Composition of Capital and Gains from Trade in Equipment

Piyusha Mutreja*
Syracuse University

January 2017

Abstract

Income differences across countries are enormous. In this paper, I quantify a novel channel through which countries gain from equipment trade: composition of capital. During 1985-2005, while the rich-poor gap in aggregate capital-output ratio is relatively stable, composition of capital evolved substantially: share of equipment increased in rich countries and it declined in many poor countries. Using a multi-country Ricardian model of trade, I quantify the impact of 1985-2005 fall in equipment trade barriers on capital composition and incomes. The decline in trade barriers accounts for approximately one-third of the changes in equipment capital shares. All countries gain income and 45 percent of the gains are transmitted via the capital composition channel. Poor countries benefit predominantly through the capital composition channel and rich countries gain mostly through increases in total factor productivity.

JEL Classification: F43, F14, O16, O47, E22

Keywords: Equipment capital, Structures capital, Capital composition, Equipment Trade, Income, Gains from trade

*Email: pmutreja@syr.edu. Many people have provided helpful comments. I am thankful to Gary Fethke, Ariell Reshef, Guillaume Vandenbroucke, Gustavo Ventura, Jeffrey Weinstein, Mark Wright, and seminar participants at Colgate University, Syracuse University, the 2010 Conference on Economic Growth and Development at ISI Delhi, the 2009 Midwest Trade Meetings, the 2009 Midwest Macro Meetings, University of Iowa, and University of Pittsburgh. I especially thank B. Ravikumar, Raymond G. Riezman and Kei-Mu Yi for their insightful comments and invaluable guidance.

1 Introduction

Income disparity across countries is enormous. One of the most robust relationships in economic growth literature is that differences in physical capital intensity are systematically related to the differences in income. This has led economists to examine the determinants of capital formation and the resulting implications for cross-country incomes. The broad consensus is that low productivity levels in poor countries are mainly responsible for low capital-output ratios and, thus, low incomes.[1] Another stylized fact is that the world equipment production is highly concentrated, and most countries import their equipment (see Eaton and Kortum, 2001). Since equipment is the tradable component of capital, researchers have examined the role of equipment trade in incomes and have found that reductions in barriers to equipment trade result in large income gains.[2]

The mechanism through which lower equipment trade barriers translate into income gains is largely a black box. I dig into this black box and focus on the composition of capital. Rich countries have higher equipment capital intensity than poor countries. In 2005, twenty-one percent of the capital stock in rich is in equipment, and the remainder is in structures.[3] Equipment capital share in poor is only seven percent (for rich versus poor comparisons, I use 90th and 10th percentiles of the world income per worker distribution to represent rich and poor, respectively). During 1985-2005, while the rich-poor gap in aggregate capital-output ratio is relatively unchanged at approximately a factor of three, significant changes have taken place in the composition of capital. The share of equipment has increased in rich countries, but it has declined in many poor countries. In this paper, I assess the role of equipment trade in the evolution of composition of capital and how it affects incomes through capital composition.

Quantitatively, equipment trade is important for capital composition. The fall in barriers to equipment trade during 1985-2005 accounts for 30 percent of the increase in equipment capital share in rich and 32 percent in poor. With lower trade barriers, rich specialize in equipment and reap efficiency gains. Poor benefit by trading their comparative advantage good for equipment, which is inefficiently produced at home. This is the first contribution of this paper. Second, I examine the channels through which equipment trade affects incomes. The 1985-2005 fall in equipment trade costs leads to higher incomes in all countries. I quantify a novel channel, namely capital composition, through which income gains are transmitted. This channel is quantitatively more important for poor countries. It accounts for 35 percent of the income gain in rich and 64 percent in poor. To the best of my knowledge, this is the first paper that studies the role of equipment trade in cross-country composition of capital and quantifies a new mechanism through which countries reap the gains from trade.

[1] Restuccia and Urrutia (2001), Hsieh and Klenow (2007) and Greenwood, Sanchez, and Wang (2013) are examples.

[2] See, for instance, Eaton and Kortum (2001) and Mutreja, Ravikumar, and Sposi (2016).

[3] Equipment comprise fabricated metal products, electrical and non-electrical machinery, transport and communication equipment, office machinery, and professional and scientific equipment. Structures are residential and non-residential buildings.

One might argue that the *level* of capital stock, as compared to its *composition* is more important for determining income. As noted previously, the cross-country gap in level of aggregate capital-output ratio exhibits little change over time and the composition of capital has changed significantly across countries. In a standard income accounting exercise, this implies that the importance of capital composition for income has more than quadrupled overtime. Most models of economic growth focus on the aggregate capital-output ratios and inevitably ignore the changes in composition that have taken place over time. These changes are important because they potentially reflect the extent of investment-specific technological change that has taken place across countries. Textbooks on economic growth and development characterize the process of economic growth by rapid capital accumulation. One key feature of rapid capital accumulation has been the substantial rise in equipment capital intensity. Trade speeds-up this process. Countries that gain the most from equipment trade do so not only because they accumulate more capital but also because they accumulate equipment capital at a faster rate than structures.

I begin by extending the multi-country Ricardian trade model in Eaton and Kortum (2002) and incorporate four sectors: equipment goods (tradable investment goods), structures (non-traded investment goods), tradable intermediate goods, and a non-traded final good. Countries differ in their average level of productivity for each of the tradable goods and in their final good productivity. International trade is subject to bilateral iceberg costs. A representative household consumes the final good and allocates its savings to investment in equipment and structures. The stocks of equipment and structures capital, as well as the equipment capital share, are determined endogenously in the world general equilibrium and are functions of a country's productivity levels, and home expenditure shares (fraction of expenditure on home produced goods).

To quantify the multi-country model, I calibrate productivity levels and trade costs to match the data on relative prices and bilateral trade flows in a sample of 65 countries in 2005. The quantitative model fits calibration targets well and is also consistent with observed cross-country differences in equipment capital share, equipment and structures capital stocks and cross-country incomes. The calibrated productivity levels imply that rich countries are highly productive in equipment. Rich have a comparative advantage in equipment, while poor have a comparative advantage in intermediate goods. Similar to Waugh (2010), poor countries face higher trade costs than rich countries to export to all destinations.

In the structural framework, the equipment capital share in a country is function of its equipment productivity, intermediate goods productivity, and trade flows. A variance decomposition exercise implies that equipment trade flows account for 23 percent of the cross-country dispersion in equipment capital share in 2005. Equipment productivity differences account for 50 percent, and the remaining variation in equipment capital share is accounted for by intermediate goods productivity and trade flows.

To explore and quantify the mechanisms through which equipment trade affects capital composition and incomes, I conduct counterfactual experiments by adjusting equipment trade costs.

In the principal experiment, I assess the impact of 1985-2005 decline in equipment trade barriers. For this, I calibrate equipment trade costs in 1985 for all bilateral country pairings among the 65 countries in 2005 sample. The average fall in equipment trade costs during 1985-2005 is 71 percent, with rich exporters experiencing a slightly larger decline. In the counterfactual experiment, I adjust equipment trade barriers to their level in 1985, and set other parameters at their calibrated levels in 2005. The results imply that 1985-2005 decline in equipment trade costs increased equipment capital share by 10 percentage points in rich and 3 percentage points in poor. Incomes, on average, increased by 8.4 percent, with poor gaining slightly more. Note that these gains are attributable only to the 1985-2005 fall in equipment trade costs as other parameters are set at their 2005 level.

How are the income gains from reduced trade costs transmitted? Income in my model is determined by a country's total factor productivity (henceforth, TFP), level of capital stock, and a term that captures the effect of capital composition. Capital composition is a quantitatively significant channel through which income gains are transmitted: changes in the capital composition term account for 35 percent of the income gain in rich and 64 percent in poor. While all countries gain from reductions in trade costs, poor gain mostly through changes in the composition of capital and not per-se the level. Rich countries gain via changes in the level of capital stock and TFP.[4]

The mechanics of above income gains lie in how *effective* equipment productivity responds to adjustments in equipment trade costs via prices. The equipment sector has a continuum of goods. Intuitively, effective equipment productivity captures a country's average productivity over the subset of continuum that is produced at home. The 1985-2005 fall in equipment trade costs affects the relative price of equipment and leads to specialization according to comparative advantage in all countries. Rich countries specialize more in production of those equipment goods for which they have the highest idiosyncratic productivity draws and poor countries reduce the production of equipment goods with low idiosyncratic productivity draws. Owing to the declining equipment trade costs between 1985 and 2005, effective equipment productivity across countries increases by a factor of 1.4, on average. Countries that experience larger gains in effective equipment productivity, benefit most via the capital composition channel.

The importance of equipment capital for economic growth is well known. A growing body of research quantifies the role of equipment trade in economic growth and related outcomes.[5] Technological improvements are often embodied in improved equipment (see, for instance, Greenwood, Hercowitz, and Krusell, 1997), tend to be skill-biased and so, exhibit capital-skill complementarity (see, for instance, Krusell et al., 2000). The more recent quantitative models connect endogenous capital formation with equipment trade flows. A common finding of existing empirical and quantitative research on trade and incomes is that reductions in trade costs lead to large gains in economic well-being, but it is relatively silent on transmission mechanisms for these gains. I assess

[4]TFP is partially endogenous and depends on the trade flows.

[5]See, for example, Eaton and Kortum (2001), Burstein, Cravino, and Vogel (2013), Parro (2013), and Raveh and Reshef (2016).

the channels through which these gains are transmitted.

