trade is subject to bilateral iceberg costs. Each country also has a final goods sector, which produces a homogeneous non-tradable good with constant returns technology common to all countries.

The theoretical model allows capital goods to flow across countries and so, the equipment capital and structures capital stocks are determined endogenously. Labor is, thus, the only factor of production that is immobile across countries. Within the realms of the model, the pattern of capital goods trade affects capital accumulation in each country. The equipment share of capital stock in a country is a function of the country specific productivity parameters and the pattern of bilateral trade. This theoretical relationship enables me to determine the quantitative relationship between capital goods trade and the capital composition differences. The model also implies that a country's income per worker relative to US can be expressed as a function of its equipment capital-output ratio, structures capital-output ratio and a total factor productivity (TFP) term, all relative to US. The TFP term is a function of exogenous productivity parameters and an endogenous trade term. Thus, TFP is partially *endogenous* in the model.

To quantify the model, I use a structural relationship implied by the model that connects productivity parameters and trade costs to the bilateral pattern of trade.

I specify the trade costs parsimoniously as a function of distance, shared border, language and an exporter effect. Incorporating this specification into the structural relationship, I recover the productivity parameters and trade costs for equipment, structures and intermediate goods from the bilateral trade data for a sample of 76 countries. My model fits the data on bilateral trade volumes well: the R^2 is 84% for equipment, 73% for structures and 76% for intermediate goods.

I examine the quantitative implications of the model for certain aspects of the data that I did not use to calibrate the model. Specifically, I focus on the implications for capital composition, economic development and price of capital goods. First, my model generates over 80% of the observed cross-country variation in equipment share of capital. The model also generates equipment capital-output ratio and structures capital-output ratio consistent with the data.

Second, my model matches well the data on per worker income. It generates 76% of the observed cross-country variation in income per worker. The trade factor accounts for over 26% of the variation in the relative TFP differences. Third, the calibrated model accounts for 68% of the observed variation in aggregate investment rate across countries.

Finally, my model also produces prices consistent with the data. Trade barriers affect the prices of both equipment and structures in my model. The observed cross-country variation in price of equipment is almost zero. My model implies that the elasticity of price of equipment with respect to per worker income is approximately -0.09. The income elasticity of price of structures, on the other hand, is 0.29 in the data and 0.19 in the model. Price of capital goods relative to consumption, as pointed out by Hsieh and Klenow (2007), exhibits a strong negative correlation with income per worker. The income elasticity of price of equipment relative to consumption is -2.1 in the data and -2.8 in the model. The corresponding elasticity for structures is -4.4 in the data and -5.2 in the model.

I conduct several counterfactual exercises by adjusting trade costs to examine the quantitative implications of capital goods trade for cross-country capital composition and economic development. In the first counterfactual exercise, I shut down trade. This increases the cross-country variation in equipment capital-output ratio. The income differences increase by up to 17% and the welfare costs for poor countries are large at 13%.

I also assess implications of reductions in trade barriers for capital composition and economic development. Reductions in trade barriers reduce cross-country differences in capital composition and result in significant welfare gains. In an experiment, I eliminate barriers to equipment trade. In this counterfactual world, the variance of log of equipment capital-output ratio would decline by 11%. The welfare gain experienced by poor countries is 9% while the overall gain in world welfare is 3%. In another experiment, I eliminate all trade barriers. Here, the variance of log equipment capital-output ratio declines by 28% and poor countries' welfare increases by 34%. Since trade determines equipment flow to poor countries, distortions in the world trading system affect equipment share of capital in poor countries. If there were a central planner who efficiently allocated capital goods production and usage across countries, then she would allocate production to countries most efficient in producing capital goods and distribute the capital goods to the other countries. Eliminating trade barriers essentially accomplishes this in a decentralized manner, by facilitating an efficient allocation of world stock of capital across countries. My results demonstrate that barriers to capital goods trade are quantitatively important for economic development.

1.1 Literature

Relative to recent research by Eaton and Kortum (2001), the key distinctions are the question that I address and the quantitative results implied by my model. Eaton and Kortum (2001) model trade in equipment only and focus on the price of equipment and cross-country productivity differences. I model trade in equipment and structures and study the effect on capital composition, price of equipment and structures, and productivity differences across countries. As in Eaton and Kortum (2001), trade costs in my model are reflected in the price of capital goods. As Hsieh and Klenow (2007) criticize, the results in Eaton and Kortum (2001) are inconsistent with the fact that absolute price of investment shows little variation across countries. For the sample of countries in Eaton and Kortum (2001), the income elasticity of price of equipment in the data is 0.04. While Eaton and Kortum (2001) price estimates imply an elasticity of -1.6, my price estimates have an income elasticity of only 0.05. Further, Eaton and Kortum (2001) focus on a sample 34 countries which are mostly rich OECD countries. My sample of countries is larger and more suited to a study economic development questions as 15 out of 76 countries are in the lowest quartile of the world income distribution. I use equilibrium conditions in the model and show that there are considerable gains to poor countries associated with changes in the world trading system.

This dissertation also relates with the segment of literature studying relationship between international trade and economic development. Most studies in this segment have focussed on the statistical relationship between volume of international trade and income levels. However, the results from these studies are subject to Lucas Critique owing to the endogeneity of income and pattern of trade. Relative to recent quantitative models of international trade such as Alvarez and Lucas (2004) and Waugh (2009), I develop a three sector trade model which allows for trade in both equipment and structures. While in Waugh (2009) trade is not important in accounting for income differences, according to my calibrated model, international trade accounts for 19% of income differences across countries. Also, significant welfare gains are associated with reductions in trade barriers. The gains from Alvarez and Lucas (2004) are small while in my setup, poor countries gain up to 34% when all barriers to trade are eliminated.

This dissertation has four chapters. Chapter 2 describes the theoretical model and an equilibrium. Chapter 3 presents a description of the calibration methodology, the data and the quantitative implications of the calibrated model. Chapter 4 presents results from counterfactual exercises and sensitivity analyses.

CHAPTER 2
MODEL

There are N countries in the world economy. Each country has three tradable sectors: equipment, structures and intermediate goods; and a non-tradable final good sector. Within each country i, there is a measure of consumers L_i. Each consumer has one unit of time, which is supplied inelastically in the domestic labor market. Equipment capital, structures capital and labor are used to produce the flow of equipment goods, structures, intermediate goods and the final good. In short, my model augments the static trade model in Waugh (2009) to three sectors and allows for trade in equipment and structures in addition to trade in intermediate goods. Thus, labor is the only factor that is immobile across countries. In the following, all variables for country i are normalized relative to workforce in country i, L_i.

2.1 Production Technology for Tradable Goods

As in Dornbusch, Fischer, and Samuelson (1977), there is a continuum of goods within each tradable sector indexed by $x^J \in [0,1]$, where $J = E, S, M$ denotes equipment, structures and intermediate goods sector. In country i, equipment capital k_i^E, structures capital k_i^S, labor l_i and aggregate tradable good Q_i^J are combined by the following nested Cobb-Douglas production function to produce quantity $q_i^J(x^J)$ of the good x^J:

$$q_i^J(x^J) = z_i^J(x^J)^{-\theta} \left(\left[\mu {k_i^E}^{\frac{\sigma-1}{\sigma}} + (1-\mu) {k_i^S}^{\frac{\sigma-1}{\sigma}} \right]^{\left(\frac{\sigma}{\sigma-1}\right)\alpha} l_i^{1-\alpha} \right)^{\beta^J} {Q_i^J}^{1-\beta^J}$$

Across goods x^J, production technology within a tradable sector differs only in idiosyncratic productivity level $z_i^J(x^J)^{-\theta}$. Power terms α, β^J, σ and θ, and share μ are common to all countries. All firms in country i have access to the technology for good x^J with idiosyncratic productivity level $(z_i^J)^{-\theta}$.

The aggregate tradable good Q_i^J is produced by aggregating individual tradable goods within each tradable sector J according to a standard Dixit-Stiglitz technology with elasticity of substitution $\eta > 0$.

$$Q_i^J = \left[\int_0^1 q_i^J(x^J)^{\frac{\eta-1}{\eta}} dx^J\right]^{\frac{\eta}{\eta-1}}$$

2.2 Distribution of Productivity Levels

Following Eaton and Kortum (2002), I assume that the idiosyncratic productivities in each tradable sector are realizations of a random variable z_i^J. As in Alvarez and Lucas (2004), I assume that z_i^J is distributed independently and exponentially with parameter λ_i^J, which differs across countries and sectors.

Under this distributional assumption, $(z_i^J)^{-\theta}$ follows a Fréchet distribution. For each country, the mean of this distribution is proportional to $(\lambda_i^J)^\theta$ and θ is the coefficient of variation. A country with a higher λ_i^J, on average, can produce the goods in sector J more efficiently. In this respect, λ_i^J governs absolute advantage in tradable sector J. Parameter θ controls the dispersion of productivity levels around the mean. A larger θ implies that there is more variation relative to the mean. As Eaton and Kortum (2002) point out, θ controls the degree of comparative advantage. Intuitively, a larger θ implies more heterogeneity in productivity levels and hence the gains from trade would be larger. Figures A.4 and A.5 plot the the efficiency distribution for several values of θ and λ.

Given above structure, without loss of generality, each good x^J may be relabeled by its productivity level, z_i^J. Thus, the aggregate tradable good in sector J can be written as:

$$Q_i^J = \left[\int_0^1 q_i^J(z_i^J)^{\frac{\eta-1}{\eta}} \psi^J(z_i^J) dz^J\right]^{\frac{\eta}{\eta-1}}$$

where ψ^J is the joint density of productivities for all countries in sector J:

$$\psi^J(z^J) = \left(\prod_{n=1}^{N} \lambda_n^J\right) exp\left(-\sum_{n=1}^{N} \lambda_n^J z_n^J\right)$$

2.3 Final Goods Sector

In each country, there is a representative firm producing a homogenous non-tradable final good which is non-tradable. Each firm has access to the following nested Cobb-Douglas production function that combines equipment capital k_i^E, structures capital k_i^S, labor l_i and aggregate intermediate good Q_i^M:

$$y_i^f = \left(\left[\mu k_i^{E\frac{\sigma-1}{\sigma}} + (1-\mu) k_i^{S\frac{\sigma-1}{\sigma}}\right]^{(\frac{\sigma}{\sigma-1})\alpha} l_i^{1-\alpha}\right)^{\gamma} Q_i^{M\,1-\gamma}$$

where α, γ are the factor shares and same across countries.

2.4 Capital Stocks

To close the mode, I assume that equipment and structures capital stocks are linear functions of current flows of equipment and structures. That is, $k_i^E = \frac{I_i^E}{\delta}$ and

$k_i^S = \frac{I_i^S}{\delta}$, where $\delta \in (0,1)$ and is common to all countries. I_i^E and I_i^S are functions aggregate equipment and aggregate structures respectively (more details in section 3). This relationship between flows and stocks resembles a steady state relationship in the neoclassical growth model, although my model is not dynamic. This assumption enables me to study the relationship between current volume of trade and capital stock composition in a static framework.

2.5 Trade Costs

Trade costs are assumed to be of the iceberg type. $\tau_{in}^J > 1$ of good z^j must be shipped from country n for one unit to arrive in country i so, $(\tau_{in}^J - 1)$ units 'melt away' in transit. τ_{in}^J comprises both of policy and non-policy barriers to trade. It also represents the adjustment costs, if any, associated with adaptation of an imported equipment and structures to domestic production conditions. For consistency, $\tau_{ii}^J = 1$ for each country and for each sector.

2.6 Equilibrium

Each economy is characterized by exogenous country-specific productivity parameters and trade costs. The equilibrium allocations, prices and trade shares are all functions of these primitives given that the firms optimize and international trade is balanced. In equilibrium, allocations and prices are functions of price of equipment, structures and intermediate good, wages and trade shares. Once these are known, the equilibrium is completely determined.

2.6.1 Firm Optimization

In country i, let w_i denote the wage rate, r_i^E denote the rental rate for equipment capital, r_i^S denote the rental rate for structures capital and P_i^J denote the price of aggregate tradable good in sector J. These prices are determined in a general equilibrium (described in the next section) and they are internationally comparable.

Given the prices, wage rate and rental rates for equipment and structures capital, the representative firm producing individual tradable good z_i^J in country i minimizes the cost of supplying $q_i^J(z_i^J)$:

$$p_i^J(z_i^J)q_i^J(z_i^J) = \min_{k^E,k^S,l,Q^J} r_i^E k_i^E + r_i^S k_i^S + w_i l_i + P_i^J Q_i^J \qquad \text{s.t.}$$
$$z_i^{J-\theta}\left(\left[\mu k_i^{E\frac{\sigma-1}{\sigma}} + (1-\mu)k_i^{S\frac{\sigma-1}{\sigma}}\right]^{\left(\frac{\sigma}{\sigma-1}\right)\alpha} l_i^{1-\alpha}\right)^{\beta^J} Q_i^{J1-\beta^J} \geq q_i^J(z_i^J)$$

where $p_i^J(x^J)$ is the price of individual good x^J. The first order conditions for this optimization problem are as follows:

$$l_i(z_i^J) = q_i^J(z_i^J)(z_i^J)^\theta \left\{\frac{1-\alpha}{\alpha}\right\}^{\alpha\beta^J} \left\{\frac{(1-\alpha)\beta^J}{1-\beta^J}\right\}^{1-\beta^J}$$
$$\left\{\frac{(r_i^{E1-\sigma} + r_i^{S1-\sigma})^{\frac{1}{1-\sigma}}}{w_i}\right\}^{\alpha\beta^J} \left(\frac{P_i^J}{w_i}\right)^{1-\beta^J}$$
$$Q_i^J(z_i^J) = q_i^J(z_i^J)(z_i^J)^\theta \left\{\frac{1-\beta^J}{\alpha\beta^J}\right\}^{\alpha\beta^J} \left\{\frac{1-\beta^J}{(1-\alpha)\beta^J}\right\}^{(1-\alpha)\beta^J}$$
$$\left\{\frac{(r_i^{E1-\sigma} + r_i^{S1-\sigma})^{\frac{1}{1-\sigma}}}{P_i^J}\right\}^{\alpha\beta^J} \left(\frac{w_i}{P_i^J}\right)^{(1-\alpha)\beta^J}$$

$$\left\{k_i^E(z_i^J)^{\frac{\sigma-1}{\sigma}}+k_i^S(z_i^J)^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}}=q_i^J(z_i^J)z_i^{J\theta}\left\{\frac{\alpha\beta^J}{1-\beta^J}\right\}^{1-\beta^J}\left\{\frac{\alpha}{1-\alpha}\right\}^{(1-\alpha)\beta^J}$$
$$\left\{\frac{w_i}{(r_i^{E^{1-\sigma}}+r_i^{S^{1-\sigma}})^{\frac{1}{1-\sigma}}}\right\}^{(1-\alpha)\beta^J}\left\{\frac{P_i^J}{(r_i^{E^{1-\sigma}}+r_i^{S^{1-\sigma}})^{\frac{1}{1-\sigma}}}\right\}^{1-\beta^J}$$
$$k_i^E(z_i^J)=\left\{k_i^E(z_i^J)^{\frac{\sigma-1}{\sigma}}+k_i^S(z_i^J)^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}}r_i^{E^{-\sigma}}(r_i^{E^{1-\sigma}}+r_i^{S^{1-\sigma}})^{\frac{\sigma}{1-\sigma}}$$
$$k_i^S(z_i^J)=\left\{k_i^E(z_i^J)^{\frac{\sigma-1}{\sigma}}+k_i^S(z_i^J)^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}}r_i^{S^{-\sigma}}(r_i^{E^{1-\sigma}}+r_i^{S^{1-\sigma}})^{\frac{\sigma}{1-\sigma}}$$

The representative firm producing aggregate tradable good Q_i^J in each sector J optimizes by purchasing $q_i^J(z_i^J)$ from the lowest cost producer across all countries. The solution to this problem yields the following price of the aggregate tradable good in sector J:

$$P_i^J=\left[\int_0^\infty p_i^J(z_i^J)^{1-\eta}\phi^E(z_i^J)dx^J\right]^{\frac{1}{1-\eta}}$$

where $p_i^J(z^J)=\min\{p_{i1}^J(z^J),p_{i2}^J(z^J),...,p_{iN}^J(z^J)\}$ and $p_{in}^J(z^J)$ is the price country i can purchase good x^J from country n including the trade costs.

The representative firm's problem in the final goods sector is to minimize the cost of supplying y_i^f given the factor prices w_i, r_i^E, r_i^S and P_i^M. The optimization problem is as follows:

$$p_i^f y_i^f=\min_{k^E,k^S,l,Q^M} r_i^E k_i^E+r_i^S k_i^S+w_i l_i+P_i^M Q_i^M \text{ s.t.}$$
$$\left(\left[\mu k_i^{E^{\frac{\sigma-1}{\sigma}}}+(1-\mu)k_i^{S^{\frac{\sigma-1}{\sigma}}}\right]^{\left(\frac{\sigma}{\sigma-1}\right)\alpha}l_i^{1-\alpha}\right)^{\beta^J}Q_i^{J^{1-\beta^J}}\geq y_i^f$$

The first order conditions for this optimization problem are as follows:

$$l_i = y_i^f \left\{\frac{1-\alpha}{\alpha}\right\}^{\alpha\gamma} \left\{\frac{(1-\alpha)\gamma}{1-\gamma}\right\}^{1-\gamma} \left\{\frac{({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{1}{1-\sigma}}}{w_i}\right\}^{\alpha\gamma} \left(\frac{P_i^J}{w_i}\right)^{1-\gamma}$$

$$Q_i^M = y_i^f \left\{\frac{1-\gamma}{\alpha\gamma}\right\}^{\alpha\gamma} \left\{\frac{1-\gamma}{(1-\alpha)\gamma}\right\}^{(1-\alpha)\gamma} \left\{\frac{({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{1}{1-\sigma}}}{P_i^J}\right\}^{\alpha\gamma} \left(\frac{w_i}{P_i^J}\right)^{(1-\alpha)\gamma}$$

$$\left\{{k_i^E}^{\frac{\sigma-1}{\sigma}} + {k_i^S}^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}} = y_i^f \left\{\frac{\alpha\gamma}{1-\gamma}\right\}^{1-\gamma} \left\{\frac{\alpha}{1-\alpha}\right\}^{(1-\alpha)\gamma} \left\{\frac{w_i}{({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{1}{1-\sigma}}}\right\}^{(1-\alpha)\gamma} \left\{\frac{P_i^J}{({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{1}{1-\sigma}}}\right\}^{1-\gamma}$$

$$k_i^E = \left\{{k_i^E}^{\frac{\sigma-1}{\sigma}} + {k_i^S}^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}} {r_i^E}^{-\sigma} ({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{\sigma}{1-\sigma}}$$

$$k_i^S = \left\{{k_i^E}^{\frac{\sigma-1}{\sigma}} + {k_i^S}^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{1-\sigma}} {r_i^S}^{-\sigma} ({r_i^E}^{1-\sigma} + {r_i^S}^{1-\sigma})^{\frac{\sigma}{1-\sigma}}$$

2.6.2 Price Indices:

Given that tradable the goods producing firms behave optimally, the price of individual tradable good z_i^J is as follows:

$$P_i^J(z^J)^{\frac{1}{\theta}} = {\Gamma^J}^{\frac{1}{\theta}} min_v \left\{ \left[\left(\mu^\sigma {r_i^E}^{(1-\sigma)} + 1 - \mu^{1-\sigma} {r_i^S}^{1-\sigma} \right)^{\alpha\beta^J} w_i^{(1-\alpha)\beta^J} {P_i^J}^{1-\beta^J} \tau_{iv}^J \right]^{\frac{1}{\theta}} z_v^J \right\}$$

where $\Gamma^J = \beta^J \alpha^{-\beta^J\alpha} (\beta^J(1-\alpha))^{-\beta^J(1-\alpha)} (1-\beta^J)^{-(1-\beta^J)} S(\theta,\eta)^{\frac{1}{1-\eta}}$.