The literature on composition of capital is relatively small. Mutreja (2014) measures the effect of capital composition on cross-country incomes, but does not investigate the determinants of capital composition. While the existing literature has mainly focussed on investment composition and its determinants, this is the first paper to quantify the role of trade in capital composition. Caselli and Wilson (2004) study nine capital goods categories and explain investment composition based on efficiency and abundance of complementary factors inputs. Although they use imports in each category of capital as a proxy for the overall investment in that type of capital, they find no role for trade in investment composition. Bems (2008) presents facts on investment in tradable and non-tradable goods but does not shed light on the determinants of disaggregate investment levels.

This paper relates to the section of economic growth literature that studies the role of trade in capital formation and income across countries. Eaton and Kortum (2001) employ a structural model of bilateral trade in equipment, and find that equipment trade barriers explain approximately 12.5 percent of the income differences. Contrary to Eaton and Kortum (2001), capital stocks and capital composition are endogenous in my model. I find that during 1985-2005, on average, 45 percent of income gains from a removal of equipment trade costs are transmitted through the capital composition channel.

My paper is related to parallel research in Mutreja, Ravikumar, and Sposi (2016). Relative to Mutreja, Ravikumar, and Sposi (2016), the main distinctions are the question and the quantitative results. Mutreja, Ravikumar, and Sposi (2016) construct a multi-country Ricardian model of trade in which equipment trade affects incomes through TFP and capital formation. While the theoretical setup and calibration strategy used in this paper are similar to Mutreja, Ravikumar, and Sposi (2016), I separate the the effect of composition of capital from its level. Using recent data on capital composition (from Mutreja, 2014), I *quantify* a novel channel for the transmission of gains from equipment trade. Poor countries gain incomes mostly through the capital composition channel while rich reap income gains via increases in the level of capital stock and TFP.

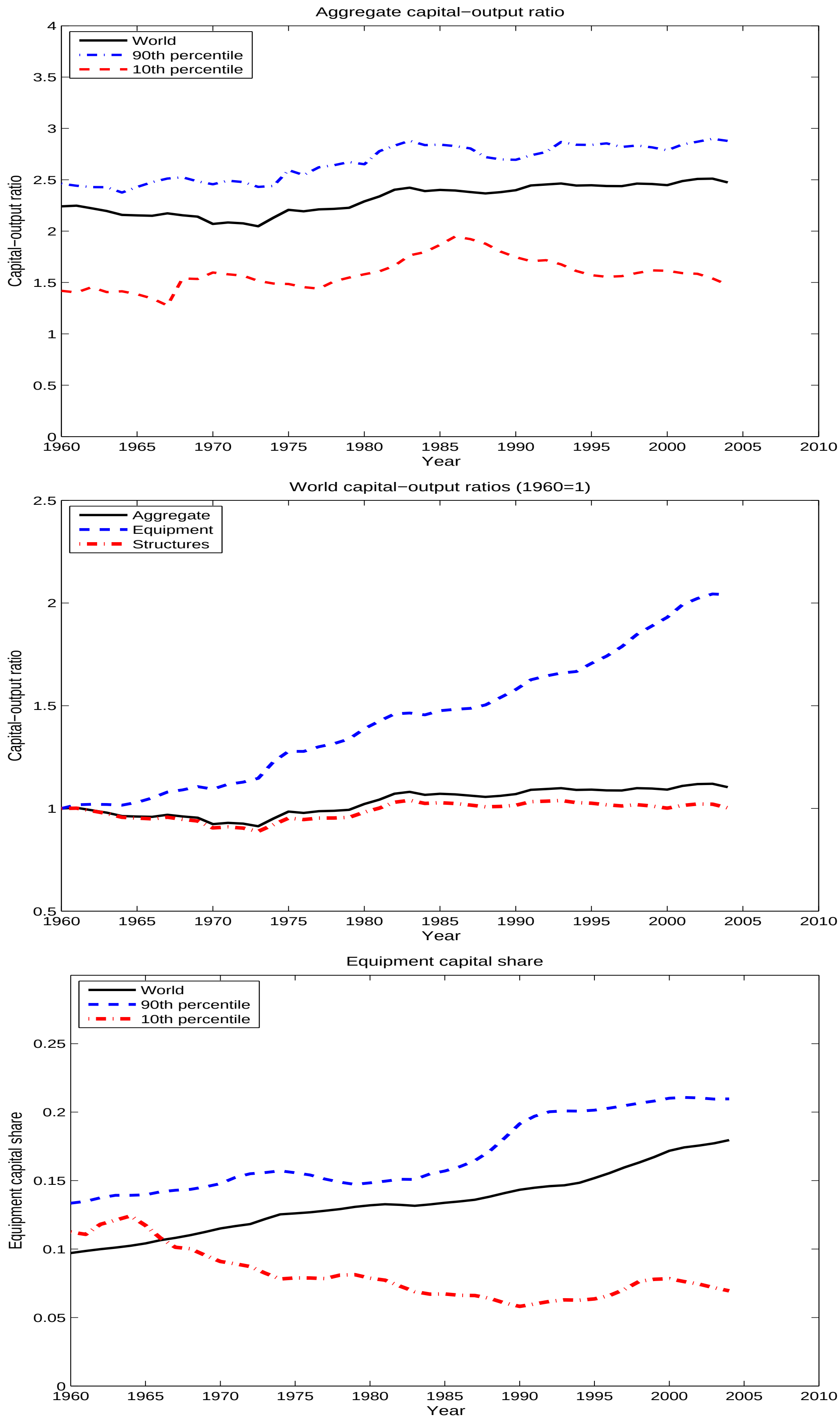
2 Motivating facts

Why should we focus on composition of capital? In this section, I present facts on capital composition and conduct exercises to motivate the significance of capital composition, in particular how this significance has evolved over time. The data on capital stocks and its composition correspond to 119 countries (see Mutreja, 2014, for details).

The top panel in figure 1 plots aggregate capital-output ratios over time for the world, the 90th percentile country (representative rich) and the 10th percentile country (representative poor).[6] The facts presented in this figure are already well known. Over the 45 year time period, the aggregate capital-output ratios show little upward movement and are essentially flat. The gap in capital-

[6] "World" comprises of 119 countries from Mutreja (2014).

Figure 1: Capital and its composition



output ratios between rich and poor is relatively stable: the 90th to 10th percentile ratio falls in the range 3-4, though this gap has slightly widened overtime.

The picture looks different when we decompose aggregate capital stock into equipment and structures. The middle panel of figure 1 plots the evolution of aggregate, equipment and structures capital-output ratios for the world, all relative to their respective levels in 1960. The world stock of equipment capital has grown tremendously over the years. The equipment capital-output ratio in the world has increased by more than a factor of two, while the structures capital-output ratio has declined, albeit modestly.

Is the rise of equipment capital distributed equally across countries? The answer is no. Many poor countries experience a decline instead of an increase in their equipment capital shares. The bottom panel of figure 1 plots equipment capital share in the world, the representative rich country and the representative poor country. The equipment capital share increases by 84 percent in rich and it declines by 36 percent in poor. A majority of rich and poor countries exhibit this pattern. For instance, during this time period the equipment capital share more than triples in the US and it nearly doubles in Luxembourg. In Niger, equipment capital share declines by 65 percent and in Gambia, it declines by 44 percent. Countries growing at high rates experience episodes of steep rise in their equipment capital shares. Between 1960 and 1990, Korea's structural transformation coincided with a growth of equipment capital share by 264 percent and since 1980, China's manufacturing growth has been accompanied by a near doubling of its equipment capital share.

Thus, while cross-country gap in the *level* of aggregate capital-output ratio is stable over the years, the *composition* of capital has changed substantially. Are these changes in composition important for income across countries? Here, I motivate the importance of capital composition through a standard income accounting exercise (see Caselli, 2005), though this question is answered much more rigorously in the remainder of the paper. Assuming a Cobb-Douglas production function with equipment capital, structures capital and human capital augmented labor as factors, the income per worker in country i is given by

$$y_i = A_i k_{ei}^{\mu\alpha} k_{si}^{(1-\mu)\alpha} h_i^{\alpha}$$

where A_i represents country i's TFP, k_{ei} and k_{si} are equipment and structures capital per worker and h_i denotes the average human capital per worker. α and μ are the factor shares. Using $\alpha = 1/3$ and $\mu = 0.56$ from Mutreja (2014), equipment and structures capital per worker account for 22.5 percent of the log variance in income per worker. The remaining 77.5 percent of the log variance is due to differences in h_i and residual TFP.

Defining equipment capital share in country i as $z_i = \frac{k_{ei}}{k_{ei}+k_{si}}$, the income per worker is:

$$y_i = A_i \left(k_{ei} + k_{si}\right)^{\alpha} \left\{z_i^{\mu}(1-z_i)^{1-\mu}\right\}^{\alpha} h_i^{\alpha}.$$

The contribution of capital to incomes is given by the expression $(k_{ei} + k_{si})^{\alpha} \left\{z_i^{\mu}(1-z_i)^{1-\mu}\right\}^{\alpha}$. Of this, while the first term captures the contribution of the level of capital stock, the second term captures the effect of its composition.[7] Consider the following numerical exercise. Suppose each country's total capital stock per worker, $k_{ei} + k_{si}$, is kept fixed and the equipment capital share, z_i, is adjusted to that in the US. This eliminates capital composition differences across countries while the differences in the level of capital stock remain. In the income accounting, this reduces the contribution of capital by 25 percent. Thus, composition differences are responsible for one-fourth of the overall contribution of capital in income accounting. Has the importance of capital composition evolved over time? Yes. If the same numerical exercise is conducted for prior years, the role of composition is smaller the further back we go. For instance in 1990 capital composition accounts for only 14 percent of the overall contribution of capital in income accounting and in 1980 it is much smaller at six percent. Clearly, differences in capital composition, much more now than they used to 30 or so years ago.