According to the distributional assumption for productivities, z_i^J is distributed exponentially with parameter λ_i^J. Following properties of the distribution are used in the derivation of price index and trade share:

- If $z \sim \exp(\lambda), \kappa > 0 \rightarrow \kappa z \sim \exp\left(\frac{\lambda}{\kappa}\right)$
- If $z = \min(x,y), x \sim \exp(\mu)$ and $y \sim \exp(\xi) \rightarrow z \sim \exp(\mu + \xi)$

This implies that the distribution of prices faced by each country is:

$$P_i^J(z^J)^{\frac{1}{\theta}} \sim \exp(\xi_i^J)$$

$$\text{where } \xi_i^J = \Gamma^{J-\frac{1}{\theta}} \sum_v^N \left[\left(\mu^\sigma r_i^{E\,1-\sigma} + (1-\mu)^{1-\sigma} r_i^{S\,1-\sigma} \right)^{\alpha\beta^J} w_i^{(1-\alpha)\beta^J} P_i^{J\,1-\beta^J} \tau_{iv}^J \right]^{\frac{-1}{\theta}} \lambda_v^J$$

This implies that price index in tradable sector J is:

$$(P_i^J)^{1-\eta} = \int_0^\infty \left\{ \xi_i^J p_i^J(z^J)^{1-\eta} exp\{-\xi_i^J p_i^J(z^J)^{\frac{1}{\theta}}\} dp_i^{J\frac{1}{\theta}} \right\}$$

Let $s = \xi_i^J p_i^J(z^J)^{\frac{1}{\theta}}$. Then the above expression modifies to:

$$(P_i^J)^{1-\eta} = (\xi_i^J)^{-1(1-\eta)\theta} \int_0^\infty s^{\theta(1-\eta)} exp(-s) ds$$

where the integral is the gamma function. Hence,

$$P_i^J = \Gamma^J S(\theta,\eta)^{\frac{1}{1-\eta}} \left\{ \sum_v^N \left[\left(\mu^\sigma r_i^{E\,1-\sigma} + (1-\mu)^{1-\sigma} r_i^{S\,1-\sigma} \right)^{\alpha\beta^J} w_i^{(1-\alpha)\beta^J} P_i^{J\,1-\beta^J} \tau_{iv}^J \right]^{\frac{-1}{\theta}} \lambda_v^J \right\}^{-\theta}$$

$S(\theta,\eta)$ is the gamma function evaluated at $1+\theta(1-\eta)$. For existence of $S(\theta,\eta)$, it is assumed that $1 > \theta(1-\eta)$. Hence, each country faces the following price index of aggregate good in sector J:

$$P_i^J = \Gamma^J \left\{ \sum_{n=1}^N \left\{ \left(\left[\mu^\sigma r_i^{E\,1-\sigma} + (1-\mu)^\sigma r_i^{S\,1-\sigma} \right]^{\frac{1}{1-\sigma}} \right)^{\alpha\beta^J} w_i{}^{(1-\alpha)\beta^J} P_i^{J\,1-\beta^J} \tau_{in}^J \right\}^{-\frac{1}{\theta}} \lambda_n^J \right\}^{-\theta} \tag{2.1}$$

$$\Gamma^J = \beta^J \alpha^{-\beta^J\alpha} (\beta^J(1-\alpha))^{-\beta^J(1-\alpha)} (1-\beta^J)^{-(1-\beta^J)} S(\theta,\eta)^{\frac{1}{1-\eta}} \tag{2.2}$$

The price indices of equipment, structures and intermediate good summarize how the states of technology around the world, input costs across countries and geographic barriers govern the prices in each country. As Eaton and Kortum (2002) point out, international trade enlarges each country's effective state of technology. With no geographic barriers, above price index is same in each country and the law of one price holds.

2.6.3 Trade Shares

Let π_{in}^J denote the share of country n in country i's total expenditure in sector J. Since there is a continuum of goods, π_{in}^J is also the fraction of goods in sector J that country i imports from country n. Given the distributional assumption for productivities, this boils down to finding the probability that country n is lowest cost supplier of goods in sector J to country i. The following fact about exponential distribution aids in finding an expression for this probability:

- If x and y are independent and $x \sim exp(\mu)$ and $y \sim exp(\xi)$, then $\text{prob}(x \leq y) = \frac{\mu}{\mu+\xi}$

Note that:

$$\text{prob}[p_n^J(z^J) \leq \min_{n \neq v}\{p_v^J(z^J)\}] = \text{prob}[p_n^J(z^J)^{\frac{1}{\theta}} \leq \min_{n \neq v}\{p_v^J(z^J)^{\frac{1}{\theta}}\}]$$

This results in following expression for trade shares in sector J for $n = 1, 2, ..., N$:

$$\pi_{in}^J = \frac{\left\{\left(\left[\mu^\sigma {r_n^E}^{1-\sigma} + (1-\mu)^\sigma {r_n^S}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}\right)^{\alpha\beta^J} {w_n}^{(1-\alpha)\beta^J} {P_n^J}^{1-\beta^J} \tau_{in}^J\right\}^{-\frac{1}{\theta}} \lambda_n^J}{\Sigma_{v=1}^N \left\{\left(\left[\mu^\sigma {r_v^E}^{1-\sigma} + (1-\mu)^\sigma {r_v^S}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}\right)^{\alpha\beta^J} {w_v}^{(1-\alpha)\beta^J} {P_v^J}^{1-\beta^J} \tau_{iv}^J\right\}^{-\frac{1}{\theta}} \lambda_v^J} \tag{2.3}$$

Thus, the home trade share (fraction of goods that country i produces domestically) for sector J in country i is:

$$\pi_{ii}^{J} = \frac{\left\{\left(\left[\mu^{\sigma} r_i^{E\,1-\sigma} + (1-\mu)^{\sigma} r_i^{S\,1-\sigma}\right]^{\frac{1}{1-\sigma}}\right)^{\alpha\beta^J} w_i^{(1-\alpha)\beta^J} P_i^{J\,1-\beta^J}\right\}^{-\frac{1}{\theta}} \lambda_i^J}{\Sigma_{v=1}^{N}\left\{\left(\left[\mu^{\sigma} r_v^{E\,1-\sigma} + (1-\mu)^{\sigma} r_v^{S\,1-\sigma}\right]^{\frac{1}{1-\sigma}}\right)^{\alpha\beta^J} w_v^{(1-\alpha)\beta^J} P_v^{J\,1-\beta^J} \tau_{iv}^J\right\}^{-\frac{1}{\theta}} \lambda_v^J}$$

Note that the sum of trade shares over all countries within each tradable sector is equal to 1. Also, if all trade costs are equal to 1 (no trade barriers), trade shares are independent of the importing country. That is, in a zero gravity world, all countries would import an equal fraction of each tradable good from the same source.

These trade shares are important objects as they map the pattern of trade to productivity parameters, trade costs and factor prices in each country. Since trade shares are measurable, these expressions for trade shares can be employed in estimation of productivity parameters and trade costs. I will provide details of the procedure in chapter 3.

2.6.4 Wages

An equilibrium wage vector is computed given the trade shares and by imposing balanced trade. Country i's imports are defined as

$$L_i\left(P_i^E Q_i^E \sum_{v\neq i}^{N} \pi_{iv}^E + P_i^S Q_i^S \sum_{v\neq i}^{N} \pi_{iv}^S + P_i^M Q_i^M \sum_{v\neq i}^{N} \pi_{iv}^M\right)$$

Exports may be defined as:

$$\sum_{v\neq i}^{N} L_v P_v^E Q_m^E \pi_{vi}^E + \sum_{v\neq i}^{N} L_v P_v^S Q_v^S \pi_{vi}^S + \sum_{v\neq i}^{N} L_v P_v^M Q_v^M \pi_{vi}^M$$

Including each country's consumption of tradable goods produced at home and imposing balanced trade implies the following relationship:

$$L_i \left(P_i^E Q_i^E + P_i^S Q_i^S + P_i^M Q_i^M \right) = \sum_{v=1}^{N} L_v P_v^E Q_v^E \pi_{vi}^E + \sum_{v=1}^{N} L_v P_v^S Q_v^S \pi_{vi}^S + \sum_{v=1}^{N} L_v P_v^M Q_v^M \pi_{vi}^M \tag{2.4}$$

2.6.5 Capital Stocks

In equilibrium, a fraction $1-\beta^E$ of the aggregate equipment good is allocated to production of individual equipment goods and a fraction β^E is allocated to equipment capital: $I_i^E = \beta^E Q_i^E$. Similarly for structures, $I_i^S = \beta^S Q_i^S$. Hence, equipment and structures capital stocks are given by:

$$k_i^E = \frac{\beta^E Q_i^E}{\delta} \text{ and } k_i^S = \frac{\beta^S Q_i^S}{\delta}$$

2.6.6 Allocations

In equilibrium, all firms optimize by minimizing cost of production given the prices and technologies. Allocations rules for equipment capital, structures capital, labor are easy to compute once the wages, trade shares and price indices for equipment, structures, intermediate good are known.

2.7 Empirical Implications

In this section, I derive the theoretical expressions for equipment share of capital, income per worker and investment rate. In the chapters that follow, I will employ these relations to study the quantitative implications of trade for capital composition, economic development and prices of capital goods.

Throughout the rest of the dissertation, I set $\beta^E = \beta^S = \beta$. For a meaningful interpretation of the theoretical expressions that I derive in this section, we need to know the value of the elasticity of substitution between equipment and structures, σ. As outlined later in section 4, the value of σ is such that $1 - \sigma < 0$.

2.7.1 Composition of Capital

To quantify the relationship between capital goods trade and capital stock composition, I derive an equilibrium relationship which connects the share of equipment in capital to country-specific productivity parameters for equipment and structures, and the pattern of bilateral trade.

Rearranging (2.3) and using (2.1) for equipment provides the following expression for country i's home trade share for equipment:

$$\pi_{ii}^E = \frac{\left(\left\{\left[\mu^\sigma r_i^{E(1-\sigma)} + (1-\mu)^\sigma r_i^{S1-\sigma}\right]^{\frac{1}{1-\sigma}}\right\}^{\alpha\beta} w_i{}^{(1-\alpha)\beta} P_i^{E1-\beta}\right)^{\frac{-1}{\theta}} \lambda_i^E}{P_i^{E\frac{-1}{\theta}} \phi}$$

Further rearrangement leads to following expression for the price of aggregate equipment:

$$P_i^E = \phi^{\frac{\theta}{\beta^E}} \left(\left\{\left[\mu^\sigma r_i^{E1-\sigma} + (1-\mu)^\sigma r_i^{S1-\sigma}\right]^{\frac{1}{1-\sigma}}\right\}^{\alpha\beta} w_i{}^{(1-\alpha)\beta}\right)^{\frac{1}{\beta}} \left(\frac{\lambda_i^E}{\pi_{ii}^E}\right)^{-\frac{\theta}{\beta}} \tag{2.5}$$

Similarly price of aggregate structures is given by:

$$P_i^S = \phi^{\frac{\theta}{\beta}} \left(\left\{ \left[\mu^\sigma r_i^{E\,1-\sigma} + (1-\mu)^\sigma r_i^{S\,1-\sigma} \right]^{\frac{1}{1-\sigma}} \right\}^{\alpha\beta} w_i^{(1-\alpha)\beta} \right)^{\frac{1}{\beta}} \left(\frac{\lambda_i^S}{\pi_{ii}^S} \right)^{-\frac{\theta}{\beta}} \tag{2.6}$$

The theoretical model also implies that:

$$\frac{P_i^E k_i^E}{P_i^S k_i^S} = \left(\frac{P_i^E}{P_i^S} \right)^{1-\sigma} \tag{2.7}$$

We can use the price of equipment and structures from (2.5) and (2.6) in (2.7) to derive an expression for the share of equipment in capital stock of a country:

$$\frac{P_i^E k_i^E}{P_i^E k_i^E + P_i^S k_i^S} = \frac{\frac{\lambda_i^E}{\pi_{ii}^E}^{-\frac{\theta(1-\sigma)}{\beta}}}{\frac{\lambda_i^E}{\pi_{ii}^E}^{-\frac{\theta(1-\sigma)}{\beta}} + \frac{\lambda_i^S}{\pi_{ii}^S}^{-\frac{\theta(1-\sigma)}{\beta}}} \tag{2.8}$$

Similar to (2.8), share of structures in capital is given by:

$$\frac{P_i^S k_i^S}{P_i^E k_i^E + P_i^S k_i^S} = \frac{\frac{\lambda_i^S}{\pi_{ii}^S}^{-\frac{\theta(1-\sigma)}{\beta}}}{\frac{\lambda_i^E}{\pi_{ii}^E}^{-\frac{\theta(1-\sigma)}{\beta}} + \frac{\lambda_i^S}{\pi_{ii}^S}^{-\frac{\theta(1-\sigma)}{\beta}}} \tag{2.9}$$

These expressions enable me to quantify the role played by international trade in determining cross-country capital composition differences. In a closed economy, when trade costs are infinite, countries must consume what is produced at home. That is, $\pi_{ii}^J = 1$ for all sectors J. The equipment share of capital is determined solely by country's average productivity in equipment relative to structures:

$$\left(\frac{P_i^E k_i^E}{P_i^E k_i^E + P_i^S k_i^S} \right)_{closed} = \frac{\lambda_i^{E^{-\frac{\theta(1-\sigma)}{\beta}}}}{\lambda_i^{E^{-\frac{\theta(1-\sigma)}{\beta}}} + \lambda_i^{S^{-\frac{\theta(1-\sigma)}{\beta}}}}$$

When trade costs are finite (open economy), countries are able to import equipment and structures from relatively more efficient producers. That is, $\pi_{ii}^E < 1$

and $\pi_{ii}^S < 1$. So, a country that has a low λ_i^E relative to λ_i^S, but imports more equipment relative to structures, would have a higher share of equipment in capital than it would under autarky. Also, if the world economy is characterized by a larger θ and hence, a higher degree of comparative advantage, trade will matter more for capital composition than otherwise.

2.7.2 Income per worker

Real income per worker in country i is:

$$y_i = \frac{w_i}{P_i^f} + \frac{r_i^E k_i^E}{P_i^f} + \frac{r_i^S k_i^S}{P_i^f}$$

As in Waugh (2009), using the expression for price of final good and the expressions for trade shares (2.3), income-per worker is given by the following:

$$y_i = \psi \ \text{TFP}_i \left[\mu k_i^{E\frac{\sigma-1}{\sigma}} + (1-\mu) k_i^{S\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}(\alpha-(1-\alpha)\gamma)}$$

where $\text{TFP}_i = \left[\mu \left(\frac{\pi_{ii}^E}{\lambda_i^E}\right)^{\frac{\sigma-1}{\sigma}\frac{\theta}{\beta}} + (1-\mu)\left(\frac{\pi_{ii}^S}{\lambda_n^S}\right)^{\frac{\sigma-1}{\sigma}\frac{\theta}{\beta}}\right]^{-\frac{\gamma\sigma}{\sigma-1}} \left(\frac{\pi_{ii}}{\lambda_i^M}\right)^{-\frac{\theta(1-\gamma)}{\beta M}}$

and ψ is a collection of constants that do not depend upon the country. Income in a country depends on its TFP, and its equipment and structures capital stock. TFP is determined by the country's exogenous productivity parameters and endogenous trade shares.

2.7.3 Investment Rate

Using the expression for investment levels and income per worker, the aggregate investment rate in country i is as follows:

$$I_i = \frac{P_i^E I_i^E + P_i^S I_i^S}{P_i^f y_i}$$

CHAPTER 3
QUANTITATIVE IMPLICATIONS

Equilibrium allocations and prices in the model economy are characterized by country-specific productivity parameters and the trade costs. In order to explore the quantitative relationship between capital goods trade and cross-country capital composition, and the resulting implications for economic development, I need to estimate these country-specific productivity parameters and trade costs.

3.1 Methodology

In this section, I outline the methodology I employ to estimate these unknown parameters from the pattern of bilateral trade. To derive a structural relationship between pattern of trade, productivity parameters and trade costs, I use the following compact expression for trade shares in sector J from equation (2.3):

$$\pi_{in}^J = \frac{(c_n^J \tau_{in}^J)^{\frac{-1}{\theta}} \lambda_n^J}{\Sigma_{v=1}^N (c_v^J \tau_{iv}^J)^{-\frac{1}{\theta}} \lambda_v^J}\ , \qquad n = 1, 2, ..., N$$

where $c_n^J = \left(\left[\mu^\sigma r_n^{E\,1-\sigma} + (1-\mu)^\sigma r_n^{S\,1-\sigma} \right]^{\frac{1}{1-\sigma}} \right)^{\alpha\beta^J} w_n{}^{(1-\alpha)\beta^J} P_n^{J\,1-\beta^J}$ is the unit cost of producing goods in sector J in country n. Clearly, country i's home trade share is:

$$\pi_{ii}^J = \frac{c_i^{J\,-\frac{1}{\theta}} \lambda_i^J}{\Sigma_{v=1}^N (c_v^J \tau_{iv}^J)^{-\frac{1}{\theta}} \lambda_v^J}$$

As discussed in Eaton and Kortum (2002), the framework here nests a 'gravity equation' relationship between trade shares, productivity parameters and trade costs.

To derive this relationship, divide trade share π_{in}^{J} with home trade share π_{ii}^{J}:

$$\frac{\pi_{in}^{J}}{\pi_{ii}^{J}} = \frac{(c_n^J \tau_{in}^J)^{-\frac{1}{\theta}} \lambda_n^J}{c_i^{J^{-\frac{1}{\theta}}} \lambda_i^J} \tag{3.1}$$

Taking logs on both sides yields the following relationship for each of the tradable sectors:

$$log\left(\frac{\pi_{in}^{J}}{\pi_{ii}^{J}}\right) = F_n^J - F_i^J - \frac{1}{\theta} log \tau_{in}^J, \qquad J = E, S, M \tag{3.2}$$

where $F_i^J = c_i^{J^{-\frac{1}{\theta}}} \lambda_i^J$.

This equation describes a structural relationship between trade shares, productivity parameters and trade costs for each of the tradable goods. Hence, (3.2) can be used to estimate the productivity parameters and trade costs. For each tradable sector, N productivity parameters λ_i^J's need to be estimated. Also, for each tradable sector there are $N^2 - N$ bilateral trade relations, so $(N^2 - N)$ trade costs need to be estimated. But, there are only $N^2 - N$ measurable bilateral trade shares for each tradable sector. To mitigate the high data requirement, I specify the trade costs parsimoniously as:

$$log \tau_{in}^J = dis_s + b_{in} + lang_{in} + ex_{in}^J + \varepsilon_{in}^J \tag{3.3}$$

where trade costs are a logarithmic function of distance, shared border effect and an exporter fixed effect. dis_s captures the effect of distance (in miles) between country n capital city and country i capital city, lying in the sth distance interval. The intervals are [0, 375), [375, 750), [750, 1500), [1500, 3000), [3000, 6000) and [6000, maximum). b_{in} is the effect of a shared border. $lang_{in}$ is the effect of shared official language. An exporter effect, ex_{in}^J, is included to capture the role played by exporter competitiveness. I assume that ε_{in}^J represents barriers to trade arising from other factors and is orthogonal to the ones considered.

Combining equation (3.2) and (3.3) leads to following:

$$log\left(\frac{\pi_{in}^J}{\pi_{ii}^J}\right) = F_n^J - F_i^J - \frac{1}{\theta}\left[dis_s + b_{ni} + lang_{ni} + ex_{ni}^J + \varepsilon_{ni}^J\right] \tag{3.4}$$

I estimate equation (3.4) for all tradable sectors goods with F_i^J's recovered as coefficients on country-specific dummy variables. Given the estimated regression coefficients and an assumed value for θ, τ_{in}^J's can be recovered using equation (3.3). Using F_i^J's and τ_{in}^J's, the price index in sector J is then computed as:

$$P_i^J = \Gamma^J\left\{\sum exp(F_i^J){\tau_{in}^J}^{-\frac{1}{\theta}}\right\}^{-\theta} \tag{3.5}$$

where Γ^J from equation (2.2) is constant across countries. Then, given the P_i^J's, λ_i^J's are computed from the following system of equations:

$$L_i\left(P_i^E Q_i^E + P_i^S Q_i^S + P_i^M Q_i^M\right) = \sum_{v=1}^{N} L_v P_v^E Q_v^E \pi_{vi}^E + \sum_{v=1}^{N} L_v P_v^S Q_v^S \pi_{vi}^S + \sum_{v=1}^{N} L_v P_v^M Q_v^M \pi_{vi}^M$$

$$\ldots Trade\ Balance$$

$$F_i^J = {c_i^J}^{\frac{-1}{\theta}} \lambda_i^J \ \ldots 3N\ equations$$

$$c_i^J = \left(\left[\mu^\sigma {r_i^E}^{1-\sigma} + (1-\mu)^\sigma {r_i^S}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}\right)^{\alpha\beta^J} {w_i}^{(1-\alpha)\beta^J} {P_i^J}^{1-\beta^J} \ \ldots 3N\ equations$$

$$k_i^E = \frac{I_i^E}{\delta} \ \ldots 3N\ equations$$

$$k_i^S = \frac{I_i^S}{\delta} \ \ldots 3N\ equations$$

$$
\begin{aligned}
I_i &= P_i^E I_i^E + P_i^S I_i^S \; ...3N \; equations \\
r_i^E &= \frac{\gamma}{1-\gamma}\left[\mu k_i^{E\frac{\sigma-1}{\sigma}} + (1-\mu) k_i^{S\frac{\sigma-1}{\sigma}}\right]^{-1} k_i^{E-\frac{1}{\sigma}} w_i \; ...3N \; equations \\
r_i^S &= \frac{\gamma}{1-\gamma}\left[\mu k_i^{E\frac{\sigma-1}{\sigma}} + (1-\mu) k_i^{S\frac{\sigma-1}{\sigma}}\right]^{-1} k_i^{S-\frac{1}{\sigma}} w_i \; ...3N \; equations
\end{aligned} \tag{3.6}
$$

3.2 Data

The model year is 1996 and number of countries considered for the current exercise is 76. For estimation purposes, I assume that all the good categories in Standard International Trade Classification (SITC) Rev. 2 apart from equipment and structures, correspond to intermediate goods. The final goods sector is thought of as the sector producing all final goods and services for each economy.

Trade shares for each of the sectors have been constructed following Bernard, Eaton, Jenson, and Kortum (2003), as follows:

$$\pi_{in}^J = \frac{(\text{Value of country } i\text{'s imports from country } n)^J}{\text{Domestic production}^J + \text{Imports}^J \text{ - Exports}^J}$$

This is a way to map production and trade data into the unit interval, by dividing inputs from country n used in country i divided by total inputs in country i. Country i's home trade share is then, constructed as:

$$\pi_{ii}^J = 1 - \sum_{v \neq i}^{J} \pi_{iv}^J$$

The data necessary for construction of trade shares is compiled from various sources. I took the production data from INDSTAT 4 and INDSTAT 3 which is maintained by UNIDO. The bilateral trade data is compiled from Robert C. Feenstra and Mo (2005). I took construction data from the World Bank compilation of national accounts. The INDSTAT data is arranged according to International Standard of Industrial Classification 4-digit Rev.2 and trade data is arranged according to SITC 4-digit Rev.2. In order to construct the trade shares, I established concordance between these two classification systems. Table A.15 lists the SITC and ISIC 4-digit industry codes corresponding to equipment and structures.

Tables A.13 and A.14 present equipment and structures trade shares for selected countries. Rich and poor countries differ in their dependence on imports for equipment. While US, UK and Japan domestically produce large fraction of their equipment, countries like Senegal produce only 28% at home. Another key feature is that poor countries import a larger volume of equipment from rich countries, than rich import from poor. Structures are mostly domestically produced, both in rich and poor countries.

These data on distance, common border and language are from the Centre Dtudes Prospectives Et Dnformations Internationales (http://www.cepii.fr). The bilateral distance measure used to estimate trade costs is in miles from capital cities of the trading partners. I used labor endowment data from Caselli (2005) which are constructed from information in Heston and Summers (2002).

An implication of my model is that, in aggregate, every country should purchase some non-zero amount of goods from all other countries. However, the bilateral trade matrix has many zeros. For the sample of 76 countries and 3 sectors, there are 17,100 possible trading combinations. Of these, 1,639 for intermediate goods, 2,761 for equipment and 4,221 for structures show no trade. This presents both an estimation issue and a computational issue.

For estimation, I deal with this issue by omitting any zero observed trade flows from estimation of equation (3.4). This has been a standard approach in empirical trade literature. Silva and Tenreyro (2006) propose a poisson pseudo maximum likelihood estimator to lessen any bias resulting from log-linearizing of equation (3.4) and from omission of zero observed trade flows. It has been noted in the literature that any bias resulting from omission of zero observed trade flows is quantitatively small (E. Helpman and Rubinstein (2007)). I also estimated equation (3.4) using left truncated OLS, as in Eaton and Kortum (2001). The results from two estimations are very similar.

The estimation yields trade costs for country pairs for whom bilateral trade data is available. However, for computation I need trade costs for all the $N^2 - N$ country pairs, including the instances where there are no trade flows between countries. I set the trade cost in such instances to twice the highest trade cost in my estimates.

3.3 Parameter Estimates

3.3.1 Common Parameters

Calibrated parameter values, common to all countries, are summarized in the following table:

Table 3.1: Calibrated Common Parameter Values

Parameter	Description	Value
α	k's share	1/3
β^M	k and $\imath$'s share in intermediate goods production	0.33
β	k and $\imath$'s share in equipment and structures production	0.41
γ	k and $\imath$'s share in final goods production	0.72
η	elasticity of substitution in the aggregator	2
δ	depreciation rate	0.06
θ	variation in efficiency levels	0.15
μ	output share of equipment	0.194
σ	elasticity between k^E and k^S	1.58

I have calibrated parameter values as follows. Value of α is set at 1/3 in accordance with Gollin (2002). Following Alvarez and Lucas (2004), I have set θ equal to 0.15 and η equal to 2. I have estimated the elasticity of substitution σ and the share parameter μ from US data (available on BEA website). An elasticity of 1.58 implies that equipment and structures are not perfect substitutes. This estimate contradicts the underlying assumption behind aggregation of equipments and structures to arrive at total capital stock of a country. An elasticity of 1 is also used commonly in the literature (Per Krusell and Violante (2000)), implying a Cobb-Douglas relation for the production technology[1].

3.3.2 Trade Costs

The parameter estimates are presented in Tables A.1- A.6 of appendix. Reconstructed trade costs are inputs into the model and determine the price levels countries face. Consistent with the gravity literature, distance is an impediment to trade and the trade cost estimate increases as the distance between trading partners increases. Also, a shared border and common official language reduce the trade cost between any two trading partners. The exporter fixed effect is negatively correlated with the level of development. Rich countries have a trade cost advantage in the international market. The correlation between exporter effect and log income per worker is -0.46 for intermediate goods, -0.24 for equipment and -0.13 for structures.

3.3.3 Productivity Parameters

Tables A.7- A.9 in the appendix present the estimates for productivity parameters. Consistent with the trade patterns, richer countries have better technologies and hence, have a competitive advantage in international trade of all goods. This technology advantage is more pronounced in case of equipment. While the productivity parameter for equipment differs between rich and poor countries by a factor of over 2.5, for rest of the goods it differs only by a factor of 1.6. This is consistent with Eaton and Kortum (2001) and Caselli and Wilson (2004). Another important feature is that productivity parameter for structures shows the least variation with level of

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[1] In chapter 5, I assess the sensitivity of results to parameter values chosen for the elasticity of substitution and depreciation rates.

development. The correlation between structures productivity parameter and income per-worker is 0.18. This corresponds well with the observation that structures are largely domestically produced.

3.4 Results: Composition of Capital

What role does capital goods trade play in determining cross-country capital composition differences? To answer this question, I use the framework outlined in chapter 2. As discussed, I can express equipment share of capital as a function of country-specific productivity parameters and home trade shares. Specifically the expression for equipment share of capital, as derived in equation (2.8), is:

$$\frac{P_i^E k_i^E}{P_i^E k_i^E + P_i^S k_i^S} = \frac{\frac{\lambda_i^E}{\pi_{ii}^E}^{-\frac{\theta(1-\sigma)}{\beta}}}{\frac{\lambda_i^E}{\pi_{ii}^E}^{-\frac{\theta(1-\sigma)}{\beta}} + \frac{\lambda_i^S}{\pi_{ii}^S}^{-\frac{\theta(1-\sigma)}{\beta}}}$$

The results are presented in following table:

Table 3.2: Results: Share of equipment in total capital

	Log Variance	90/10 ratio
Data	0.37	3.29
Model	0.29	2.76

In the data, equipment constitute over 21% of the capital in rich countries and only 8% in poor countries. The cross-country variance of log equipment share of capital is 0.37. My model generates over 80% of the observed cross-country variation in equipment share of capital.

The calibrated model also matches well with data on equipment capital-output ratio and structures capital-output ratio relative to US. Following table gives summary statistics for cross-country variation in the data and in the calibrated model:

Table 3.3: Results: Capital-Output Ratio

		Log Variance	90/10 percentile ratio
Equipment Capital-Output ratio	Data	1.09	6.3
	Model	1.26	7.16
Structures Capital-Output ratio	Data	0.73	1.8
	Model	0.58	1.43

My model slightly over-predicts both the 90/10 percentile ratio and variance of log relative equipment capital-output ratio and accordingly, under-predicts corresponding summary statistics for structures capital-output ratio.

As an alternative measure of composition of capital, I consider the dispersion of equipment capital relative to structures capital across countries. Model implies following expression for this measure, relative to the US:

$$\frac{P_i^E k_i^E / P_i^S k_i^S}{P_{US}^E k_{US}^E / P_{US}^E k_{US}^S} = \frac{\lambda_i^E}{\lambda_{US}^E}^{\frac{-\theta(1-\gamma)}{\beta}} \frac{\lambda_{US}^S}{\lambda_i^S}^{\frac{-\theta(1-\gamma)}{\beta}} \frac{\pi_{ii}^E}{\pi_{USUS}^E}^{\frac{\theta(1-\gamma)}{\beta}} \frac{\pi_{USUS}^S}{\pi_{ii}^S}^{\frac{\theta(1-\gamma)}{\beta}}$$

The observed variance of log of equipment capital relative to structures capital is 0.216. My model generates over 78% of the observed variation, of which capital goods trade accounts for over 47%.

Capital goods trade plays a considerable role in reducing the cross-country dispersion in composition of capital. Underlying the current pattern of international trade are distortions and trade costs affecting the pattern of observed π_{in}^{J}. If these distortions go down, the pattern of trade in capital goods would be altered. In turn, this would affect the cross-country composition of capital, thereby suggesting quantitative implications for not only capital composition, but also for economic development. In chapter 5, I conduct such counterfactual exercises.

3.5 Results: Income Differences

As an assessment of the model, I consider the model's ability to replicate observed cross-country differences in income. The model implies that a country's per-worker income relative to US can be expressed as a function of its equipment capital-output ratio, structures capital-output ratio and a total factor productivity (TFP) term, all relative to US:

$$\frac{y_i}{y_{US}} = \frac{\text{TFP}_i}{\text{TFP}_{US}} \left(\frac{\mu {k_i^E}^{\frac{\sigma-1}{\sigma}} + (1-\mu) {k_i^S}^{\frac{\sigma-1}{\sigma}}}{\mu {k_{US}^E}^{\frac{\sigma-1}{\sigma}} + (1-\mu) {k_{US}^S}^{\frac{\sigma-1}{\sigma}}} \right)^{\frac{\sigma}{\sigma-1}(\alpha-(1-\alpha)\gamma)}$$

where $\text{TFP}_i = \left[\mu \left(\frac{\pi_{ii}^E}{\lambda_i^E} \right)^{\frac{\sigma-1}{\sigma}\frac{\theta}{\beta}} + (1-\mu) \left(\frac{\pi_{ii}^S}{\lambda_n^S} \right)^{\frac{\sigma-1}{\sigma}\frac{\theta}{\beta}} \right]^{-\frac{\gamma\sigma}{\sigma-1}} \left(\frac{\pi_{ii}}{\lambda_i^M} \right)^{-\frac{\theta(1-\gamma)}{\beta^M}}$

With productivity parameters and trade costs recovered from the pattern of trade, I compute each country's income per worker. Given the definition of income, the natural empirical analog is purchasing power parity adjusted income per worker taken from Heston and Summers (2002). Following table provides some summary statistics: the variance of log income per worker and the 90/10 percentile ratio.

Table 3.4: Results: Income Differences

	Var(log y)	y_{90}/y_{10}
Data	1.19	21.31
Model	0.96	18.07

The model only slightly under-predicts cross-country variation in income.

My results show that differences in equipment and structures capital stocks explain roughly 38% of the cross-country variation in income. The rest is due to the TFP term. The TFP term is a function of exogenous productivity parameters and endogenous trade terms. The trade terms account for 26% of relative TFP differences and hence, for 16% of the relative income differences.

3.6 Investment Rate

As another assessment of the model, I look at model's ability to replicate the cross-country dispersion in investment rates. With estimated productivity parameters and trade costs, and computed income levels, I determine the investment rates in each country as defined in chapter 2:

$$I_i = \frac{P_i^E I_i^E + P_i^S I_i^S}{P_i^f y_i}$$

The empirical counterpart for investment rates are taken from citePWT61. Figure A.6 plots the investment rate implied by model to the ones observed in data. The model accounts for 74% of the variation in investment rate.

3.7 Results: Prices of Capital Goods

Barriers to trade affect the prices of equipment and structures in my model. Prices recovered from the calibration exercise, vary negatively with the level of development. Figures A.7 and A.8 respectively plot absolute price of equipment and structures. The price of equipment is only slightly higher for poor countries as compared to rich countries. The elasticity with respect to income is -0.13 in the data and -0.09 in the model. The income elasticity of price of structures is 0.29 in the data and that implied by the model is 0.19.

The model is also able to generate price of equipment and structures relative to consumption that is consistent with the data. The income elasticity of price of equipment relative to consumption is -2.1 in the data and -2.8 in the model. The corresponding elasticity for structures is -4.4 in the data and -5.2 in the model. Figures A.9 and A.10 plot model implied relative price of equipment and structures against the relative prices in data. Consistent with data, in model economy poor countries face substantially higher price for equipment relative to structures. Price of equipment relative to structures is plotted in Figure A.11.

Hsieh and Klenow (2007) criticize the results of Eaton and Kortum (2001) in their study of investment prices and real investment rates. According to Hsieh and Klenow (2007), Eaton and Kortum (2001) capture the fact price of investment relative to consumption is negatively correlated with income per worker, but their results are inconsistent with the fact that absolute price of capital shows little variation across countries. For the sample of countries in Eaton and Kortum (2001), the income elasticity of price of equipment in the data is 0.04. While Eaton and Kortum (2001) price estimates imply an elasticity of -1.6, my price estimates have an income elasticity of only 0.05. Thus, the prices generated by my model are more consistent with the data than the prices in Eaton and Kortum (2001).

CHAPTER 4
COUNTERFACTUAL EXPERIMENTS AND SENSITIVITY ANALYSIS

4.1 Counterfactual Experiments

International trade in capital goods plays a quantitatively significant role in determining cross-country capital composition. As noted in section 3.4, reductions in barriers to capital goods trade can reduce the cross-country dispersion in equipment share of capital and consequently affect economic development. Trade distortions alter the world general equilibrium in at least two ways. One, since the distribution of equipment across countries is determined by international trade, any distortion to trade affects equipment flows to poor countries. Two, distortions in trade may also reflect a distorted allocation of production across countries.[1] Reductions in trade costs working through these two channels may play an important role for economic development. To explore quantitative relationship between trade, capital composition and economic development, I perform counterfactual exercises by adjusting trade costs while keeping the estimated productivity parameters fixed.

4.1.1 Autarky

In the first counterfactual experiment, I shut down all trade and assess welfare costs of autarky for poor countries. This counterfactual world simulates a scenario

[1] Waugh (2009) motivates reallocation of production of intermediate goods resulting from reduction in trade costs as a source of gains from trade. In my model, reductions in trade barriers change the pattern of capital goods trade, which is an additional source of welfare gain.

where the trade costs are infinitely high and hence, prohibit trade. For purposes of computation, I assume $\tau_{in}^{J} = 15$ and compute the world general equilibrium. Welfare loss/gain is defined as the percentage decrease in consumption from the baseline equilibrium to the counterfactual equilibrium. If trade is shut down, the cross-country differences in capital composition would increase by up to 13%. The equipment capital-output ratio would be factor of more than 9 between rich and poor countries. Following table summarizes the results:

Table 4.1: Autarky: Capital-Output Ratio

		Log Variance	90/10 ratio
Equipment capital - output ratio	Baseline	1.26	7.16
	Autarky	1.42	9.3
Structures capital - output ratio	Baseline	0.58	1.43
	Autarky	0.63	1.56

The cross-country income differences also increase. The variance of log income per worker increases to 1.12 from 0.96 in the baseline model. The 90/10 percentile ratio increases to 20.1. The welfare costs of autarky are very high for poor countries relative to rich countries. Poor countries welfare decreases by 13% and rich countries welfare decreases by only 3%.