In an online appendix to this paper, I show that a neoclassical growth model along the lines of Restuccia and Urrutia (2001) and Hsieh and Klenow (2007) is consistent with observed capital-output ratios but it fails to produce the observed differences in capital composition.[8] Most models of economic growth focus on aggregate capital-output ratios and inevitably ignore the changes in composition that have taken place over time. These changes are important because they potentially reflect the extent of investment-specific technological change that has taken place across countries. Additionally, equipment is the tradable component of capital. Over the years, capital composition has potentially emerged as a significant channel through which equipment trade affects incomes. Accordingly, in this paper, I study the role of equipment trade in determining capital composition and assess resulting implications for incomes.

3 Multi-Country Trade Model

The world economy consists of N countries. Each country has four sectors: equipment, investment structures, intermediate goods, and final good. Broadly, equipment correspond to producer durables, and investment structures correspond to residential and non-residential buildings (see also Mutreja, Ravikumar, and Sposi, 2016). Equipment and intermediate goods are tradable, while structures and final good are non-traded. Within each country i, there is a measure of consumers, L_i, that grows at the rate n. Each consumer has one unit of time, which is supplied inelastically in the domestic labor market. Stocks of equipment capital, structures capital, and labor are used to produce the flow of equipment, structures, intermediate goods, and final good. Factors are mobile across sectors, and labor is immobile across countries. In what follows, all variables for country i are normalized relative to the labor force in country i and denote per worker quantities. The country and time subscripts are omitted where they are understood.

[7] k_{ei} and k_{si} are measured in PPP with US GDP as numeraire.

[8] The online appendix is available at the author's webpage.

3.1 Production Technology

3.1.1 Tradable Equipment Goods

Equipment goods sector has a continuum of goods that are indexed by $e \in [0, 1]$, and are produced via the following nested Cobb-Douglas production function between equipment capital k_e, structures capital k_s, labor l, and the aggregate intermediate good Q_m (described along with the production technology for intermediate goods):

$$q_e(e) = z_e(e)^{-\theta}[({k_e}^{\mu}{k_s}^{1-\mu})^{\alpha} l^{1-\alpha}]^{\gamma_e} {Q_m}^{1-\gamma_e},$$

where, similar to Dornbusch, Fischer, and Samuelson (1977), the production technology across individual goods differs only in the idiosyncratic productivity level, i.e., $z_e(e)^{-\theta}$. α, μ, and γ_e are the factor shares that are common across countries. Goods along the continuum are aggregated with a Dixit-Stiglitz technology with elasticity of substitution $\eta > 0$:

$$Q_e = \left[\int_0^1 q_e(e)^{\frac{\eta-1}{\eta}} de\right]^{\frac{\eta}{\eta-1}}$$

Productivity distribution: Following Alvarez and Lucas (2007), I assume that z_e are distributed independently and exponentially with parameter λ_e that differs across countries. Under this distributional assumption, the idiosyncratic productivity levels, $z_e^{-\theta}$, follow a Fréchet distribution, as used by Eaton and Kortum (2002). Parameter θ controls the dispersion of productivity levels around the mean. A larger θ implies more variation relative to the mean. I assume that θ is common to all countries.

The mean of the productivity distribution is proportional to λ_e^{θ}. λ_e governs the absolute advantage of country i in equipment. A country with a higher λ_e^{θ}, on average, can produce equipment more efficiently.

3.1.2 Non-traded Investment Structures

Each country has a structures sector, in which a representative firm produces homogeneous structures or buildings that are non-tradable across countries. Factors of production are combined via the following nested Cobb-Douglas production technology:

$$Q_s = [({k_e}^{\mu}{k_s}^{1-\mu})^{\alpha} l^{1-\alpha}]^{\gamma_s} {Q_m}^{1-\gamma_s},$$

where γ_s is the share of value added and is identical across countries.

3.1.3 Tradable Intermediate goods

The production technology for intermediate goods is similar to that for equipment goods. There are a continuum of goods indexed by $m \in [0, 1]$. Each individual good is produced via:

$$q_m(m) = z_m(m)^{-\theta}[({k_e}^{\mu}{k_s}^{1-\mu})^{\alpha} l^{1-\alpha}]^{\gamma_m} {Q_m}^{1-\gamma_m},$$

where $z_m(m)^{-\theta}$ is the idiosyncratic productivity level. γ_m is the factor share, which is the same across countries. The aggregate intermediate good is a C.E.S. aggregate of the individual goods with a constant elasticity of substitution $\eta > 0$:

$$Q_m = \left[\int_0^1 q_m(m)^{\frac{\eta-1}{\eta}} dm \right]^{\frac{\eta}{\eta-1}}$$

Productivity distribution: Similar to the equipment sector, z_m are distributed independently and exponentially with parameter λ_m that varies across countries. λ_m governs the absolute advantage of country i in intermediate goods. Comparative advantage is determined by relative average productivity across the two tradable sectors. A country with higher $(\lambda_e/\lambda_m)^\theta$ will have comparative advantage in the equipment sector relative to the intermediate goods sector. I assume that θ is identical across the two tradable sectors.[9]

3.1.4 Non-traded Final Good

In each country, there is a representative firm that employs factors and produces a non-tradable homogenous final good with the following production technology:

$$Q_c = A_c[({k_e}^{\mu} {k_s}^{1-\mu})^{\alpha} l^{1-\alpha}]^{\gamma_c} {Q_m}^{1-\gamma_c},$$

where γ_c is the factor share, which is common to all countries. A_c is country i's productivity in the final good.

3.2 Representative Household

Each country has a representative household that owns the labor endowment, as well as the stocks of both equipment and structures capital. In time period t, the representative household starts with k_e stock of equipment and k_s stock of structures and derives utility from consuming the final good:

$$\sum_{t=0}^{\infty} \beta^t \frac{c_{it}^{1-\sigma}}{1-\sigma},$$

where c_{it} is the consumption level of the final good in country i at time t. β is the period discount factor, which satisfies $\frac{1}{\beta} > 1 + n$, and σ is the inter-temporal elasticity of substitution.

Investment in time period t augments the existing capital stocks. Given prices, the representative household maximizes discounted lifetime utility subject to a budget constraint and two capital accumulation equations at time $t = 0, 1, ..., \infty$:

$$P_{cit} c_{it} + P_{eit} x_{eit} + P_{sit} x_{sit} = w_{it} + r_{eit} k_{eit} + r_{sit} k_{sit}$$

[9] Mutreja, Ravikumar, and Sposi (2016) estimate θ separately for capital goods and non-capital goods. The capital goods in Mutreja, Ravikumar, and Sposi (2016) are analogous to equipment in this paper. They find that θ is not significantly different across the two sectors.

$$(1+n)k_{eit+1} = (1-\delta_e)k_{eit} + x_{eit}$$

$$(1+n)k_{sit+1} = (1-\delta_s)k_{sit} + x_{sit},$$

where δ_e and δ_s are the depreciation rates of equipment and structures, respectively. P_c, P_e, and P_s denote the prices of the final good, equipment, and structures, respectively. w is the wage rate, and r_e and r_s are the rental rates for equipment and structures, respectively. x_{eit} and x_{sit} denote investments in the two types of capital in country i in period t.

3.3 International Trade

Both equipment trade and intermediate goods trade are subject to iceberg trade costs, denoted by τ_{eij} and τ_{mij}, respectively. More than one unit of an equipment good must be shipped from country j for one unit to arrive in country i. That is, $\tau_{eij} - 1$ units are lost in the transit. Likewise, for τ_{mij}. τ_{eij} and τ_{mij} comprise both policy and non-policy barriers to trade. τ_{eij} also represents the adjustment costs, if any, associated with adaptation of imported equipment to domestic production conditions. For consistency, $\tau_{eii} = 1$ and $\tau_{mii} = 1$ for each country i.

3.4 Equilibrium

The competitive world general equilibrium is a set of prices, allocations, and trade shares such that, in each country i, the representative household maximizes utility, firms in four sectors minimize their costs, all goods and factors markets clear, and trade is balanced.