In autarky, since poor countries can no longer import capital goods, they rely

Table 4.2: Autarky: Income Differences and Welfare Loss

	var [log(y)]	y_{90}/y_{10}	Welfare Loss		
			Poor	Rich	World
Baseline	0.96	18.07	-	-	-
Autarky	1.12	20.1	-13%	-3%	-8%

on domestic production of capital goods. This altered pattern of world production of equipment and structures results in higher prices of equipment and structures for poor countries relative to rich countries. Following table presents 90/10 percentile ratio of absolute price of equipment and structures in the baseline case and under autarky:

Table 4.3: Autarky: Price of Equipment and Structures

	p^E 90/10 ratio	p^S 90/10 ratio
Baseline	0.84	0.94
Autarky	0.73	0.91

In the baseline case, price of equipment is 19% higher in poor countries relative to rich countries. If trade is shut down, price of equipment would be 37% higher in poor countries than in rich countries. The income elasticity of absolute price of equipment is -0.09 in the baseline model and -0.21 in autarky. The income elasticity of absolute price of structures is 0.19 in the baseline model and 0.23 in autarky. Figures A.12 and A.13 respectively plot the price of equipment and structures against income per worker for the baseline model and autarky.

Rich countries, on average, are more productive than poor countries in the production of equipment. In the absence of trade, this inefficiency in domestic equipment sector of poor countries alters the allocation of factors to various production sectors. The size of the overall pie decreases and hence, income gap between rich and poor countries widens. Also, the higher price of capital goods faced by poor results in lower levels of investment and a smaller overall capital stock. Thus, a comparison of equilibrium allocations in the baseline model and autarky experiment reveals that capital goods trade reduces the gap between rich and poor both by reducing the income differences and the capital stock differences.

4.1.2 Elimination of Trade Barriers in Equipment

In the second counterfactual experiment, I eliminate barriers to equipment trade. For numerical computation of model, trade costs for structures and intermediate goods are kept at their baseline levels, given by tables 3, 5, 6 and 8. The productivity parameters are also kept fixed at the calibrated levels, given by tables 9-11. Using these parameters, I compute the general equilibrium of counterfactual world and arrive at the new set of prices, factor allocations, capital stocks and consumption levels for each of the 76 countries. Welfare gain is then calculated as the percentage increase in consumption from baseline equilibrium to the counterfactual equilibrium.[2]

With the elimination of equipment trade barriers, the cross-country dispersion of both equipment capital-output ratio and structures capital-output ratio declines. The equipment capital - output ratio would be a factor of 6.7 in this counterfactual world as compared to 7.16 in the baseline case. Structures capital - output ratio would also reduce to a factor of 1.31 from 1.43 in baseline case. Poor countries would experience a welfare increase of 9% while rich countries gain would be only 1.4%. The overall world welfare gain would be 3%.

Table 4.4: Capital-Output Ratio, $\tau_{in}^E = 1$

		Log Variance	90/10 ratio
Equipment capital -	Baseline	1.26	7.16
output ratio	$\tau_{in}^E = 1$	1.12	6.7
Structures capital -	Baseline	0.58	1.43
output ratio	$\tau_{in}^E = 1$	0.55	1.31

[2]Certain caveats behind the counterfactual results must be mentioned. The trade costs are modeled as iceberg costs to trade and not as tariffs. So, the goods that ‘melt away’ in transit are not accounted for like tariff revenue as being rebated to agents in each country.

Table 4.5: Welfare Gains, $\tau_{in}^{E} = 1$

	Poor	Rich	World
Baseline	-	-	-
$\tau_{in}^{E} = 1$	9%	1.4%	3%

4.1.3 Elimination of Trade Barriers in Structures

In the third experiment, I eliminate trade costs in structures. In this experiment, I keep the trade costs for equipment and intermediate goods fixed at the calibrated values from the baseline model, given by tables 3, 4, 7 and 8. The productivity parameters used for computation are also same as in the baseline model, given by tables 9-11. With the new set of parameters, I recompute the model and assess welfare gains associated with elimination of barriers in structures only.

Table 4.6: Equipment Capital-Output Ratio, $\tau_{in}^{S} = 1$

	Log Variance	90/10 ratio
Baseline	1.26	7.16
$\tau_{in}^{E} = 1$	1.12	6.7
$\tau_{in}^{S} = 1$	1.29	7.3

With $\tau_{in}^{S} = 1$, cross-country capital composition differences increase, but only

Table 4.7: Structures Capital-Output Ratio, $\tau_{in}^{S} = 1$

	Log Variance	90/10 ratio
Baseline	0.58	1.43
$\tau_{in}^{E} = 1$	0.55	1.31
$\tau_{in}^{S} = 1$	0.57	1.43

marginally. In this counterfactual world, the equipment capital - output ratio would be a factor of 7.3 between rich and poor while it is a factor of 7.16 in the baseline model. The structures capital - output ratio would be a factor of 1.43 in the counterfactual world and 1.43 in the baseline model. Hence, reduction in barriers to structures trade does not significantly affect cross-country capital composition. Removal of barriers to equipment trade, on the other hand, plays a significant role in reducing capital composition differences across countries. Equipment capital-out ratio is a factor of 6.7 when $\tau_{in}^{E} = 1$ and 7.3 when $\tau_{in}^{S} = 1$. The welfare gains are summarized in the following table:

Poor countries welfare gain is 1.5% and rich countries welfare gain is 0.8% when $\tau_{in}^{S} = 1$. The welfare gains in this counterfactual world are significantly smaller than the case when barriers to equipment trade are eliminated. Poor countries gain relative to rich both when $\tau_{in}^{E} = 1$ and $\tau_{in}^{S} = 1$, but the gain is nearly 4 times higher in the former case.

Table 4.8: Welfare Gains, $\tau_{in}^{S} = 1$

	Poor	Rich	World
Baseline	-	-	-
$\tau_{in}^{E} = 1$	9%	1.4%	3%
$\tau_{in}^{S} = 1$	1.5%	0.8%	1.1%

4.1.4 Elimination of Trade Barriers in Intermediate Goods and Zero Gravity

In this section I consider two more counterfactual exercises: elimination of trade barriers in intermediate goods and zero gravity. For the first one, I set $\tau_{in}^{M} = 1$ and trade barriers for equipment and structures are kept fixed at the baseline levels. For the zero gravity experiment, barriers in all three tradable sectors are eliminated, i.e., $\tau_{in}^{J} = 1,\ J = E, S, M$. This counterfactual world simulates a zero gravity world as geographic variables cease to be impediments to trade and the goods flow across borders as they flow within a country. This exercise is, admittedly, extreme. But, it does capture the potential of international trade in affecting capital composition.

Using the trade costs and productivity parameters for two counterfactual experiments, I compute the respective equilibria. Using these equilibrium allocations, I then assess the implications for cross-country capital composition and welfare gains. Equipment capital-output ratio is a factor of 7.16 between rich and poor in the baseline model, 6.7 when $\tau_{in}^{E} = 1$, 6.1 when $\tau_{in}^{M} = 1$ and 5.6 when $\tau_{in}^{J} = 1$. Hence, reduction in cross-country capital composition differences is the largest when all trade barriers are eliminated. A noteworthy observation is that the elimination of barriers in intermediate goods trade has a larger impact on cross-country capital composition differences than the elimination of trade barriers in equipment. I'll elaborate more on this in a bit. The results are presented in following tables:

Table 4.9: Equipment Capital-Output Ratio, $\tau_{in}^{M} = 1$ and Zero Gravity

	Log Variance	90/10 ratio
Baseline	1.26	7.16
$\tau_{in}^{E} = 1$	1.12	6.7
$\tau_{in}^{M} = 1$	1.02	6.1
$\tau_{in}^{J} = 1$ (zero gravity)	0.91	5.6

Table 4.10: Structures Capital-Output Ratio, $\tau_{in}^{M} = 1$ and Zero Gravity

	Log Variance	90/10 ratio
Baseline	0.58	1.43
$\tau_{in}^{E} = 1$	0.55	1.31
$\tau_{in}^{M} = 1$	0.52	1.27
$\tau_{in}^{J} = 1$ (zero gravity)	0.49	1.21

As in section 4.1.2 and 4.1.3, poor countries gain relative to rich both when $\tau_{in}^{M} = 1$ and $\tau_{in}^{J} = 1$. Poor countries welfare increase is 22% and rich countries welfare increase is 5% when trade barriers in intermediate goods are eliminated. In case of zero gravity, the welfare improvement for poor countries would be 34% and for rich countries is 8%.

Table 4.11: Welfare Gains, $\tau_{in}^{M} = 1$ and Zero Gravity

	Poor	Rich	World
Baseline	-	-	-
$\tau_{in}^{E} = 1$	9%	1.4%	3%
$\tau_{in}^{M} = 1$	22%	5%	10%
$\tau_{in}^{J} = 1$ (zero gravity)	34%	8%	16%

Another noteworthy observation is that poor countries welfare gain is 34% when all trade barriers are eliminated, 9% when barriers only to equipment trade are eliminated, and 22% when barriers only to intermediate goods trade are eliminated. Does this imply that most of the gains associated with elimination of barriers come from intermediate goods trade and not from equipment trade? This implication must be understood in light of following two facts. One, equipment is traded less as compared to the intermediate goods. In 1996, equipment comprise roughly 25% of total imports for poor countries and less than 10% for rich countries. Two, the results here satisfy balanced trade. When barriers to equipment trade are eliminated, poor countries can import equipment cheaply. But, because of balanced trade, the increase in volume of equipment imports is limited by their capacity to export intermediate goods. On the other hand, when barriers to intermediate goods trade are eliminated, sufficient trade surplus is generated to finance a larger quantity of equipment import. This results in a larger reduction in capital composition differences and a larger overall size of the pie when $\tau_{in}^{M} = 1$ and hence, larger welfare gains.

Since poor countries mostly import their equipment and trade determines equipment flows to poor countries, distortions in world trading system affect the cross-country variation in equipment share of capital. Eliminating trade barriers facilitates an efficient allocation of world stock of capital across countries. In my model, productivity parameters and trade costs together determine both capital goods trade and allocation of capital goods production across countries. In a world with lower trade barriers, reallocation of world capital to poor countries enables them to gain relative to rich countries. Hence, the barriers to capital goods trade are quantitatively important for economic development.

4.2 Sensitivity Analysis

The results presented in sections 3.3-3.5 and 4.1 hinge on the calibrated values of parameters that I use in numerical computations of the model. In the calibration exercise, I pin down values for the common parameters based on information from the existing literature and my estimate of the elasticity of substitution and the share parameter from US data. Then, using these values, I calibrate country specific parameters to data on bilateral trade, bilateral distance, border and language. In this section, I assess the sensitivity of results presented in sections 3.3-3.5 and 4.1 to the choice of parameter values for elasticity of substitution between equipment and structures, and the depreciation rates for equipment and structures.

4.2.1 Elasticity of Substitution

To assess the sensitivity of results to the elasticity of substitution between equipment and structures, I recalibrate the model for the case when $\sigma = 1$. A unitary elasticity of substitution between equipment and structures is commonly used in the literature (Per Krusell and Violante (2000)). For purposes of this analysis, I use the values from Per Krusell and Violante (2000). The values for common parameters used in this calibration exercise are given in table 4.12.

To calibrate the country-specific parameters, I use the method outlined in section 3.2. Specifically, the coefficients from estimation of equation (3.4) remains unchanged with the change in elasticity of substitution. Thus, the trade costs and price implications (eqn. (3.5)) are the same as in the case with $\sigma = 1.58$. The productivity parameters are then arrived at by solving the system of equations in (3.6).

The calibrated model in the case of unitary elasticity explains approximately 74% of observed variation in equipment share of capital. Thus, the decline in explanatory power of the model is marginal in case of capital-output ratios. However,

Table 4.12: Common Parameter Values, $\sigma = 1$

Parameter	Description	Value
α	k's share	1/3
β^M	k and $\imath$'s share in intermediate goods production	0.33
β	k and $\imath$'s share in equipment and structures production	0.41
γ	k and $\imath$'s share in final goods production	0.72
η	elasticity of substitution in the aggregator	2
δ	depreciation rate	0.06
θ	variation in efficiency levels	0.15
μ	output share of equipment	0.216
σ	elasticity between k^E and k^S	1

the model's ability to replicate income differences is very sensitive to the value of elasticity that is used. In the case of $\sigma = 1$, model explains 48-66% of observed income variation across countries. This is because with $\sigma = 1$, the general equilibrium level of capital stock is lower for poor countries as compared to rich countries.

The results for autarky experiment are in tables 4.15 and **??**.

Similar to the prediction of the baseline case, if trade is shut down, the cross-country capital composition differences and income differences would increase. While the baseline model predicts that if trade is shut down, cross-country dispersion in equipment capital-output ratio would increase by nearly 29%, the unitary elasticity

Table 4.13: Capital-Output Ratio, $\sigma = 1$

		Log Variance	90/10 ratio
Equipment	Data	1.09	6.3
	Baseline ($\sigma = 1.58$)	1.26	7.16
	$\sigma = 1$	0.81	4.7
Structures	Data	0.73	1.8
	Baseline ($\sigma = 1.58$)	0.58	1.43
	$\sigma = 1$	0.62	1.5

Table 4.14: Income per Worker, $\sigma = 1$

	Var(log y)	y_{90}/y_{10}
Data	1.19	21.31
Baseline ($\sigma = 1.58$)	0.96	18.07
$\sigma = 1$	0.69	14.1

case predicts this increase to be 27%. The dispersion in income per worker increases by up to 17% in the baseline model and by nearly 27% in the case with $\sigma = 1$. With regard to welfare change, the direction of change is same as in the baseline model, but the numerical values of welfare losses are substantially lower.

Table 4.15: Autarky: Capital-Output Ratio, $\sigma = 1$

		Log Variance	90/10 ratio
Equipment capital -	Baseline ($\sigma = 1.58$)	1.42	9.3
output ratio	$\sigma = 1$	1.03	6.1
Structures capital -	Baseline ($\sigma = 1.58$)	0.63	1.56
output ratio	$\sigma = 1$	0.71	1.58

Table 4.16: Autarky: Income Differences and Welfare Loss, $\sigma = 1$

	var $[\log(y)]$	y_{90}/y_{10}	Welfare Loss		
			Poor	Rich	World
Baseline ($\sigma = 1.58$)	0.63	14.1	-13%	-3%	-8%
$\sigma = 1$	0.8	16.8	-7.1%	-1.6%	-5.9%

4.2.2 Depreciation rate

I also assess the importance of depreciation rate for model's ability to reproduce observed cross-country variation in capital composition and incomes. In the baseline case, I assume both equipment and structures depreciate at 6%. In this exercise I assume that equipment depreciate at 15% and structures depreciate at 4%. These values are in accordance with the Penn World Table. The following table lists common parameter values used in the calibration.

Table 4.17: Common Parameter Values, $\delta^E \neq \delta^S$

Parameter	Description	Value
α	k's share	1/3
β^M	k and $\imath$'s share in intermediate goods production	0.33
β	k and $\imath$'s share in equipment and structures production	0.41
γ	k and $\imath$'s share in final goods production	0.72
η	elasticity of substitution in the aggregator	2
δ^E	depreciation rate for equipment	0.15
δ^S	depreciation rate for structures	0.04
θ	variation in efficiency levels	0.15
μ	output share of equipment	0.194
σ	elasticity between k^E and k^S	1.58

I use the method outlined in section 3.2 to calibrate the trade costs and productivity parameters. As in the previous case, the estimated coefficients from equation (3.4) are same as in the baseline case. Consequently, the trade costs and price implications remain unchanged. The productivity parameters are then arrived at by solving the system of equations in (3.6). The capital-output ratios and income per worker implied by this calibrated model are presented in the following tables:

Table 4.18: Capital Output Ratio, $\delta^E \neq \delta^S$

		Log Variance	90/10 ratio
Equipment	Data	1.09	6.3
	Baseline ($\delta^E = \delta^S$)	1.26	7.16
	$\delta^E \neq \delta^S$	1.31	7.92
Structures	Data	0.73	1.8
	Baseline ($\delta^E = \delta^S$)	0.58	1.43
	$\delta^E \neq \delta^S$	0.55	1.31

Table 4.19: Income per Worker, $\delta^E \neq \delta^S$

	Var(log y)	y_{90}/y_{10}
Data	1.19	21.31
Baseline ($\delta^E = \delta^S$)	0.96	18.07
$\delta^E \neq \delta^S$	0.98	18.63

The results from the calibrated model are not very sensitive to the change in depreciation rates. The explanatory power of the model slightly worsens in case of capital-output ratios and marginally improves for income per worker. The variance of log equipment capital-output ratio is 1.26 in the baseline model and 1.31 when $\delta^E \neq \delta^S$. The model implied income per worker also changes marginally with the change in depreciation rates for equipment and structures. The income per worker is a factor of 18.07 between rich and poor in the baseline case and 18.63 when $\delta^E \neq \delta^S$. The results for autarky experiment are presented in the following tables.

Table 4.20: Autarky: Capital-Output Ratio, $\delta^E \neq \delta^S$

		Log Variance	90/10 ratio
Equipment capital -	Baseline ($\delta^E = \delta^S$)	1.42	9.3
output ratio	$\delta^E \neq \delta^S$	1.56	9.7
Structures capital -	Baseline ($\delta^E = \delta^S$)	0.63	1.56
output ratio	$\delta^E \neq \delta^S$	0.6	1.43

Table 4.21: Autarky: Income per Worker, $\delta^E \neq \delta^S$

	var [log(y)]	y_{90}/y_{10}
Baseline $\delta^E = \delta^S$	0.98	18.63
$\delta^E \neq \delta^S$	1.19	20.8

As in the baseline case, autarky increases the cross-country capital composition differences and widens the income gap. In this economy, the cross-country capital composition differences increase by 28% and the income differences increase by 17%. The direction of welfare change is also same as in the baseline model and the numerical

Table 4.22: Autarky: Welfare Loss, $\delta^E \neq \delta^S$

	Poor	Rich	World
Baseline $\delta^E = \delta^S$	-13%	-3%	-8%
$\delta^E \neq \delta^S$	-14.3%	-3.1%	-8.1%

values of welfare losses are not substantially altered.

CHAPTER 5
CONCLUSION

This dissertation examines the role played by trade in determining capital composition across countries. In a general equilibrium model of trade, I examine the quantitative relationship between international trade and cross-country capital composition. Calibrating the model to match bilateral trade pattern in 76 countries, I generate several interesting results. I show that trade is quantitatively important in explaining cross-country capital composition differences. The calibrated model does well in replicating the investment rate, the income per worker and prices of capital goods in the data. Finally, various trade liberalizations were considered and the welfare benefits are substantial with poor countries gaining relatively more than rich countries.

Understanding the implications of capital goods trade for cross-country capital composition and economic development is an important topic for continued research. Trade in capital goods is distinct from trade in other manufactures as trade in capital goods can transmit benefits of embodied technological progress across borders. In this respect, trade in equipment and structures would have stronger linkages with economic development.

APPENDIX
TABLES AND FIGURES

Table A.1: Geographic Barriers for IG Trade

Barrier	Coefficient	S.E.
Distance [0, 375)	-8.63	0.28
Distance [375, 750)	-8.65	0.16
Distance [750, 1500)	-8.98	0.09
Distance [1500, 3000)	-9.18	0.06
Distance [3000, 6000)	-9.19	0.06
Distance [6000, max)	-9.27	0.04
Shared Border	0.32	0.14
Common Official Language	-0.05	0.08

Table A.2: Geographic Barriers for Equipment

Barrier	Coefficient	S.E.
Distance [0, 375)	-7.76	0.28
Distance [375, 750)	-8.33	0.16
Distance [750, 1500)	-8.5	0.1
Distance [1500, 3000)	-8.82	0.07
Distance [3000, 6000)	-8.84	0.07
Distance [6000, max)	-9.05	0.06
Shared Border	0.59	0.14
Common Official Language	0.14	0.09

Table A.3: Geographic Barriers for Structures

Barrier	Coefficient	S.E.
Distance [0, 375)	-7.42	0.33
Distance [375, 750)	-8.22	0.2
Distance [750, 1500)	-8.7	0.13
Distance [1500, 3000)	-9.36	0.11
Distance [3000, 6000)	-9.82	0.11
Distance [6000, max)	-10.14	0.1
Shared Border	0.65	0.16
Common Official Language	0.42	0.11

Table A.4: Exporter Dummy Coeff.: Int. Goods

Country	Exporter Coefficient	S.E.
USA	-4.25	0.32
Albania	12.13	0.23
Argentina	-1.8	0.42
Australia	-2.11	0.24
Azerbaijan	0.57	0.24
Belgium & Lux	-0.87	0.37
Bulgaria	-0.19	0.22
Bolivia	0.09	0.25
Canada	-1.8	0.34
Switzerland	-2.15	0.23
Chile	-1.03	0.23
China & Hongkong	-2.06	0.25
Cameroon	2.54	0.22
Colombia	-1.25	0.31
Costa Rica	0.97	0.26
Cyprus	0.56	0.31
Germany	-3.71	0.29
Egypt	-1.25	0.23
Spain	-3.05	0.28
Estonia	5.8	0.22
Finland	-1.72	0.32
France	-3.01	0.23
United Kingdom	-2.95	0.23
Greece	-1.17	0.22
Honduras	2.59	0.23
Hungary	-0.76	0.33
Indonesia	-1.19	0.25
India	-2.29	0.24
Ireland	2.19	0.24
Iran	-0.23	0.24
Iceland	0.97	0.28
Israel	-0.74	0.32
Italy	-2.72	0.24
Jordan	-0.14	0.23
Japan	-4.05	0.31
Kazakhstan	2.59	0.23
Kenya	-0.93	0.28
Kyrgyzstan	3.68	0.31
Korea, Republic of	-2.43	0.41
Kuwait	4.21	0.23
Sri Lanka	1.26	0.3

Table A.4 – continued from previous page

Country	Exporter Coefficient	S.E
Lithuania	0.97	0.29
Latvia	1.89	0.32
Morocco	-0.39	0.33
Republic of Moldova	1.49	0.25
Mexico	-0.28	0.37
TFYR of Macedonia	1.05	0.24
Malta	1.84	0.37
Myanmar	2.12	0.32
Mauritius	1.15	0.34
Malaysia & Singapore	2.35	0.35
Nigeria	2.72	0.24
Netherlands	4.21	0.28
Norway	1.32	0.22
New Zealand	-0.62	0.24
Oman	2.47	0.26
Pakistan	-0.12	0.29
Panama	2.19	0.25
Peru	-1.09	0.3
Philippines	-0.57	0.27
Poland	-1.6	0.25
Portugal	-1.72	0.23
Romania	-2.08	0.23
Russian Fed.	-1.88	0.24
Senegal	0.8	0.23
Slovenia	-0.63	0.35
Sweden	-1.04	0.25
Syria	-1.06	0.23
Tunisia	-0.42	0.3
Turkey	-2.03	0.27
Tanzania	0.93	0.23
Ukraine	-1.13	0.39
Uruguay	-0.65	0.3
Venezuela	0.24	0.29
South Africa	-1.25	0.27
Zimbabwe	0.5	0.25

Table A.5: Exporter Dummy Coeff.: Equipment

Country	Exporter Coefficient	S.E.
USA	-2.85	0.5
Albania	5.17	0.24
Argentina	-1.35	0.96
Australia	-1.84	0.28
Azerbaijan	2.69	0.26
Belgium & Lux	-1.25	0.7
Bulgaria	-1.34	0.24
Bolivia	0.61	0.29
Canada	-2.24	0.78
Switzerland	-1.67	0.24
Chile	-0.31	0.24
China & Hongkong	2.84	0.3
Cameroon	2.26	0.24
Colombia	-0.92	0.63
Costa Rica	1.37	0.31
Cyprus	9.58	0.42
Germany	-2.67	0.32
Egypt	-0.73	0.22
Spain	-2	0.31
Estonia	0.9	0.24
Finland	-1.72	0.4
France	-3.05	0.25
United Kingdom	-2.7	0.23
Greece	0.03	0.22
Honduras	2.13	0.26
Hungary	-0.2	0.53
Indonesia	-1.69	0.26
India	-2.61	0.27
Ireland	-1.28	0.26
Iran	-1.83	0.26
Iceland	1.24	0.36
Israel	-1.21	0.37
Italy	-2.27	0.26
Jordan	0.83	0.23
Japan	-3.75	0.39
Kazakhstan	0.5	0.24
Kenya	-0.82	0.41
Kyrgyzstan	3.75	0.45
Korea, Republic of	-2.58	0.65
Kuwait	1.1	0.25
Sri Lanka	1.02	0.34

Table A.5 – continued

Country	Exporter Coefficient	S.E
Lithuania	0.58	0.37
Latvia	0.22	0.38
Morocco	-0.24	0.41
Republic of Moldova	8.83	0.32
Mexico	-0.05	0.54
TFYR of Macedonia	0.59	0.27
Malta	0.23	0.38
Myanmar	9.01	0.33
Mauritius	3.11	0.58
Malaysia & Singapore	-1.74	0.45
Nigeria	-1.5	0.25
Netherlands	-1.03	0.43
Norway	-0.5	0.23
New Zealand	-1.14	0.26
Oman	2.18	0.3
Pakistan	-0.14	0.34
Panama	2.62	0.3
Peru	-0.88	0.34
Philippines	-0.78	0.32
Poland	-1.69	0.29
Portugal	-1.85	0.26
Romania	-2.02	0.26
Russian Federation	-2.24	0.27
Senegal	1.24	0.25
Slovenia	0.3	0.62
Sweden	-1.19	0.28
Syria	-0.75	0.24
Tunisia	-0.14	0.45
Turkey	-1.66	0.37
Tanzania	4.33	0.25
Ukraine	-1.55	0.5
Uruguay	1.44	0.33
Venezuela	-1.47	0.42
South Africa	-1.8	0.32
Zimbabwe	-1.46	0.26

Table A.6: Exporter Dummy Coefficients: Structures

Country	Exporter Coefficient	S.E.
USA	0.89	1.25
Albania	-0.7	0.28
Argentina	-0.61	0.98
Australia	0.43	0.45
Azerbaijan	1.02	0.36
Belgium & Lux	0.05	0.91
Bulgaria	1.02	0.31
Bolivia	0.07	0.36
Canada	0.44	0.91
Switzerland	-0.83	0.33
Chile	-0.57	0.32
China & Hongkong	0.14	0.43
Cameroon	2.28	0.3
Colombia	-1.68	1.28
Costa Rica	0.78	0.54
Cyprus	-0.32	1.25
Germany	-0.27	0.57
Egypt	-0.2	0.26
Spain	-0.31	0.56
Estonia	0.27	0.3
Finland	0.36	0.71
France	-0.53	0.32
United Kingdom	0.24	0.27
Greece	-1.8	0.26
Honduras	0.28	0.4
Hungary	-0.6	1.28
Indonesia	-0.8	0.43
India	-1.27	0.55
Ireland	-0.72	0.38
Iran	-0.84	0.37
Iceland	0.83	0.67
Israel	-1.24	0.75
Italy	0.39	0.4
Jordan	0.91	0.27
Japan	-0.84	0.77
Kazakhstan	2.63	0.32
Kenya	-0.19	0.77
Kyrgyzstan	1.15	1.27
Korea, Republic of	1.25	0.96
Kuwait	0.67	0.31
Sri Lanka	1.09	0.55

Table A.6 – continued

Country	Exporter Coefficient	S.E
Lithuania	-2.25	1.24
Latvia	-0.63	0.78
Morocco	-0.85	0.95
Republic of Moldova	-0.17	0.62
Mexico	-0.23	1.29
TFYR of Macedonia	-0.72	0.37
Malta	1.49	0.94
Myanmar	-0.93	0.8
Mauritius	1.48	1.31
Malaysia & Singapore	1.69	0.7
Nigeria	2.2	0.35
Netherlands	-0.16	0.62
Norway	0.47	0.27
New Zealand	1.13	0.33
Oman	0.36	0.39
Pakistan	-0.24	0.91
Panama	0.36	0.9
Peru	-1.35	0.76
Philippines	0	0.75
Poland	-0.83	0.49
Portugal	0.17	0.34
Romania	-0.63	0.41
Russian Fed.	-1.3	0.41
Senegal	1.84	0.33
Slovenia	-0.64	0.94
Sweden	1.13	0.47
Syria	2.48	0.29
Tunisia	-0.53	1.29
Turkey	-0.96	0.57
Tanzania	1.1	0.34
Ukraine	-1.44	1.02
Uruguay	-3.81	0.44
Venezuela	-2.09	1.28
South Africa	1.18	0.92
Zimbabwe	-0.17	0.33

Table A.7: Productivity Parameters: IG, λ_i^M

Country	$\hat{F}_i$	S.E.	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^\theta$
USA	4.86	0.23	1.00
Albania	-13.13	0.16	3.19
Argentina	2.4	0.27	1.10
Australia	2.23	0.17	1.19
Azerbaijan	-1.26	0.16	2.80
Belgium & Lux	0.85	0.24	1.82
Bulgaria	0.16	0.16	3.75
Bolivia	-0.66	0.17	1.15
Canada	2.08	0.23	2.69
Switzerland	2.01	0.16	2.93
Chile	1.46	0.16	2.81
China & Hongkong	2.34	0.18	5.50
Cameroon	-2.24	0.15	2.09
Colombia	1.27	0.22	6.39
Costa Rica	-0.88	0.18	5.63
Cyprus	-0.86	0.22	5.65
Germany	4.36	0.2	1.56
Egypt	0.68	0.16	2.13
Spain	3.14	0.2	2.56
Estonia	-5.86	0.16	3.56
Finland	1.45	0.23	2.44
France	3.45	0.17	1.61
United Kingdom	3.18	0.16	1.48
Greece	0.99	0.16	2.58
Honduras	-2.26	0.17	2.71
Hungary	0.54	0.22	2.18
Indonesia	1.24	0.17	1.35
India	2.5	0.17	1.86
Ireland	-2.32	0.17	3.35
Iran	0.51	0.17	2.21
Iceland	-1.11	0.2	2.45
Israel	0.45	0.24	2.33
Italy	3.12	0.17	1.62
Jordan	-0.14	0.16	2.92
Japan	4.64	0.21	1.07
Kazakhstan	-2.3	0.16	3.07
Kenya	0.52	0.2	2.11
Kyrgyzstan	-4.48	0.22	2.16
Korea, Republic of	2.64	0.27	1.99
Kuwait	-2.29	0.16	2.74

Table A.7 – continued

Country	$\hat{F}_i$	S.E	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^\theta$
Sri Lanka	-1.35	0.18	2.50
Lithuania	-1.34	0.2	2.57
Latvia	-2.11	0.22	2.61
Morocco	0.22	0.24	1.99
Republic of Moldova	-2.12	0.17	3.08
Mexico	0.38	0.26	1.81
TFYR of Macedonia	-1.68	0.17	3.16
Malta	-2.19	0.26	4.75
Myanmar	-2.28	0.21	2.82
Mauritius	-1.34	0.24	3.61
Malaysia & Singapore	-2.35	0.23	1.52
Nigeria	-2.32	0.17	3.77
Netherlands	-4.1	0.19	1.79
Norway	-1.16	0.15	2.87
New Zealand	0.76	0.17	1.55
Oman	-2.28	0.19	2.18
Pakistan	0.21	0.19	3.10
Panama	-1.73	0.18	3.58
Peru	1.04	0.21	3.56
Philippines	0.32	0.19	2.36
Poland	1.73	0.17	2.78
Portugal	1.56	0.16	2.18
Romania	1.9	0.16	2.79
Russian Fed.	1.98	0.17	2.95
Senegal	-1.1	0.16	2.34
Slovenia	0.2	0.21	2.75
Sweden	1.03	0.17	1.58
Syria	1.12	0.16	1.98
Tunisia	0.36	0.2	2.67
Turkey	2.01	0.18	2.14
Tanzania	-1.56	0.16	3.56
Ukraine	1.03	0.24	2.91
Uruguay	0.35	0.21	2.95
Venezuela	0.04	0.2	3.99
South Africa	1.53	0.18	3.79
Zimbabwe	-0.05	0.17	4.51

Table A.8: Productivity Parameters: Equip., λ_i^E

Country	$\hat{F}_i$	S.E.	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^\theta$
USA	4.67	0.26	1.00
Albania	-6.04	0.17	9.77
Argentina	1.41	0.29	15.09
Australia	2.03	0.19	3.78
Azerbaijan	-2.71	0.19	4.70
Belgium & Lux	1.78	0.28	7.00
Bulgaria	0.85	0.18	1.20
Bolivia	-2.9	0.22	3.05
Canada	2.85	0.25	2.40
Switzerland	2.48	0.18	2.31
Chile	0.23	0.18	6.27
China & Hongkong	-1.87	0.19	6.18
Cameroon	-3.3	0.17	7.59
Colombia	0.59	0.26	1.05
Costa Rica	-1.56	0.19	2.46
Cyprus	-9.39	0.27	3.34
Germany	4.5	0.22	1.02
Egypt	0.36	0.15	1.88
Spain	2.85	0.2	1.31
Estonia	-1.58	0.17	5.91
Finland	2.3	0.26	1.66
France	4.16	0.19	1.70
United Kingdom	3.83	0.16	1.25
Greece	0.2	0.16	2.20
Honduras	-2.21	0.19	9.61
Hungary	0.3	0.28	0.80
Indonesia	1.84	0.2	3.82
India	2.67	0.19	2.44
Ireland	1.85	0.2	5.19
Iran	1.54	0.19	11.33
Iceland	-1.64	0.22	6.40
Israel	1.55	0.26	6.14
Italy	3.82	0.2	2.67
Jordan	-1.65	0.16	3.78
Japan	5.49	0.21	1.07
Kazakhstan	-1.69	0.19	20.31
Kenya	0.09	0.22	4.50
Kyrgyzstan	-3.36	0.23	81.33
Korea, Republic of	3.75	0.27	1.27
Kuwait	-1.35	0.19	3.86

Table A.8 – continued

Country	$\hat{F}_i$	S.E	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^{\theta}$
Sri Lanka	-1.75	0.2	9.53
Lithuania	-1.25	0.22	5.62
Latvia	-1.31	0.25	6.15
Morocco	-0.37	0.24	2.19
Republic of Moldova	-10.47	0.21	10.84
Mexico	0.59	0.28	3.58
TFYR of Macedonia	-1.39	0.19	7.65
Malta	-0.46	0.25	15.90
Myanmar	-9.44	0.22	10.15
Mauritius	-2.89	0.27	6.74
Malaysia & Singapore	2.13	0.27	1.72
Nigeria	0.99	0.17	3.37
Netherlands	1.63	0.21	1.69
Norway	1.11	0.17	8.03
New Zealand	1.06	0.19	7.46
Oman	-1.49	0.22	4.74
Pakistan	-0.08	0.22	31.32
Panama	-1.5	0.21	22.81
Peru	0.26	0.22	7.97
Philippines	1.04	0.2	5.20
Poland	1.92	0.21	4.71
Portugal	1.76	0.19	5.81
Romania	2.16	0.2	15.30
Russian Fed.	2.32	0.2	1.04
Senegal	-2.54	0.17	5.14
Slovenia	-0.2	0.26	0.17
Sweden	1.99	0.22	0.83
Syria	0.02	0.18	9.26
Tunisia	-0.35	0.22	10.02
Turkey	1.79	0.22	3.21
Tanzania	-4.65	0.18	33.42
Ukraine	0.87	0.32	11.52
Uruguay	-1.73	0.23	34.64
Venezuela	1.24	0.21	15.36
South Africa	1.83	0.21	22.00
Zimbabwe	0.44	0.18	67.68

Table A.9: Productivity Parameters: Str., λ_i^S

Country	$\hat{F}_i$	S.E.	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^\theta$
USA	2.55	0.31	1.00
Albania	-0.97	0.21	18.35
Argentina	0.74	0.49	7.34
Australia	0.58	0.25	3.45
Azerbaijan	-0.87	0.26	20.74
Belgium & Lux	1.13	0.59	2.27
Bulgaria	-0.7	0.25	1.40
Bolivia	-2.28	0.28	52.76
Canada	1.07	0.36	2.51
Switzerland	1.87	0.25	0.75
Chile	-0.14	0.27	2.50
China & Hongkong	1.18	0.24	4.02
Cameroon	-1.44	0.23	39.65
Colombia	0.47	0.34	25.32
Costa Rica	-1.45	0.27	70.10
Cyprus	-0.53	0.36	12.57
Germany	3.17	0.3	3.25
Egypt	-0.02	0.19	0.78
Spain	1.67	0.25	1.81
Estonia	-0.4	0.24	6.00
Finland	1	0.38	2.36
France	2.67	0.26	0.89
United Kingdom	2.16	0.21	3.39
Greece	1.24	0.2	3.04
Honduras	-1.15	0.25	1.11
Hungary	0.24	0.36	2.10
Indonesia	0.58	0.27	3.27
India	1.59	0.22	1.98
Ireland	0.87	0.26	2.76
Iran	0.86	0.3	6.11
Iceland	-1.05	0.3	1.36
Israel	0.6	0.29	3.59
Italy	2.19	0.25	1.70
Jordan	-1.08	0.2	1.21
Japan	3.97	0.28	1.07
Kazakhstan	-1.6	0.25	3.83
Kenya	-1.56	0.29	1.43
Kyrgyzstan	-2.53	0.31	1.11
Korea, Republic of	1.26	0.39	2.44
Kuwait	-1.02	0.24	3.44