Country i purchases each tradable good from the least-cost supplier. The fraction of country i's expenditure in each tradable sector that is spent on goods produced in country j is given by the following:

$$\pi_{eij} = \frac{\left[\left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha}\right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij}\right]^{-1/\theta} \lambda_{ej}}{\sum_l \left[\left(r_{el}^{\alpha\mu} r_{sl}^{\alpha(1-\mu)} w_l^{1-\alpha}\right)^{\gamma_e} P_{ml}^{1-\gamma_e} \tau_{eil}\right]^{-1/\theta} \lambda_{el}}$$

$$\pi_{mij} = \frac{\left[\left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha}\right)^{\gamma_m} P_{mj}^{1-\gamma_m} \tau_{mij}\right]^{-1/\theta} \lambda_{mj}}{\sum_l \left[\left(r_{el}^{\alpha\mu} r_{sl}^{\alpha(1-\mu)} w_l^{1-\alpha}\right)^{\gamma_m} P_{ml}^{1-\gamma_m} \tau_{mil}\right]^{-1/\theta} \lambda_{ml}}, \quad (1)$$

where π_{eij} and π_{mij} denote the bilateral trade shares. The price indices of aggregate equipment, Q_e, and aggregate intermediate good, Q_m, are:

$$P_{ei} = UV_e \left[\sum_l \left\{\left(r_{el}^{\alpha\mu} r_{sl}^{\alpha(1-\mu)} w_l^{1-\alpha}\right)^{\gamma_e} P_{ml}^{1-\gamma_e} \tau_{eil}\right\}^{-1/\theta} \lambda_{el}\right]^{-\theta}$$

$$P_{mi} = UV_m \left[\sum_l \left\{\left(r_{el}^{\alpha\mu} r_{sl}^{\alpha(1-\mu)} w_l^{1-\alpha}\right)^{\gamma_m} P_{ml}^{1-\gamma_m} \tau_{mil}\right\}^{-1/\theta} \lambda_{ml}\right]^{-\theta},$$

where V_e, V_m, and U are a collection of constants across countries. These are given by $V_e = (\alpha\mu\gamma_e)^{-\alpha\mu\gamma_e}(\alpha(1-\mu)\gamma_e)^{\alpha(\mu-1)\gamma_e}((1-\alpha)\gamma_e)^{(\alpha-1)\gamma_e}(1-\gamma_e)^{\gamma_e-1}$, $V_m = (\alpha\mu\gamma_m)^{-\alpha\mu\gamma_m}(\alpha(1-\mu)\gamma_m)^{\alpha(\mu-1)\gamma_m}((1-\alpha)\gamma_m)^{(\alpha-1)\gamma_m}(1-\gamma_m)^{\gamma_m-1}$, and $U = \Gamma(1+\theta(1-\eta))^{\frac{1}{1-\eta}}$, where $\Gamma(\cdot)$ is the gamma function (see appendix A for details). As in Eaton and Kortum (2002), I restrict parameters such that $U > 0$.

The prices of structures and final good are:

$$P_{si} = V_s \left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha}\right)^{\gamma_s} P_{mi}^{1-\gamma_s}$$
$$P_{ci} = \frac{V_c}{A_c} \left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha}\right)^{\gamma_c} P_{mi}^{1-\gamma_c},$$

where $V_s = (\alpha\mu\gamma_s)^{-\alpha\mu\gamma_s}(\alpha(1-\mu)\gamma_s)^{\alpha(\mu-1)\gamma_s}((1-\alpha)\gamma_s)^{(\alpha-1)\gamma_s}(1-\gamma_s)^{\gamma_s-1}$ and $V_c = (\alpha\mu\gamma_c)^{-\alpha\mu\gamma_c}(\alpha(1-\mu)\gamma_c)^{\alpha(\mu-1)\gamma_c}((1-\alpha)\gamma_c)^{(\alpha-1)\gamma_c}(1-\gamma_c)^{\gamma_c-1}$.

The two Euler equations from household optimization lead to the following equilibrium equipment and structures rental rates:

$$r_{ei} = \left[\frac{1}{\beta} - (1-\delta_e)\right] P_{ei}$$
$$r_{si} = \left[\frac{1}{\beta} - (1-\delta_s)\right] P_{si}.$$

The optimal solution is characterized by trade balance:

$$L_i P_{ei} Q_{ei} \sum_{j \neq i} \pi_{eij} + L_i P_{mi} Q_{mi} \sum_{j \neq i} \pi_{mij} = \sum_{j \neq i} L_j P_{ej} Q_{ej} \pi_{eji} + \sum_{j \neq i} L_j P_{mj} Q_{mj} \pi_{mji}.$$

The left-hand side denotes country i's imports of equipment and intermediate goods, while the right-hand side denotes country i's exports. This condition allows for trade imbalances at the sectoral level within each country: a country that is a net exporter of equipment will necessarily be a net importer of intermediate goods, and vice versa. The equipment and structures investment levels are given by:

$$x_{ei} = [(1+n) - (1-\delta_e)]k_{ei}$$
$$x_{si} = [(1+n) - (1-\delta_s)]k_{si}.$$

Composition of capital: A feature of the equilibrium is that the stocks of equipment and structures capital are endogenous. The equipment capital-output ratio and the structures capital-output ratio in equilibrium are (see appendix A for the derivations):

$$\frac{k_{ei}}{y_i} = \frac{\alpha\mu}{[\frac{1}{\beta} - (1-\delta_e)]W_e} \frac{1}{A_c} \left(\frac{\lambda_e}{\pi_{eii}}\right)^{\theta} \left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(\gamma_c-\gamma_e)}{\gamma_m}}$$
$$\frac{k_{si}}{y_i} = \frac{\alpha(1-\mu)}{[\frac{1}{\beta} - (1-\delta_s)]W_s} \frac{1}{A_c} \left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(\gamma_c-\gamma_s)}{\gamma_m}}, \tag{2}$$

where $W_e = \frac{UV_e}{V_c}(UV_m)^{\frac{(\gamma_c-\gamma_e)}{\gamma_m}}$ and $W_s = \frac{V_s}{V_c}(UV_m)^{\frac{(\gamma_c-\gamma_s)}{\gamma_m}}$ are a collection of constants. $\pi_{ejj} = 1 - \sum_v \pi_{ejv}$ is the fraction of expenditure on equipment goods that is spent on home produced equipment (henceforth, home expenditure share). Likewise, $\pi_{mjj} = 1 - \sum_v \pi_{mjv}$. The share of equipment in capital is given by:

$$\frac{k_{ei}}{k_{ei}+k_{si}} = \frac{1}{1+\frac{1-\mu}{\mu}\frac{\frac{1}{\beta}-(1-\delta_e)}{\frac{1}{\beta}-(1-\delta_s)}\frac{W_e}{W_s}\left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta(\gamma_e-\gamma_s)}{\gamma_m}}\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta}}, \tag{3}$$

Thus, the capital-output ratios and the equipment capital share are functions of a country's productivity levels, as well as home expenditure shares in equipment and intermediate goods. Since $\pi_{eii} \leq 1$ and $\pi_{mii} \leq 1$, relative to autarky, a world economy with trade is associated with a higher share of equipment in capital in all countries.

Equipment trade affects equipment capital share (and capital composition) through the equipment home expenditure share, π_{eii}. Reductions in equipment trade barriers change the relative price of equipment faced by various countries and alter the cross-country pattern of specialization. To see this, recall that the equipment sector has a continuum of goods along the unit interval. A fraction of the continuum for which a country has the high productivity draws, π_{eii}, is produced at home and the remainder, 1-π_{eii}, is imported. Reductions in equipment trade costs increase specialization and decrease the home expenditure share. $\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{\theta}$ can be interpreted as a country i's effective productivity in the equipment sector: it measures the average productivity over the subset of continuum that is produced at home. Increases in specialization increase this effective equipment productivity.

Income per worker: The real income per worker in this paper is defined as the per period earning of the representative household deflated by the price of final good:

$$y_i = \frac{w_i}{P_{ci}} + \frac{r_{ei}}{P_{ci}} + \frac{r_{si}}{P_{ci}}$$

Using equilibrium expressions for prices and trade shares, this implies that income per worker in country i is (see appendix A for the derivation):

$$y_i = \Lambda\, A_{ci}\left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(1-\gamma_c)}{\gamma_m}} \left(k_{ei}^{\mu}k_{si}^{1-\mu}\right)^{\alpha},$$

where Λ is a collection of constants. Equivalently, in terms of the equipment capital share in country i, denoted by $z_i = \frac{k_{ei}}{k_{ei}+k_{si}}$:

$$y_i = \Lambda\, A_{ci}\left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(1-\gamma_c)}{\gamma_m}} (k_{ei}+k_{si})^{\alpha}\ \{z_i^{\mu}(1-z_i)^{1-\mu}\}^{\alpha}. \tag{4}$$

Income per worker in country i is a function of three things: (i) TFP, $A_{ci}\left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(1-\gamma_c)}{\gamma_m}}$, (ii) equipment and structures capital per worker, $(k_{ei}+k_{si})^{\alpha}$, and (iii) a capital composition term,

$\{z_i^{\mu}(1-z_i)^{(1-\mu)}\}^{\alpha}$. Trade affects incomes through each of these. This paper focusses on the capital composition term. In what follows, I use this expression to quantify how equipment trade affects incomes through its impact on the capital composition term. Note that country i's income is positively related to its equipment capital share (z_i) if $z_i < \mu$. An easing of trade restrictions results in higher equipment capital shares and, therefore, higher incomes in all countries (if $z_i < \mu$ is satisfied).

To summarize, in the multi-country trade model (henceforth, model), countries differ in their labor endowment, L_i, final good productivity, A_{ci}, average equipment productivity, λ_{ei}^{θ}, average intermediate goods productivity, λ_{mi}^{θ}, and bilateral trade costs for equipment and intermediate goods, τ_{eij} and τ_{mij}. The capital stocks and the composition of capital are endogenous in the equilibrium, and trade affects incomes through the capital composition term. In the next section, I present the calibration procedure for common and country-specific parameters and discuss the fit of the quantitative model.

4 Calibration

I calibrate country-specific parameters by using data on a sample of 65 countries in 2005. This sample includes both rich and poor countries and accounts for 78 percent of the world GDP.[10] Appendix B contains the details on data sources and the procedure for the construction of the data (see table C.1 in appendix C for the list of countries).