Table A.9 – continued

Country	$\hat{F}_i$	S.E	$\left(\frac{\lambda_{US}}{\lambda_n}\right)^\theta$
Sri Lanka	-0.4	0.25	2.53
Lithuania	0.45	0.29	2.13
Latvia	-0.88	0.34	1.22
Morocco	0.23	0.36	3.01
Republic of Moldova	-1.85	0.29	2.78
Mexico	0.6	0.54	1.79
TFYR of Macedonia	-0.89	0.25	1.57
Malta	-1.18	0.35	2.01
Myanmar	-1.45	0.4	1.03
Mauritius	-1.91	0.37	2.21
Malaysia & Singapore	-0.87	0.34	2.05
Nigeria	-2.59	0.22	1.17
Netherlands	1.46	0.28	2.00
Norway	0.52	0.2	3.06
New Zealand	-0.78	0.25	1.42
Oman	-1.42	0.26	11.10
Pakistan	-0.74	0.29	1.56
Panama	-1.44	0.27	2.19
Peru	-0.35	0.29	2.19
Philippines	0	0.25	2.37
Poland	1.19	0.25	1.19
Portugal	0.07	0.25	1.46
Romania	0.71	0.3	1.32
Russian Fed.	1.73	0.26	2.09
Senegal	-2.14	0.22	1.17
Slovenia	-0.01	0.38	1.20
Sweden	0.84	0.29	1.98
Syria	-0.72	0.24	2.86
Tunisia	-0.67	0.29	1.85
Turkey	1.05	0.3	2.00
Tanzania	-1.17	0.24	1.07
Ukraine	0.65	0.61	1.07
Uruguay	-0.29	0.26	2.36
Venezuela	0.77	0.29	2.30
South Africa	-0.84	0.29	2.47
Zimbabwe	-2.53	0.24	2.39

Table A.10: Counterfactual Experiments: k^E/y

	Log Variance	90/10 ratio
Baseline	1.26	7.16
Autarky	1.42	9.3
$\tau_{in}^E = 1$	1.12	6.7
$\tau_{in}^S = 1$	1.29	7.3
$\tau_{in}^M = 1$	1.02	6.1
$\tau_{in}^J = 1$ (zero gravity)	0.91	5.6

Table A.11: Counterfactual Experiments: k^S/y

	Log Variance	90/10 ratio
Baseline	0.58	1.43
Autarky	0.63	1.56
$\tau_{in}^E = 1$	0.55	1.31
$\tau_{in}^S = 1$	0.57	1.43
$\tau_{in}^M = 1$	0.52	1.27
$\tau_{in}^J = 1$ (zero gravity)	0.49	1.21

Table A.12: Counterfactuals: Welfare Change

	Poor	Rich	World
Baseline	-	-	-
Autarky	-13%	-3%	-8%
$\tau_{in}^E = 1$	9%	1.4%	3%
$\tau_{in}^S = 1$	1.5%	0.8%	1.1%
$\tau_{in}^M = 1$	22%	5%	10%
$\tau_{in}^J = 1$ (zero gravity)	34%	8%	16%

Table A.13: Trade Shares for Equipment, π_{in}^{E}

	USA	UK	Japan	Can.	Mauritius	Arg.	India	Egypt	Senegal	Zim.
USA	87.2	0.8	6.7	0.7	0.07	0.02	0.1	0	0	0
UK	10.8	71.8	4.9	0.4	0.05	0.04	0.16	0	0	0
Japan	1.6	0.1	96.2	0.2	0	0	0	0	0	0
Can.	30.7	1.9	4.8	55.8	0	0.12	0	0	0	0
Maur.	3.4	9.3	11.6	0.3	20.7	0.1	0.5	0	0	0
Arg.	7.3	5.1	4.6	0.1	0.2	64.9	0.1	0	0	0
India	2.3	1.2	3.6	0.1	0.1	0	89.9	0	0	0
Egypt	11.0	6.1	8.7	0	0	0	0	48.2	0.8	0.17
Senegal	1.2	3.5	6.2	0.1	0	0	0	1.2	28.2	0.8
Zim.	5.8	11.3	2.0	0.5	0	0	0	0.9	0.4	68.5

Note: Zeros indicate the value is less than 10^{-3}. Entry in row i, column n, is the fraction of equipment country i imports from country n.

Table A.14: Trade Shares for Structures, π_{in}^S

	USA	UK	Japan	Can.	Mauritius	Arg.	India	Egypt	Senegal	Zim.
USA	98.4	0.06	0.01	0.4	0	0	0	0	0	0
UK	0.003	96.8	0.12	0.06	0	0	0	0	0	0
Japan	0	0	98.1	0.01	0	0	0	0	0	0
Canada	2.1	0.4	0.8	93.5	0	0	0	0	0	0
Mauritius	0.15	0.09	0.12	0.1	92.5	0	0.3	0	0	0
Argentina	0.6	0.3	0.2	0	0	97.1	0	0	0	0
India	0.09	0.3	0.5	0.01	0.1	0	98.7	0	0	0
Egypt	0.8	1.3	0.9	0.06	0	0	0	92.2	0.11	0.03
Senegal	0.95	0.26	0.67	0	0	0	0	0.12	88.7	0.01
Zimbabwe	1.3	3.7	1.1	0.05	0	0	0	0.17	0.07	72.7

Note: Zeros indicate the value is less than 10^{-3}. Entry in row i, column n, is the fraction of equipment country i imports from country n.

Table A.15: SITC and ISIC 4-digit industry codes for Equipment and Structures

	ISIC	SITC 4-digit industry code
Equipment	381	6785, 6793, 6935, 6940, 6951, 6960, 6974, 6991, 6992, 6996, 6997, 6998, 8121, 8946, 9510, 691A, 691X, 692A, 692X, 697A, 697X, 699A, 699X, 69XX, 711A, 711X
	382	6953, 6954, 7149, 7188, 7211, 7212, 7213, 7219, 7247, 7248, 7251, 7252, 7259, 7263, 7269, 7272, 7281, 7284, 7361, 7369, 7371, 7413, 7414, 7416, 7431, 7451, 7452, 7491, 7492, 7493, 7499, 7784, 695X, 712A, 712X, 714A, 714X, 718X, 721X, 724X, 725X, 726A, 726X, 727A, 727X, 728X, 72XX, 736X, 737X, 73XX, 741X, 742A, 742X, 743A, 743X, 745X, 749A, 749X, 74XX, 7511, 7512, 7591, 751A, 751X, 752A, 752X, 759X, 75XX
	383	6973, 7243, 7721, 7722, 7742, 7751, 7752, 7754, 7757, 7758, 7781, 7782, 7783, 8124, 716A, 716X, 771A, 771X, 772A, 772X, 774X, 775X, 776A, 776X, 778A, 778X, 77XX, 812X, 7641, 7642, 7649, 7788, 8983, 761A, 761X, 762A, 762X, 764A, 764X, 76XX, 898A, 898X
	384	7822, 7852, 7912, 785X, 786A, 786X, 791A, 791X, 79XX, 7133, 7139, 7810, 7821, 7831, 7849, 713X, 71XX, 782X, 783X, 784A, 784X, 78XX, 7851, 7852, 7928, 792A, 792X, 7853, 7861, 7868
	385	8710, 8710, 8720, 8720, 8741, 8741, 8745, 8745, 8748, 8748, 8749, 8749, 8811, 8811, 8813, 8813, 8822, 8822, 8822, 8822, 8830, 8830, 8830, 8830, 8841, 8841, 8841, 8841, 8842, 8842, 8842, 8842, 8851, 8851, 8851, 8851, 8851, 8852, 8852, 8852, 8996, 8996, 874X, 874X, 874X, 87XX, 881X, 881X, 881X, 881X, 882A, 882X, 882X, 882X, 884X, 884X, 884X, 885A, 885X, 88XX
Structures	5	7234, 7283, 7441, 7442, 722A, 722X, 723A, 723X, 744A, 744X

Figure A.1: Share of Imports in Equipment, $\frac{\text{Equipment imports}}{\text{Domestic Production + Imports - Exports}}$

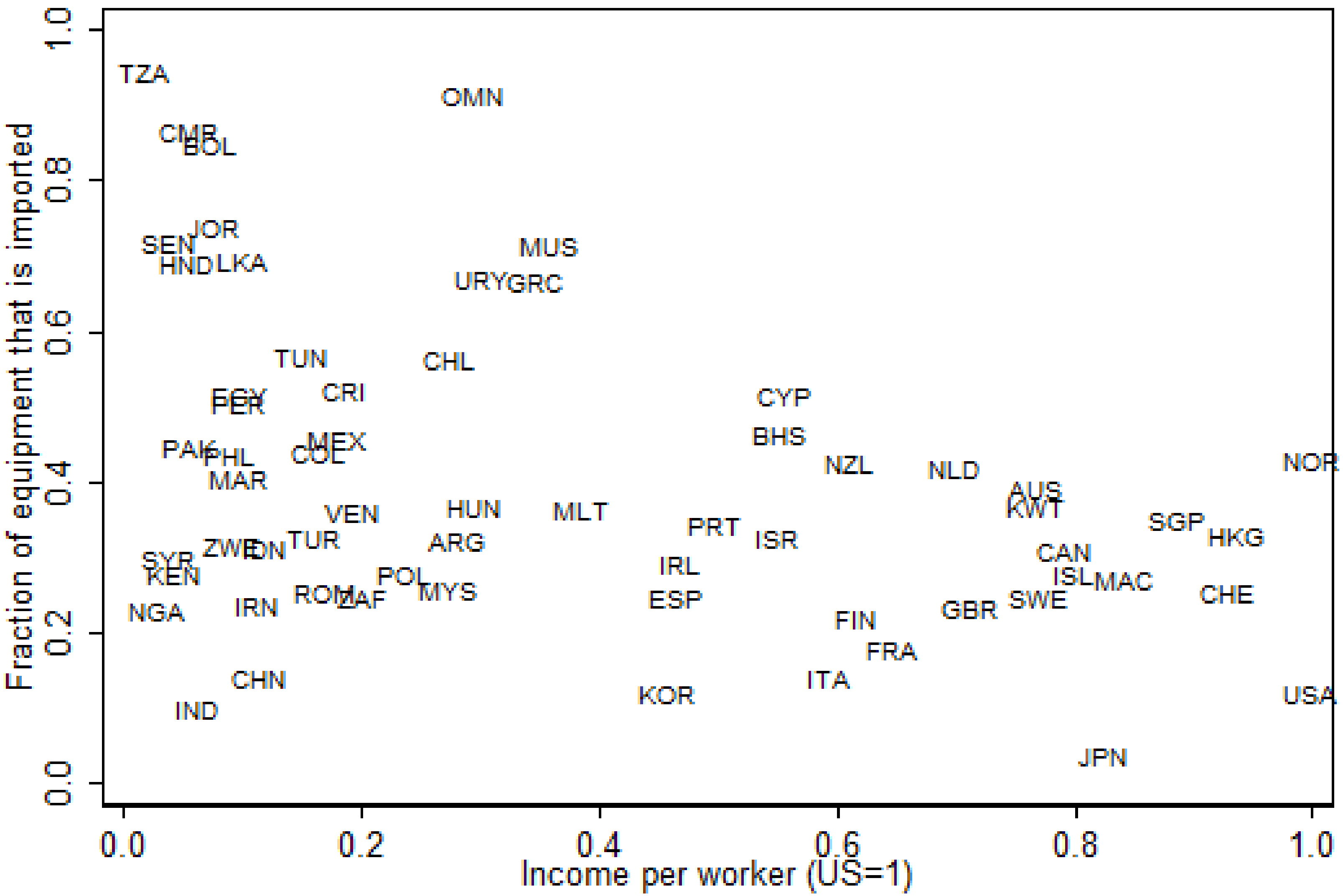


Figure A.2: Share of Equipment in Total Imports

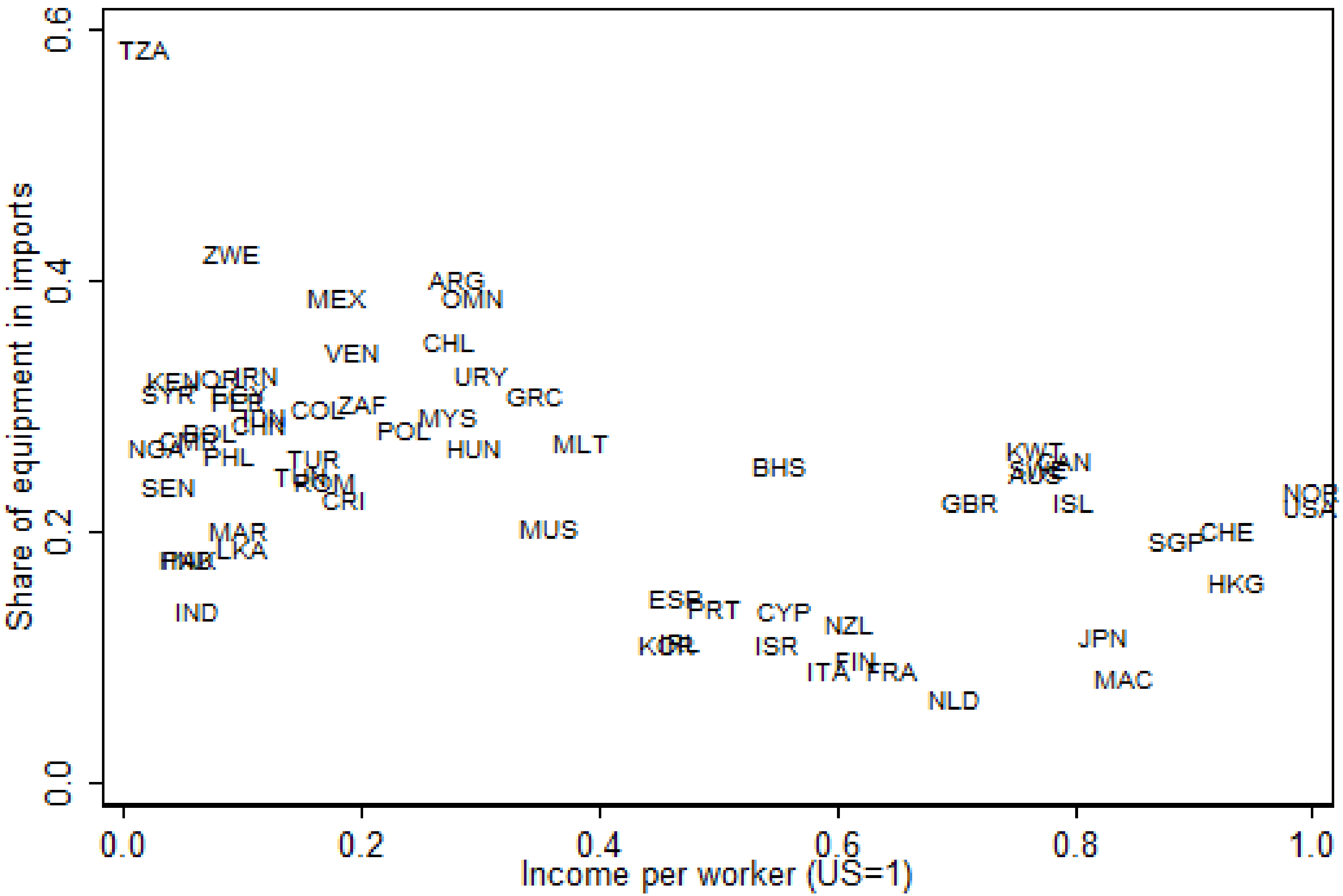


Figure A.3: Share of Equipment in Total Capital

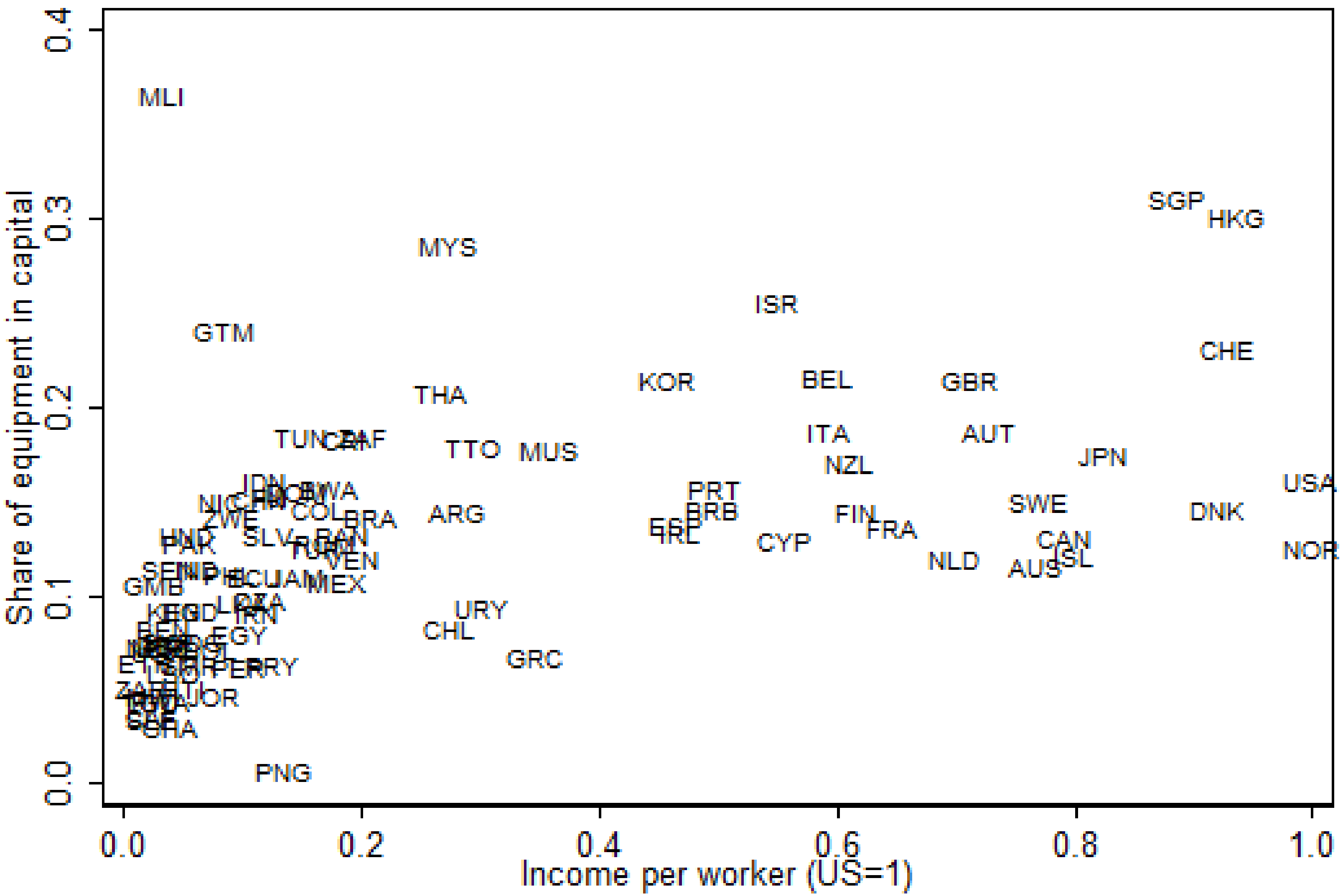


Figure A.4: Distribution of Efficiency

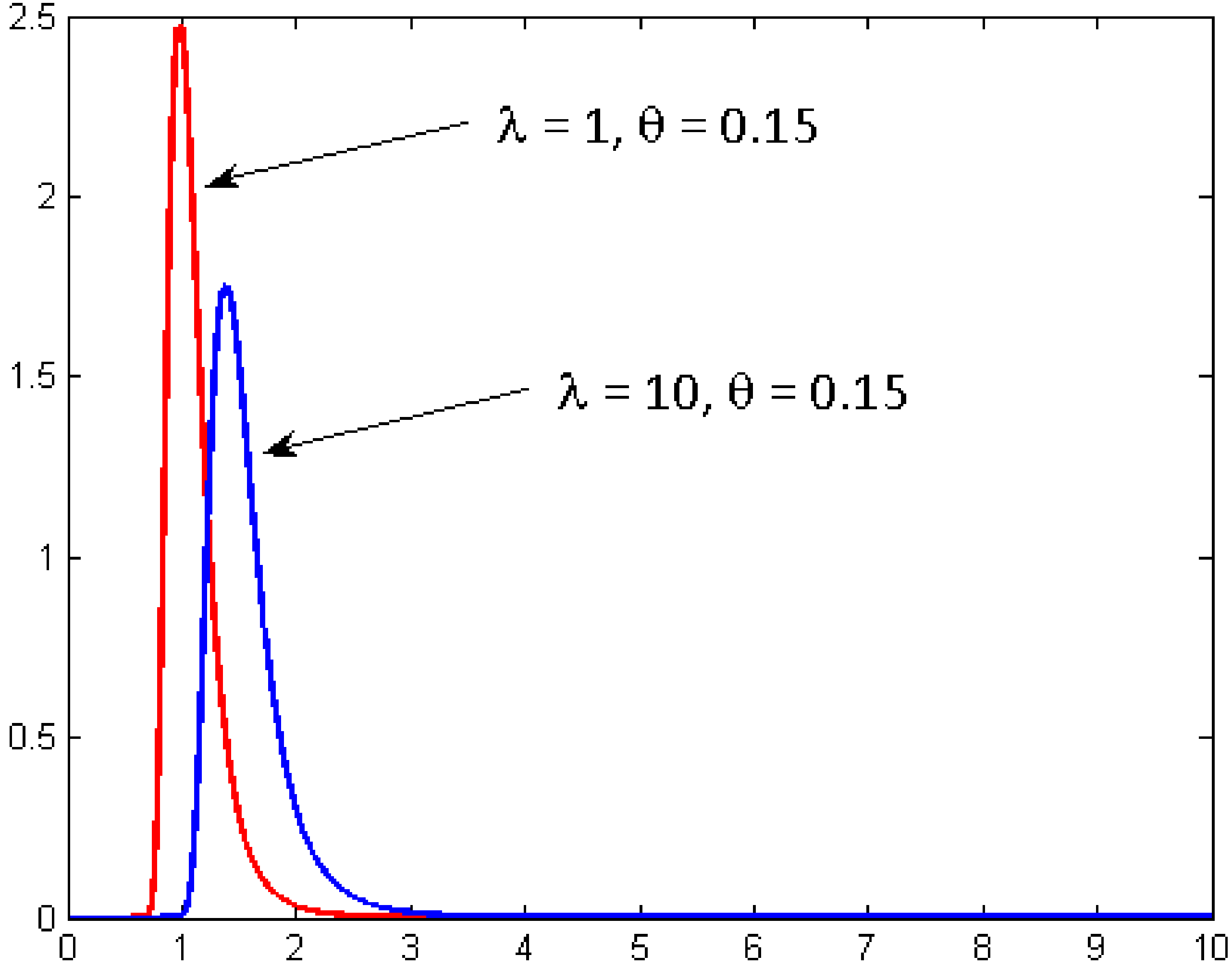


Figure A.5: Distribution of Efficiency

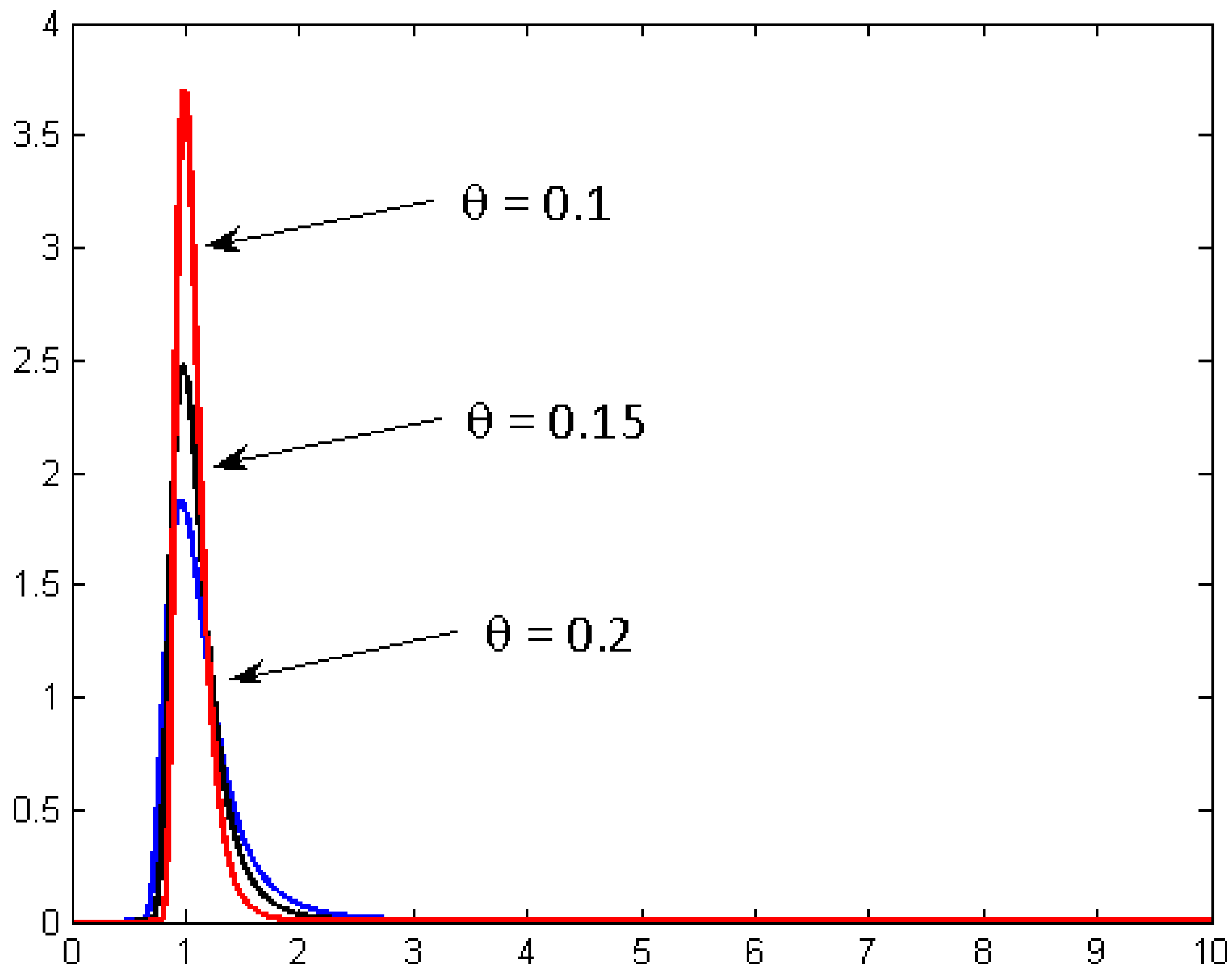


Figure A.6: Investment rate: Model vs Data. (US=1)

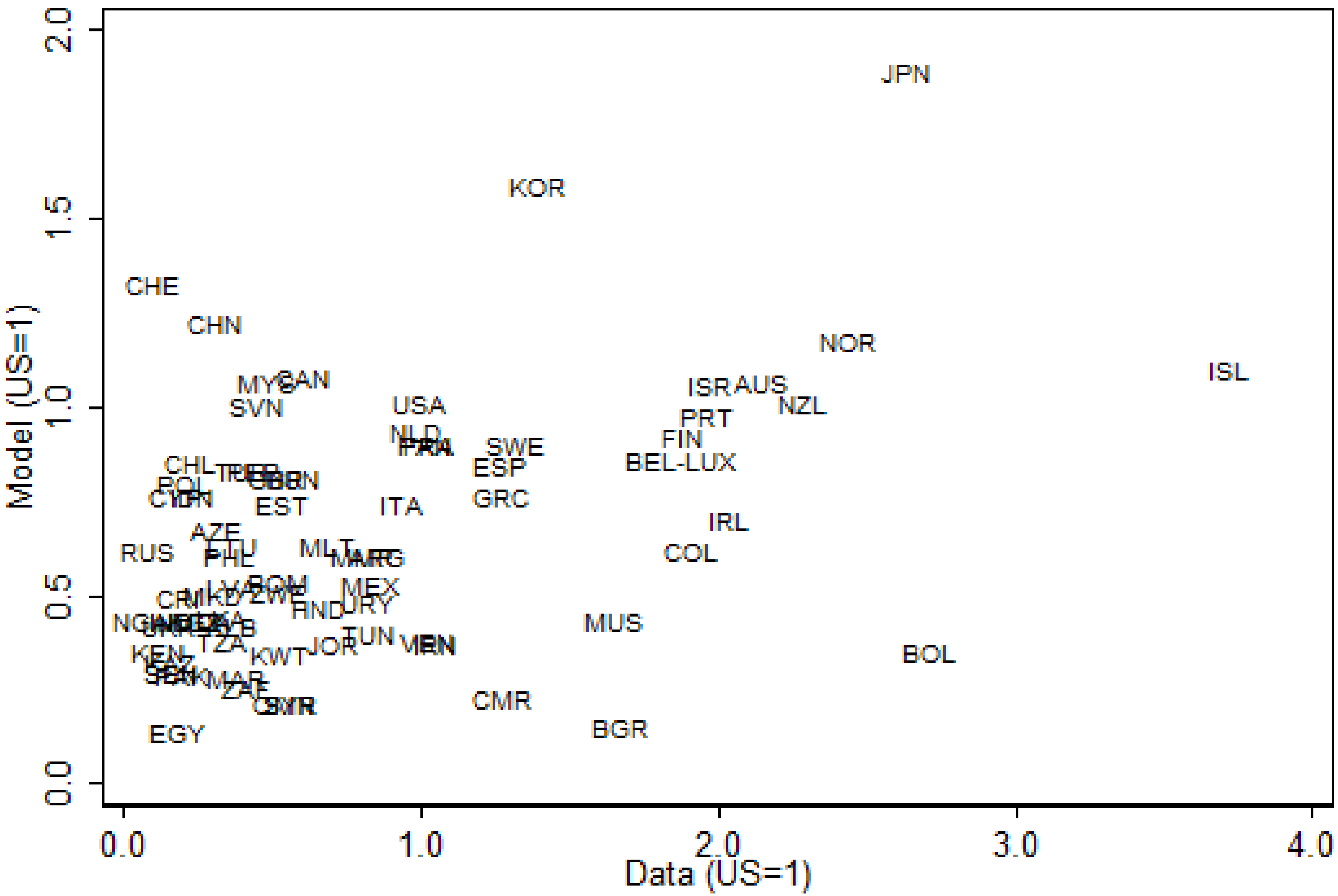


Figure A.7: Price of Equipment (US=1)

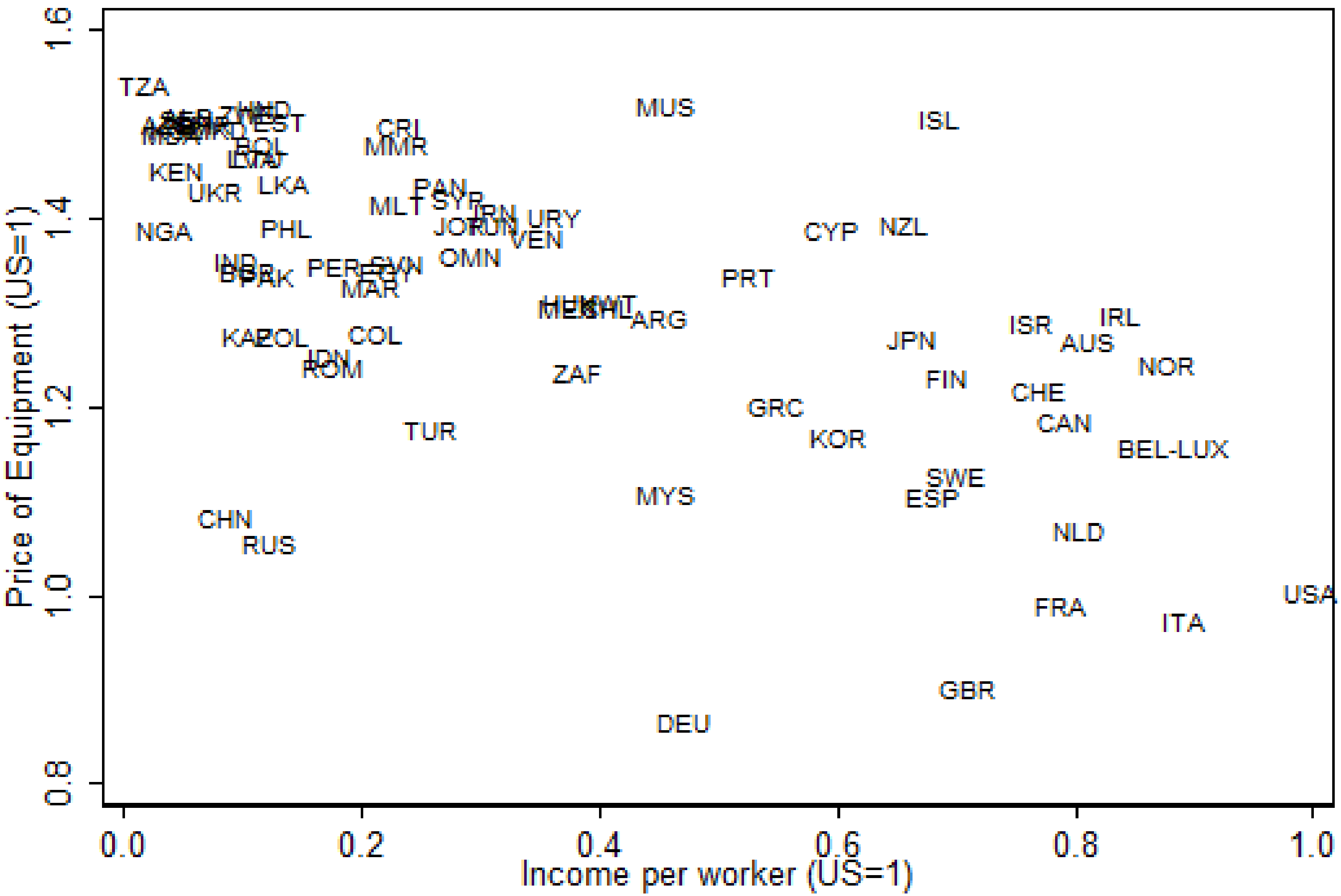


Figure A.8: Price of Structures (US=1)