To be consistent with the data on equipment and structures capital stocks employed in this paper, I map the equipment sector from the model to categories 381-385 of the International Standard Industrial Classification (ISIC) Revision 2 (see Mutreja, 2014, for details). These categories correspond to "Machinery and Equipment" in the World Bank's International Comparison Program (ICP). Structures correspond to residential and non-residential buildings. I, thus, map investment structures into the "Construction" category of ICP. The intermediate goods sector corresponds to traded manufactured goods other than the equipment. The final good sector corresponds to all non-traded goods other than investment structures.

Common Parameters: Some of the common parameters are calibrated to be consistent with the economic growth and international trade literature. Using information on self-employed and salaried individuals for a wide cross-section of countries, Gollin (2002) finds that the factor share of labor is 2/3. This corresponds to $1-\alpha$, and, so, I set the factor share of capital at 1/3. I set the factor share of equipment in capital, μ, at 0.56, in accordance with Greenwood, Hercowitz, and Krusell (1997).[11] They calibrate a model of investment-specific technological change to data on the

[10]World GDP is computed from the Penn World Tables version 6.3 (Heston, Summers, and Aten, 2009).

[11]In the literature, values for the factor share of equipment capital range between 0.54-0.65 (see Mutreja, 2014, for details). I used μ=0.5 and μ=0.6 to determine the sensitivity of results to this factor share parameter. The implications are qualitatively similar to the ones in the baseline specification.

US economy, and their estimates imply an equipment factor share of 0.56. The data on equipment and structures capital stocks employed in this paper are constructed using a 14 percent equipment depreciation rate and a 2 percent structures depreciation rate (see Mutreja, 2014, for details). I, thus, set $\delta_e = 0.14$ and $\delta_s = 0.02$. θ controls the dispersion in productivity levels. I use θ equal to 0.25, as in Simonovska and Waugh (2014).[12]

The parameters γ_e, γ_m, γ_s, and γ_c are, respectively, the share of value added in equipment, intermediate goods, investment structures, and final good production. To calibrate γ_e and γ_m, I use data on value-added and total output available in the INDSTAT 4 database (UNIDO, 2013). I calculate the share of value-added in equipment and non-equipment manufactured goods for all the available countries and average them across countries to arrive at γ_e and γ_m, respectively. For γ_s, I compute the average share of valued-added in gross output of construction for 32 OECD countries.[13] Alvarez and Lucas (2007) discuss that the share of value-added in final good production ranges in 0.7-0.8, depending on the source. I use $\gamma_c = 0.75$, in accordance with their baseline value.

The labor force growth rate, n, of 0.016 is computed by using the average geometric growth rate in the world population from 2000 through 2007. Following Alvarez and Lucas (2007), I set η equal to 2. As is common in the literature, the discount rate is set at 0.96. The inter-temporal elasticity of substitution, σ, is 1.5, as in Restuccia and Urrutia (2001). β, σ and η are quantitatively not important for the issues addressed in this paper. Note that these parameter values satisfy the following assumptions: $\frac{1}{\beta} > 1 + n$ and $1 + \theta(1 - \eta) > 0$.

Trade costs: To calibrate trade costs for equipment and intermediate goods, I use the methodology employed in Mutreja, Ravikumar, and Sposi (2016). The model implies the following structural relationships between trade costs, trade shares, and prices in each tradable sector:

$$\begin{aligned} \frac{\pi_{eij}}{\pi_{ejj}} &= \left(\frac{P_{ej}}{P_{ei}}\right)^{-\frac{1}{\theta}} \tau_{eij}^{-\frac{1}{\theta}} \\ \frac{\pi_{mij}}{\pi_{mjj}} &= \left(\frac{P_{mj}}{P_{mi}}\right)^{-\frac{1}{\theta}} \tau_{mij}^{-\frac{1}{\theta}}, \end{aligned} \tag{5}$$

where π_{ejj} and π_{mjj} are the home expenditure shares. I use data on bilateral trade shares, home expenditure shares, and aggregate prices across countries along with equations in (5) to pin down bilateral trade costs (see appendix B for how I construct the trade shares in data).

There are many zeroes in the data. Of the 4160 possible bilateral country pairs, the volume of trade for 584 pairs in equipment and 263 pairs in intermediate goods is zero. To the country pairs where no trade exists I assign a high enough trade cost such that trade is effectively eliminated.

[12] Simonovska and Waugh (2014) estimate a $\theta = 0.25$ for all tradable goods combined into one category. Conceivably, θ is different for equipment and intermediate goods. Mutreja, Ravikumar, and Sposi (2016) use the methodology in Simonovska and Waugh (2014) to estimate θ separately for capital and non-capital goods. They estimate $\theta_e = 0.23$ and $\theta_m = 0.25$. The results in this paper are not significantly altered if I instead use $\theta_e = 0.23$ and $\theta_m = 0.25$.

[13] Value added and gross output data for OECD countries are from STAN database available at http://stats.oecd.org/Index.aspx.

Equipped with all the calibrated parameters, when I compute the model equilibrium, the implied trade shares are extremely small for country pairs that have zeros in the trade data matrix. For instance, in data there are zero equipment exports from Argentina to Fiji. The calibrated model implies a trade share of 7.2×10^{-10}, which is negligible.

Similar to Waugh (2010), the calibrated trade costs are systematically higher for poor exporters. The correlation between average equipment trade cost and income per worker is -0.37, and that for intermediate goods is -0.44. The average equipment trade barrier for the poor exporter (10th percentile country) is 11.86 times the the average trade barrier faced by the rich exporter. For instance, fixing the US as the importer, the correlation between equipment trade cost and income per worker is -0.18. If the importer is fixed at China, then this correlation is -0.27. These correlations are more negative in the case of the intermediate goods. The trade costs in Waugh (2010) are estimated from a gravity equation with an exporter fixed effect. I do not assume either τ_e or τ_m to be exporter-specific. When calibrated to the data on prices and trade flows, they turn out to be higher for poor exporters. Both sets of trade costs are consistent with trade flows.

Productivity parameters: To calibrate the country-specific productivity parameters, I employ structural relationships from the model that connect productivity parameters to home expenditure shares and relative prices:[14]

$$\begin{aligned}\frac{P_{ei}}{P_{mi}} &= W_m \left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta} \left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta\gamma_e}{\gamma_m}} \\ \frac{P_{ei}}{P_{ci}} &= W_e\, A_{ci} \left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta} \left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta(\gamma_e-\gamma_c)}{\gamma_m}} \\ \frac{P_{si}}{P_{ci}} &= W_s\, A_{ci} \left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta(\gamma_s-\gamma_c)}{\gamma_m}},\end{aligned} \tag{6}$$

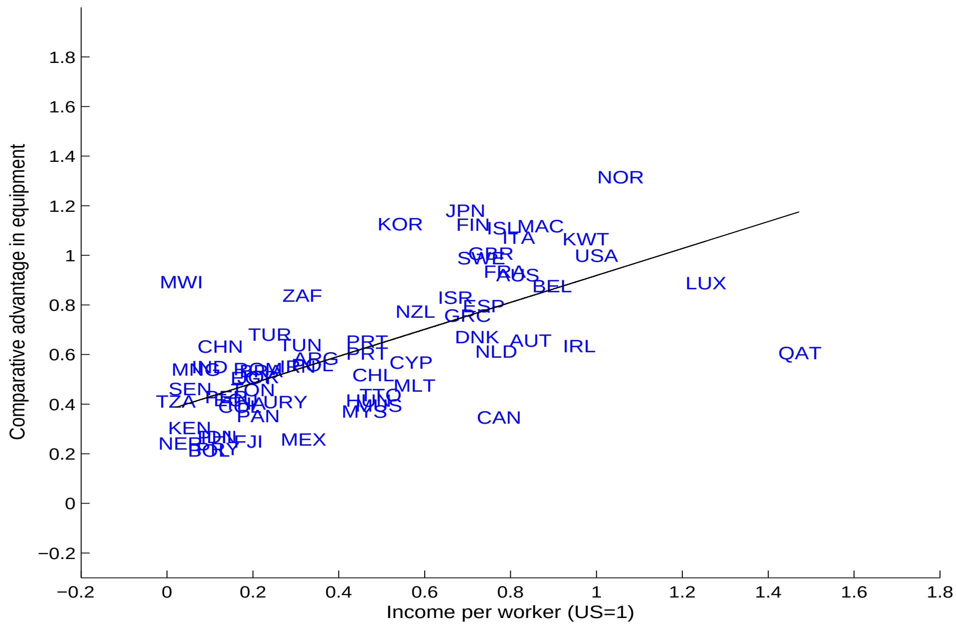
where $W_m = UV_e(UV_m)^{-\frac{\gamma_e}{\gamma_m}}$ is a constant (the derivations are in appendix A). I use data on the price of equipment relative to intermediate goods, $\frac{P_{ei}}{P_{mi}}$, the relative price of equipment, $\frac{P_{ei}}{P_{ci}}$, the relative price of structures, $\frac{P_{si}}{P_{ci}}$, and the home expenditure shares in equipment and intermediate goods to calibrate productivity parameters relative to US productivity levels.