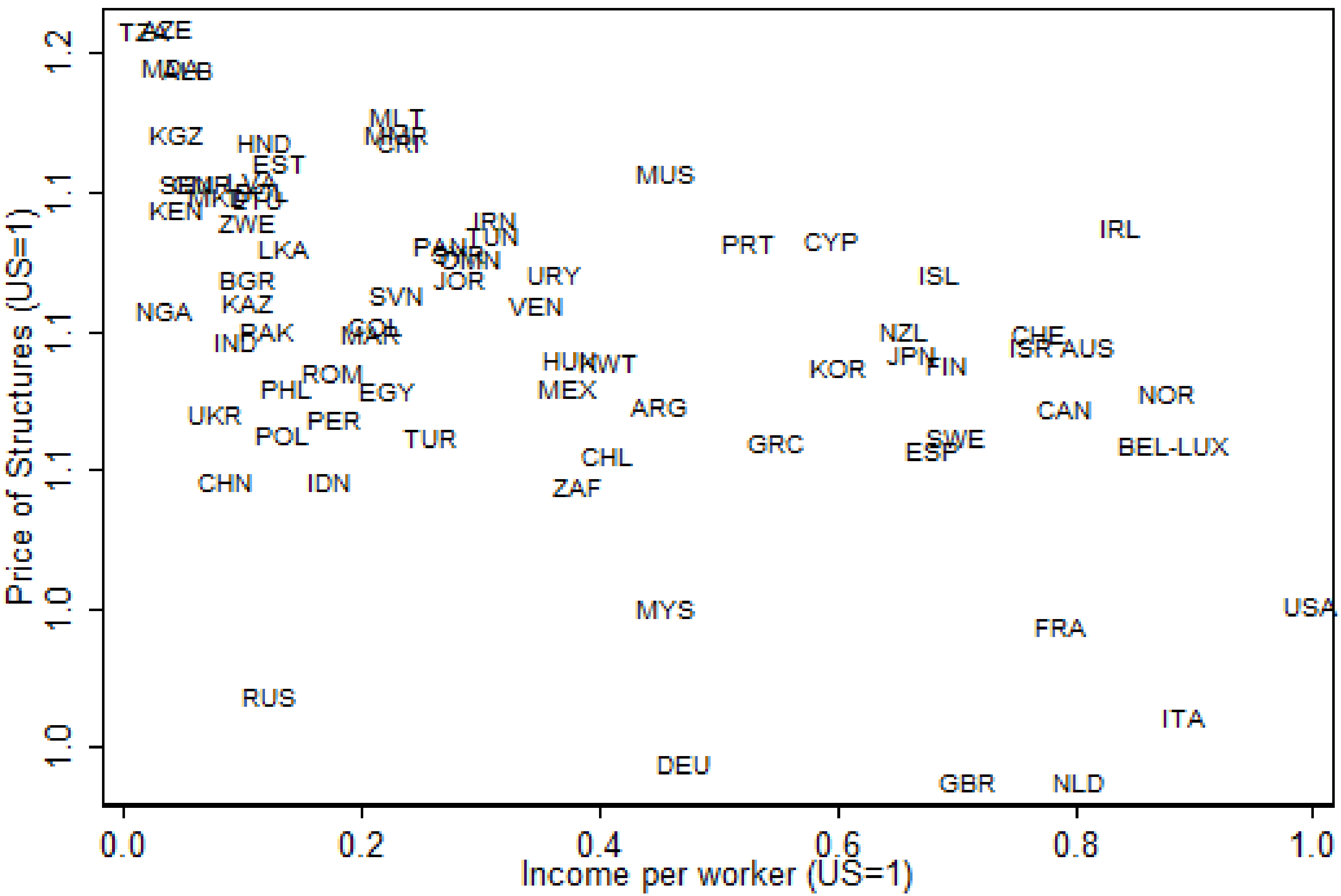


Figure A.9: Price of Equipment relative to Consumption (US=1): Model vs Data

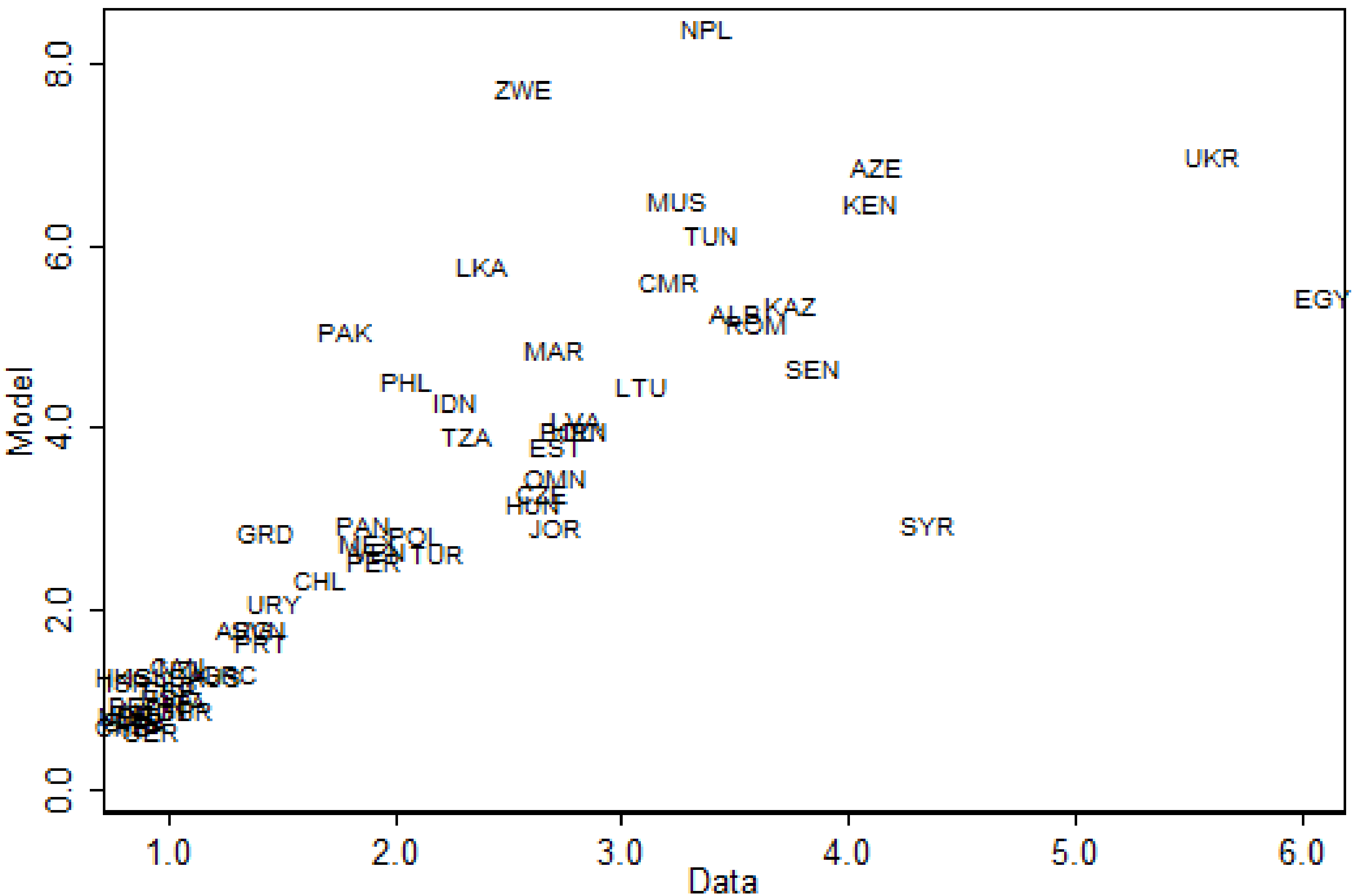


Figure A.10: Price of Structures relative to Consumption (US=1): Model vs Data

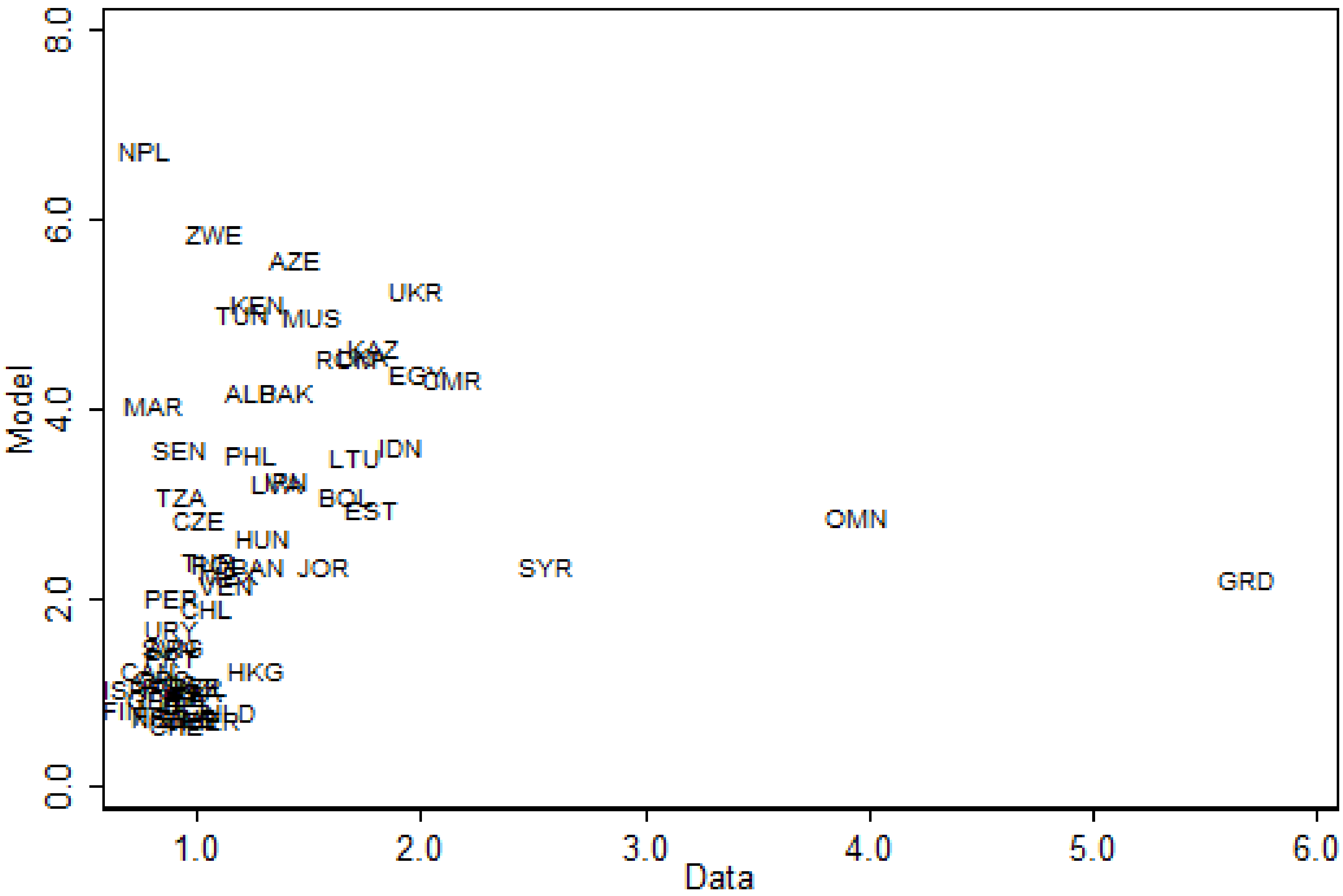


Figure A.11: Price of Equipment relative to Structures (US=1)

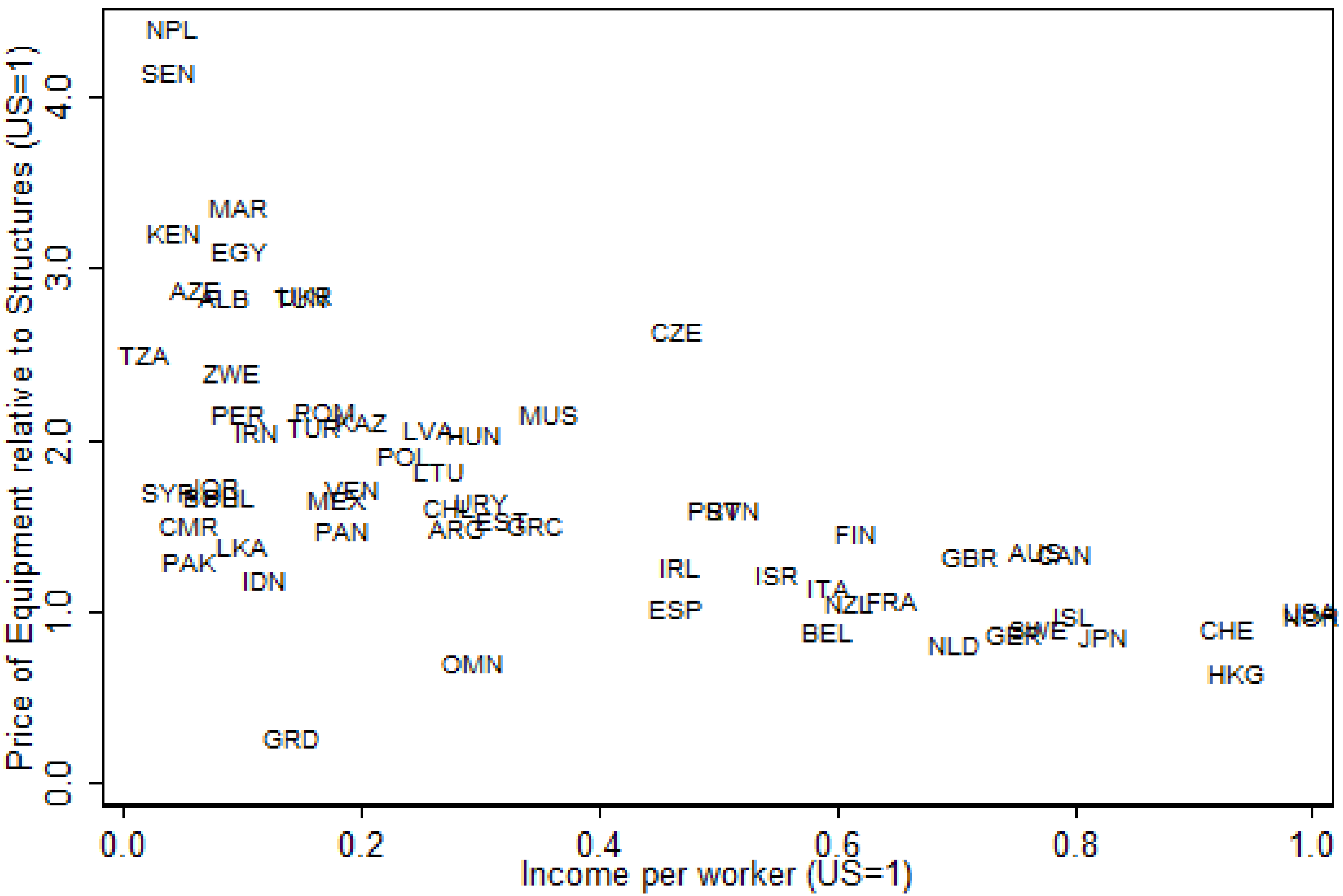


Figure A.12: Absolute Price of Equipment (US=1): Baseline and Autarky

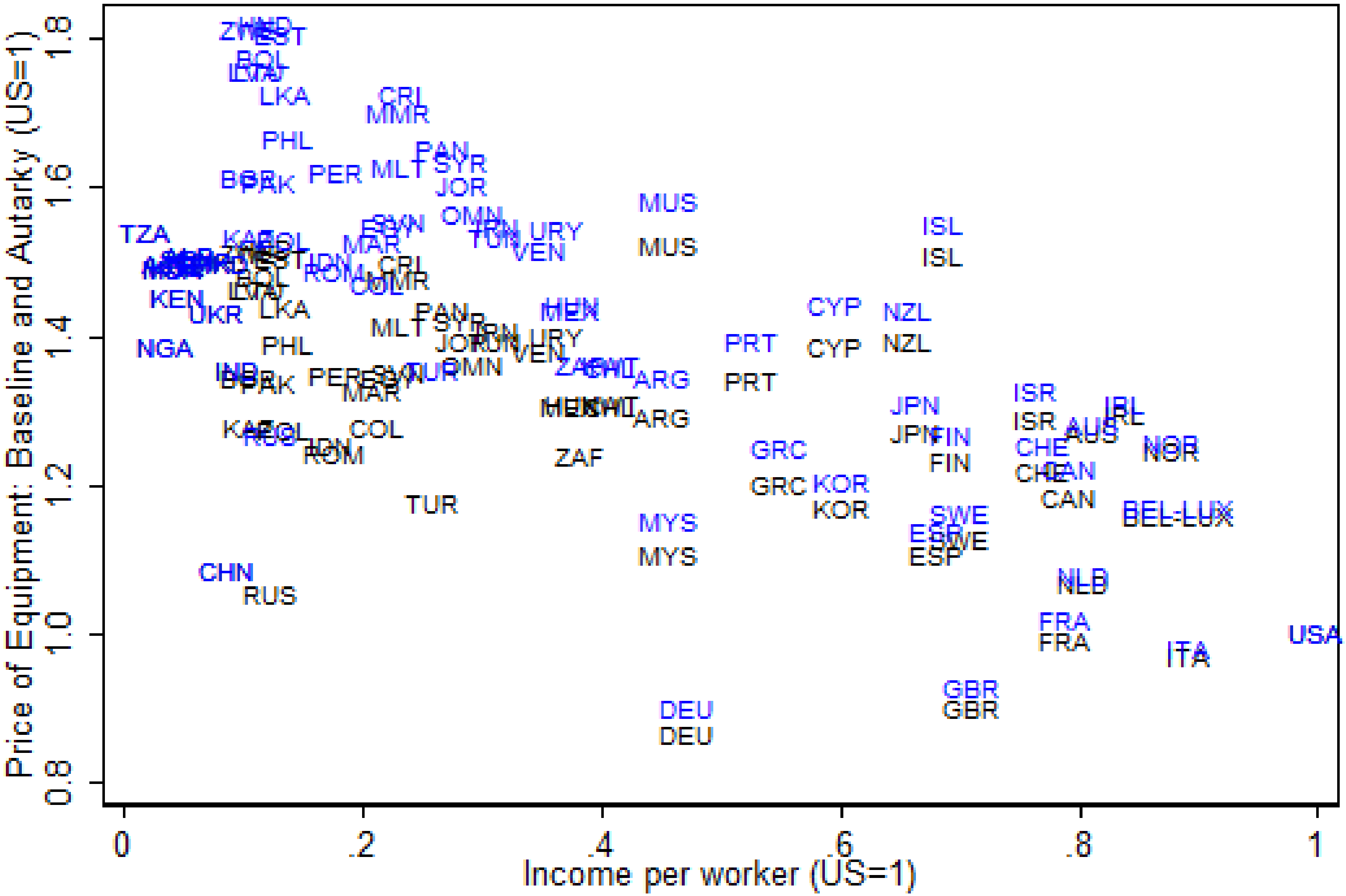
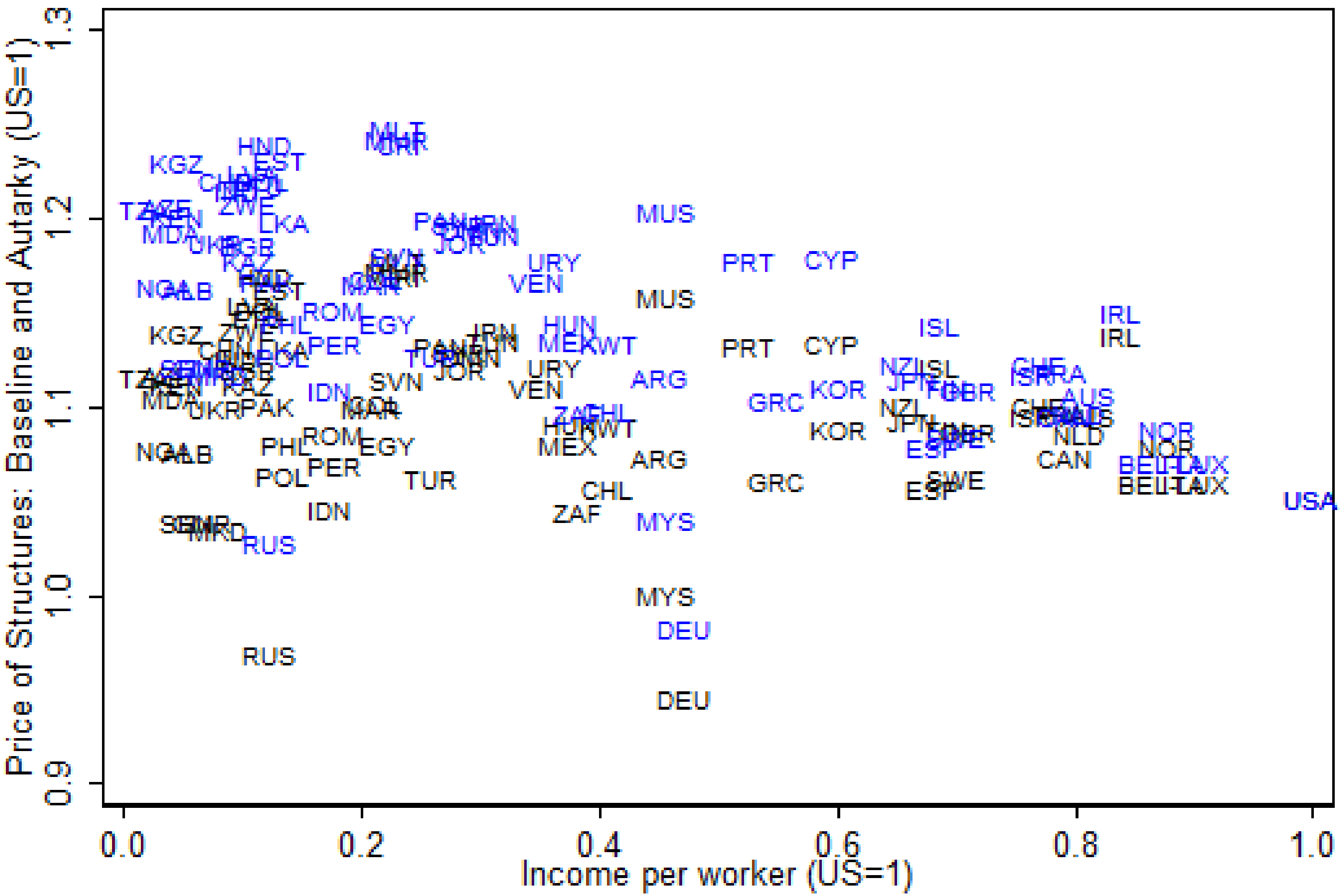


Figure A.13: Absolute Price of Structures (US=1): Baseline and Autarky



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