Cross-country differences in the calibrated productivity levels are higher for equipment than for intermediate goods (see table C.1, appendix C). The income elasticity of λ_e^θ is 0.50, and the income elasticity of λ_m^θ is 0.21. Recall that λ_{ei}^θ is country i's average equipment productivity. The 90-10th percentile ratio of λ_e^θ is 3.54 and that of λ_m^θ is 0.87. Thus, rich countries have an absolute and comparative advantage in equipment, and poor countries have a comparative advantage in intermediate goods. Figure 2 plots $\left(\frac{\lambda_{ei}}{\lambda_{mi}}\right)^\theta$ against income per worker across countries. The comparative advantage in equipment systematically increases with incomes.

[14] Mutreja, Ravikumar, and Sposi (2016) calibrate productivity parameters to relative prices and incomes in their sample. I do not use data on income per worker for the calibration.

Herrendorf and Valentinyi (2012) measure sectoral TFP for 86 countries in 1996. They estimate the 90th-10th percentile ratio of equipment TFP to be 8.7. In my model, the analogue of this equipment TFP is the effective equipment productivity, $\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{\theta}$. The 90th to 10th percentile ratio of effective equipment productivity from the quantitative model is 4.43. Thus, the equipment productivity differences that are consistent with cross-country prices and trade flows, and, as I show later, equipment production, capital stocks, and capital composition, are smaller than the ones estimated by Herrendorf and Valentinyi (2012).

Figure 2: Comparative advantage in equipment, $\frac{\lambda_{ei}^{\theta}}{\lambda_{mi}^{\theta}}$



Model fit: Calibration targets are the ratios of absolute prices of equipment and intermediate goods, $\frac{P_{ej}}{P_{ei}}$ and $\frac{P_{mj}}{P_{mi}}$; the ratios of bilateral trade shares to exporter's home expenditure share in each bilateral country pair, $\frac{\pi_{eij}}{\pi_{ejj}}$; relative prices, $\frac{P_{ei}}{P_{mi}}$, $\frac{P_{ei}}{P_{ci}}$, and $\frac{P_{si}}{P_{ci}}$; and home expenditure shares in both tradable goods, π_{eii} and π_{mii}.

Equipped with productivity parameters and trade costs, I compute the equilibrium. The equilibrium implied allocations and prices fit calibration targets well. The income elasticity of price of equipment is 0.03 in the data and 0.03 in the model. The corresponding elasticities are 0.24 and 0.25 for intermediate goods. The income elasticity of the relative price of equipment is -0.48 in the data and -0.55 in the model, while those for the relative price of structures are -0.01 and -0.04, respectively. Finally, the income elasticity for the price of equipment relative to intermediate goods is -0.21 in the data and -0.23 in the model. The model also matches trade data reasonably well. The model and data correlation are 0.66 for $\frac{\pi_{eij}}{\pi_{ejj}}$ and 0.64 for $\frac{\pi_{mij}}{\pi_{mjj}}$. The correlations between home expenditure shares in the model and the data are 0.96 for equipment and 0.89 for intermediate goods.

The model is also consistent with prices that are not specifically targeted in the calibration. The income elasticity for the price of structures is 0.49 in the data and 0.54 in the model. The elasticities for the price of final good are 0.50 and 0.58 respectively. Thus, the quantitative model is consistent with the data on prices and trade flows.

The calibrated productivity levels deliver the observed pattern of equipment production. In the data, top seven countries produce 78.3 percent of the world equipment. This share is 75.5 percent in the model. The share of equipment produced in the bottom seven countries is 0.004 percent in the data and 0.008 percent in the model. Figure D.1 in appendix D plots the cumulative distribution of equipment production for the data and the model.

A remark is in order here. One might argue that relative to the existing literature, the model puts significantly more structure on the data. The model incorporates bilateral trade in both equipment equipment and intermediate goods. An alternative theoretical setup is a model of bilateral trade that does not differentiate between trade in equipment and non-equipment goods, as in Waugh (2010). Such a model, though consistent with bilateral trade flows, would fail to produce the pattern of equipment production across countries. Another alternative framework is a model that considers only bilateral trade in equipment, as in Eaton and Kortum (2001). Such a framework would be able to explain equipment production across countries but would be inconsistent with the overall trade flows.

5 Results

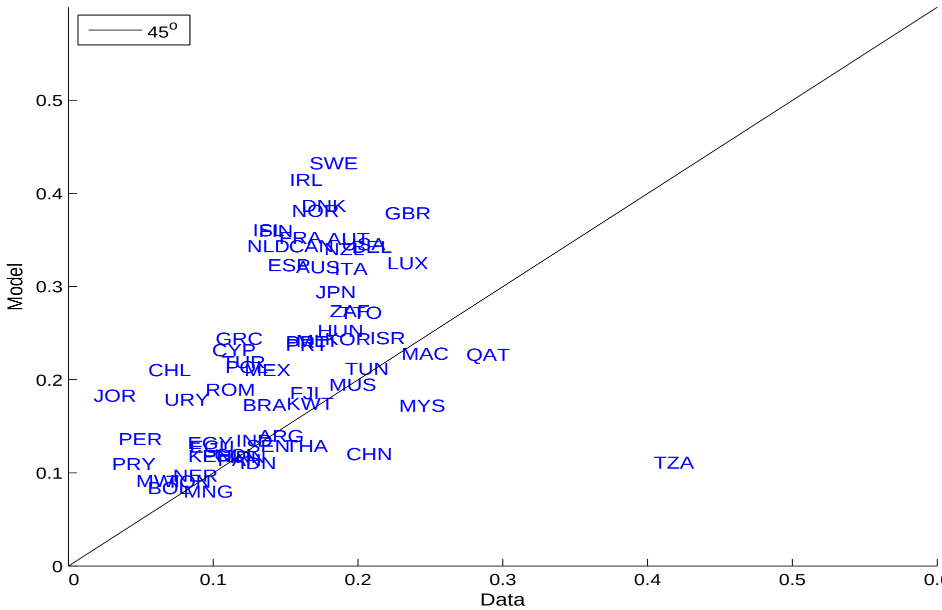
In this section, I first present the model-implied equipment capital shares, equipment and structures capital stocks, and incomes. Thereafter, I use the structural framework to examine the role of equipment trade in determining capital composition across countries.

Equipment share in capital: Figure 3 plots the equipment capital share from the model against those in the data, and table 1 presents summary statistics on cross-country differences in the equipment capital share. The model slightly over explains the equipment share in capital and reproduces 110 percent of the observed log variance. The model is also consistent with the observed equipment capital share in rich and poor. The share of equipment in the 90th percentile country is 21 percent in the data. The model implies a share of 34 percent. The share of equipment in the 10th percentile country is 7 percent in the data and 8.4 percent in the model.

Table 1: Equipment share in capital

	Data	Model
Log variance	0.20	0.22
90-10 ratio	3.02	4.08

Figure 3: Equipment share in capital

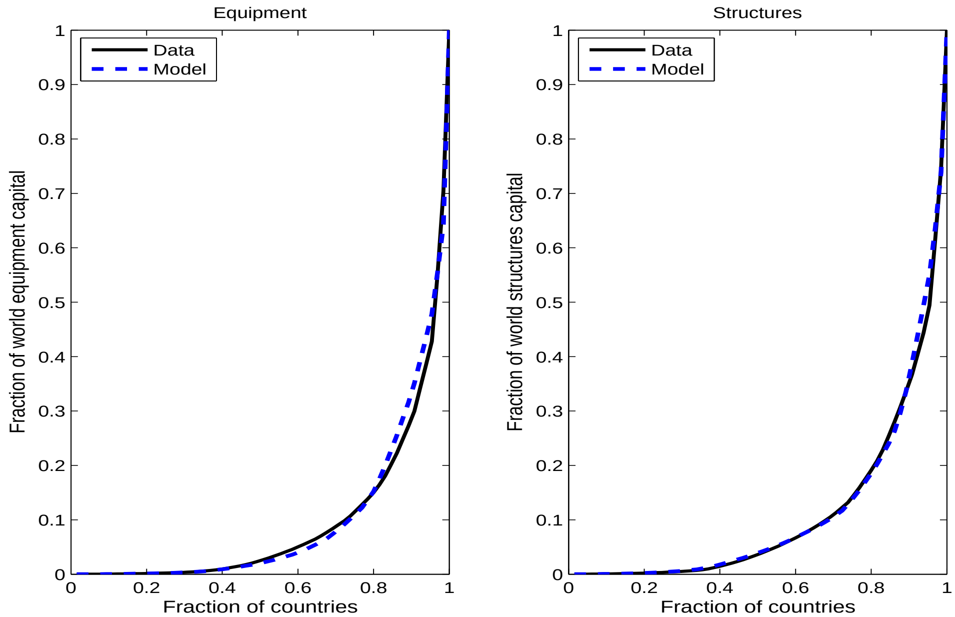


Equipment and structures capital stocks: The quantitative model matches cross-country differences in equipment and structures capital. Figure 4 presents the world distribution of equipment and structures capital in the model and data. The correlation between the model and data distribution for both kinds of capital is 0.99. Thus, the model reproduces the world distribution of capital almost perfectly.

The quantitative model also predicts capital-output ratios and capital per worker that are consistent with the data. Figure D.2 in appendix D plots the capital-output ratios from the model against the ones in data. The equipment capital-output ratio is a factor of 5.88 between rich and poor in the data and 5.69 in the model. The model also reproduces variation in structures capital across countries. The 90th-10th percentile ratio of structures capital-output ratio is 1.66 in the data and 1 in the model. Figure D.3 in appendix D presents equipment and structures capital per worker from the model and data. The 90th-10th percentile ratio of equipment capital per worker is 54.06 in the data and 58.57 in the model. The corresponding ratio for structures capital per worker is 15.22 in the data and 10.31 in the model.

Income per worker: The calibrated model is also consistent with observed income per worker differences. Recall that the calibration exercise does not employ data on incomes to calibrate any of the country-specific parameters. In the model, the income per worker in rich is 9.2 times the income per worker in poor. The corresponding ratio in the data is 10.29. World income distribution from data and model is plotted in figure D.4 in appendix D; the correlation between model and data is 0.99. The log variance of income per worker is 1.31 in the model and 0.96 in the data.

Figure 4: Cross-country distribution of capital



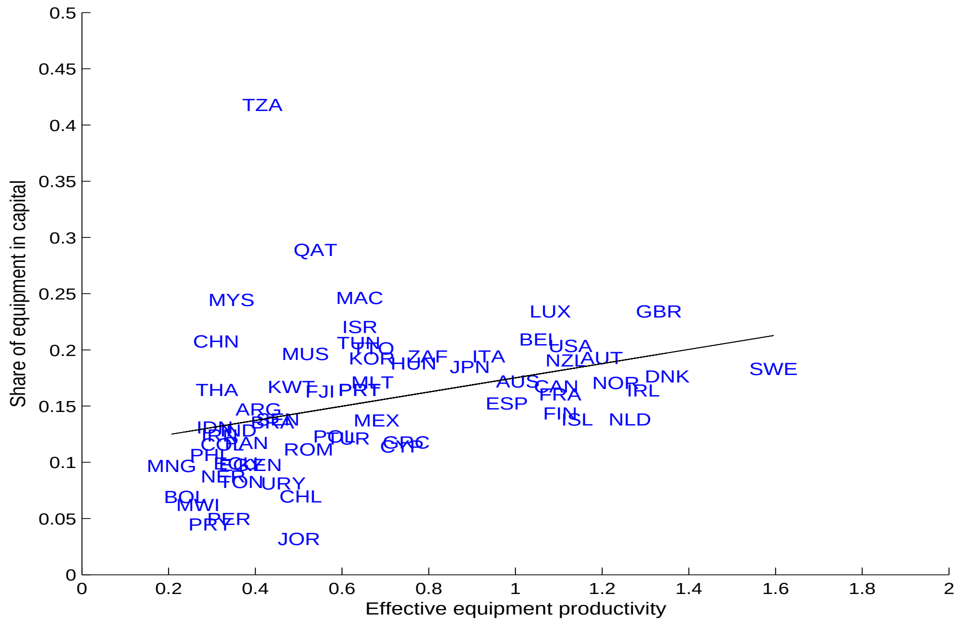
Implications: In the model, equipment capital share in a country is function of its productivity levels and trade flows. This relationship enables me to evaluate the role of equipment trade in determining cross-country capital composition. The differences in equipment capital share are entirely due cross-country variation in $\left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta(\gamma_e-\gamma_s)}{\gamma_m}}\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta}$ (see equation (3)). The log variance of this term is 1.09. Following the variance decomposition methodology commonly employed in the income differences literature, I decompose this log variance into the log variance of the four components: $\lambda_{mi}^{\frac{\theta(\gamma_e-\gamma_s)}{\gamma_m}}$, $\pi_{mii}^{\frac{-\theta(\gamma_e-\gamma_s)}{\gamma_m}}$, $\lambda_{ei}^{-\theta}$, and π_{eii}^{θ}.[15] The sum of log variances of the four components is 0.59. The remaining log variance of 0.5 is split equally amongst the four components. Of the log variance of 1.09, variation in equipment productivity accounts for 52.6 percent. The equipment home expenditure share accounts for 22.7 percent. In no way, this is small. The remaining 24.7 percent is accounted for by intermediate goods productivity and home expenditure shares.

Another way to interpret this variance decomposition is through the effective equipment productivity, $\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{\theta}$. The effective productivity in equipment accounts for over three fourths of the variation in equipment share across countries. Figure 5 plots equipment capital share against effective equipment productivity. Higher equipment productivity levels are associated with larger shares of equipment in capital. In other words, rich countries have higher equipment capital shares because they are more productive in equipment, and trade enables them to specialize in equipment production that results in higher effective equipment productivity.

To summarize, the quantitative model implies that rich have an absolute and comparative advantage in equipment, while poor have a comparative advantage in intermediate goods. The model successfully explains cross-country dispersion in capital composition, stocks of equipment and

[15]This assumes that the four components are not complementary to each other.

Figure 5: Equipment capital share and effective equipment productivity, $\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{\theta}$



structures capital, and incomes. Rich countries have higher productivity in equipment and, thus, larger shares of equipment in capital. A variance decomposition of the model-implied equipment capital share suggests that the role of trade in accounting for capital composition is non-trivial. The variance decomposition exercise abstracts from complex interactions between capital composition, productivity levels and trade. I explore these interactions and consequent implications for incomes in the next section via counterfactual experiments.

6 Gains from Trade and Capital Composition

The concurrent rise in world equipment capital intensity and equipment trade volumes has been facilitated, in part, by the declining trade costs. Equipment trade costs affect the prices faced by poor countries versus rich countries and, thus, govern the equipment-structures investment tradeoff. What role has the decline in equipment trade costs played in the evolution of equipment capital shares and incomes across countries? What are the channels through which reductions in equipment trade costs have led to income gains?

To answer these questions, I conduct a counterfactual experiment that focusses on the fall in equipment trade costs between 1985 and 2005. The choice of 1985 is for two reasons: (i) the income accounting exercise in section 2 indicates that capital composition began to play an important role in income in the 1980s, and (ii) during the early part of 1980s, investment and trade data exhibit after-effects of the oil price shocks, because of which I choose 1985 as the starting year of time period under consideration.

To measure the fall in equipment trade barriers during 1985-2005, I require bilateral equipment trade costs, τ_{eij}, for 1985. These are calibrated as follows: I employ the methodology described in section 4 (see equation 5) along with the data for 1985 on equipment prices and equipment trade shares.[16] Construction of trade shares requires data on production and bilateral trade volumes. These along with the data on equipment prices are available for a sample of 32 countries only.[17] I calibrate τ_{eij} for all bilateral pairings among 32 countries and calculate the average equipment trade cost for each exporter in 1985.[18] Subtracting these from the corresponding values in 2005, I arrive at the 1985-2005 fall in average equipment trade cost for each of the 32 exporters. Using a regression of the 1985-2005 fall in average equipment export cost on income per worker for 32 exporters, I impute the average fall in equipment trade cost (denoted by $\widehat{\rho}_{ej}$) for all 65 exporters countries in the 2005 sample. Employing $\widehat{\rho}_{ej}$ as a mark-up, I arrive at the bilateral equipment trade costs in 1985 for the 65 country sample:

$$\widehat{\tau}_{eij}^{1985} = (1 + \widehat{\rho}_{ej})\, \tau_{eij}$$

where $\widehat{\tau}_{eij}^{1985}$ is the imputed equipment trade cost for 1985 and τ_{eij} is the baseline calibrated value of equipment trade cost in 2005. That is, country j's fall in average equipment trade cost, $\widehat{\rho}_{ej}$, is applied uniformly to equipment trade cost for all the bilateral pairings where j is an exporter.

An examination of the measured trade costs (for 65 countries) reveals that the decline in equipment trade costs is slightly higher for rich exporters. During 1985-2005, equipment trade costs fall by 74 percent in rich countries and by 68.6 percent in poor countries, on average. As a result, relative to rich, poor exporters face slightly higher costs to export equipment in 2005. In 1985, the average equipment export cost for poor is 11.6 times the export cost in rich. In 2005, the corresponding ratio is only marginally higher at 11.86. Thus, while equipment trade costs have declined in all countries, their systematic variation with an exporter's income level is essentially unchanged.

To conduct the experiment, I set bilateral equipment trade barriers at their 1985 levels, i.e., $\tau_{eij} = \widehat{\tau}_{eij}^{1985}$. Other parameters, viz., common parameters, equipment productivity, λ_{ei}^{θ}, intermediate goods productivity and trade costs, λ_{mi}^{θ} and τ_{mij}, and final good productivity, A_{ci}, are set at their calibrated baseline levels in 2005. With this set of parameters, I re-compute the world general equilibrium. Note that this counterfactual simulates a situation where the only difference between 1985 and 2005 is in the equipment trade costs. Comparing between the counterfactual world and the baseline reveals the contribution of declining equipment trade costs to the evolution of capital composition and incomes across countries. While in reality, productivity parameters and intermediate goods trade costs also differ between 1985 and 2005, these differences have been shut down to shed light on the role played by decline in equipment trade costs only.

The results from the experiment are summarized in tables 2 and 3.[19] First row in table 2 presents

[16]The data on average equipment tariffs is not available for most countries, so I estimate equipment trade costs that are consistent with the pattern of trade flows and prices.

[17]See appendix B for the data sources and procedures as well as the list of 32 countries in the 1985 sample.

[18]The baseline calibrated equipment trade costs are exporter-specific, not importer-specific. This is why, a per-exporter average is computed here.

[19]I conduct additional counterfactual experiments that are in the online appendix to this paper.

Table 2: Change in share of equipment relative to baseline (percentage points)

	Rich	Poor	Overall avg.
1985 – 2005	10.3	2.7	4.7
Equip. autarky	-17.8	-3.9	-6.9
Equip. zero gravity	14.7	10.9	14.7

Table 3: Income gain/loss and contribution of trade via capital composition (percent)

	Change in income per worker			Fraction due to capital composition channel		
	Rich	Poor	Overall avg.	Rich	Poor	Overall avg.
1985 – 2005	12.5	10.2	8.4	35.1	64.2	45.1
Equip. autarky	-20.3	-14.6	12.3	46.9	70.9	49.1
Equip. zero gravity	17.6	62.6	49.2	16.8	23.2	20.1

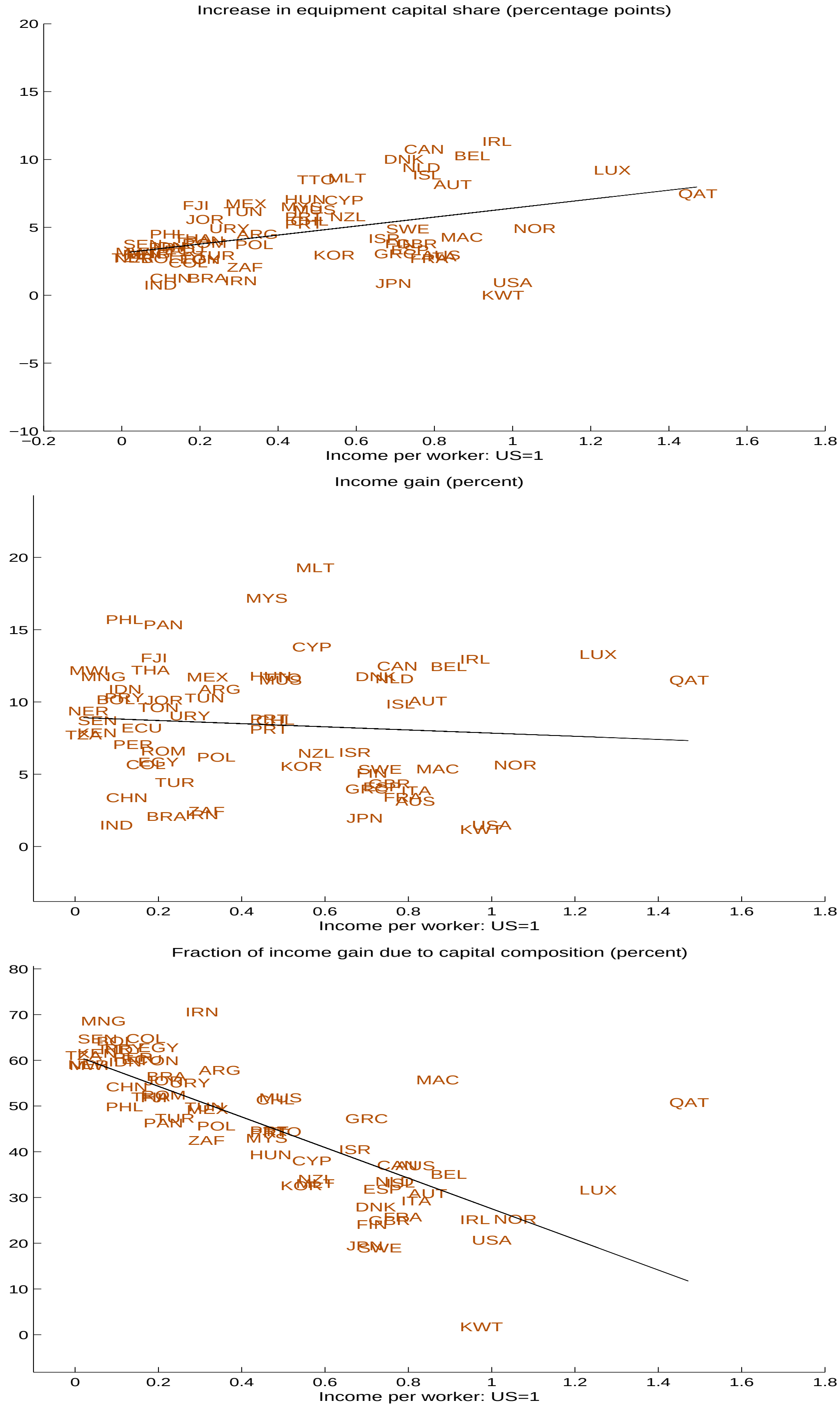
Note: Rich and poor correspond to 90th and 10th percentiles of the world income per worker distribution, respectively.

percentage points increases in equipment capital share attributable to the decline in equipment trade barriers during 1985-2005. Left panel of table 3 presents the associated income gains. Right panel of this table shows the fraction of the income gains that accrue to countries via the capital composition channel: proportion of income gains that are due to the changes in capital composition term. These tables also report results from the experiments of autarky and zero gravity in equipment, which are discussed later.

As equipment trade barriers fall between 1985 and 2005, rich specialize more in their comparative advantage good and focus resources away from the relatively inefficient intermediate goods sector. More equipment is produced at home and, so, investment in equipment capital increases. As a result, the equipment capital share in the rich increases by 10.3 percentage points from 24 percent in the counterfactual world to 34.3 percent in the baseline. Poor countries also gain. With the fall in barriers to import equipment, equipment becomes relatively less expensive and so, investment in equipment rises. The 1985-2005 decline in τ_{eij} increases equipment capital share by 2.7 percentage points. The top panel of figure 6 plots the percentage points gain in equipment capital share associated with the 1985-2005 equipment trade cost decline. Cross-country differences in equipment capital share also decline: the log variance of equipment capital share is 0.29 compared to 0.22 in the baseline.

Income per worker is highly responsive to adjustments in equipment trade costs. Average income per worker gain attributable to 1985-2005 reduction in equipment trade barriers is 8.4 percent, with poor gaining slightly more (correlation in the middle panel of figure 6 is -0.09). Countries gain income either because of changes in TFP, increase in the level of capital stock or because of changes in the composition of their capital (see equation 4). The decline in equipment trade costs has implications for TFP levels. The intermediate goods export barriers faced by poor countries

Figure 6: Declining equipment trade costs: 1985 to 2005



have a bearing on the volume of their exports and, through balanced trade, on the volume of their equipment imports. Reductions in equipment trade costs facilitate equipment investment in poor by reducing the price of equipment and easing the pressure on intermediate goods exports to finance equipment imports. With the 1985-2005 decline in τ_{eij}, poor no longer need to export as much to finance their equipment imports. Rich countries, on the other hand, increase their equipment exports and, through balanced trade, intermediate goods imports. As a result, intermediate goods home expenditure shares, π_{mii}, reduce in rich and increase in poor. This affects their TFP levels, $\left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta(1-\gamma_c)}{\gamma_m}}$. TFP increases in rich countries and it declines in poor countries.

Discussion: Clearly, equipment trade is quantitatively important for the composition of capital and incomes. Rich benefit by producing more of their comparative advantage good and poor benefit by exchanging intermediate goods for equipment that is inefficiently produced at home. Over the years, declining costs to equipment trade have fueled the rise of equipment capital intensity in the world. If equipment trade costs had remained at their level in 1985, the average world equipment capital share would have been smaller by 4.7 percentage points. This is about one-fourth of the average equipment capital share in 2005. This, in turn, contributes to the increases in income.

What are the channels through which these income gains are transmitted? As trade costs change, so does a country's capital composition term due to the change in its equipment capital share. This leads to changes in income per worker. The right panel of table 3 reports the fraction of quantitative income gains that are due to changes in the capital composition term. A large fraction of the income gains stem from the capital composition term. Changes in capital composition alone account for nearly half of the income gains, on average. Thus, capital composition channel is quantitatively important.

A key finding is that poor countries accrue income gain mostly through the capital composition channel and rich countries gain via increases in the level of capital and TFP. Changes in capital composition account for 64 percent of the income gain in poor and 35 percent in rich. The remainder of the respective gains are due to changes in level of capital and TFP. A one percent increase in income per worker decreases the contribution of capital composition channel in transmission of income gains by 0.31 percent (see table 4). The bottom panel in figure 6 plots the contribution of the capital composition channel to incomes gains (in percentage terms) against income per worker. The correlation in this figure is -0.76.[20]

The roots of income gains from equipment trade lie in what happens to *effective* equipment productivity, $\left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{\theta}$, as the trade costs are adjusted. Equipment trade affects the composition

[20] Deaton and Aten (2017) estimate that the consumption PPPs in 2005 ICP are overpriced by 18-26 percent relative to the US for certain poor countries. In my paper, trade costs affect capital composition (and income) via relative prices. If the extent of over-pricing in case of equipment and structures is similar or more relative to that of consumption, then the significance of capital composition channel would be largely unaffected (and likely strengthened if the latter is true). If over-pricing is less, the quantitative magnitudes would be dampened, though I expect that the capital composition will continue to be significant channel for the transmission of income gains.

Table 4: Significance of capital composition channel
(dependent variable: percentage of income gain because of capital composition channel)

	1980-2005	Equip. autarky	Equip. zero gravity
Income per worker	-0.31	-0.31	-0.27
	(0.05)	(0.06)	(0.07)
Intercept	3.39	3.46	2.55
	(0.08)	(0.09)	(0.10)
R-square	0.33	0.29	0.21
No. of countries	65	65	65

Note: All variables are in logs. All coefficients are significant at the 1 percent level. Standard errors are shown in parentheses.

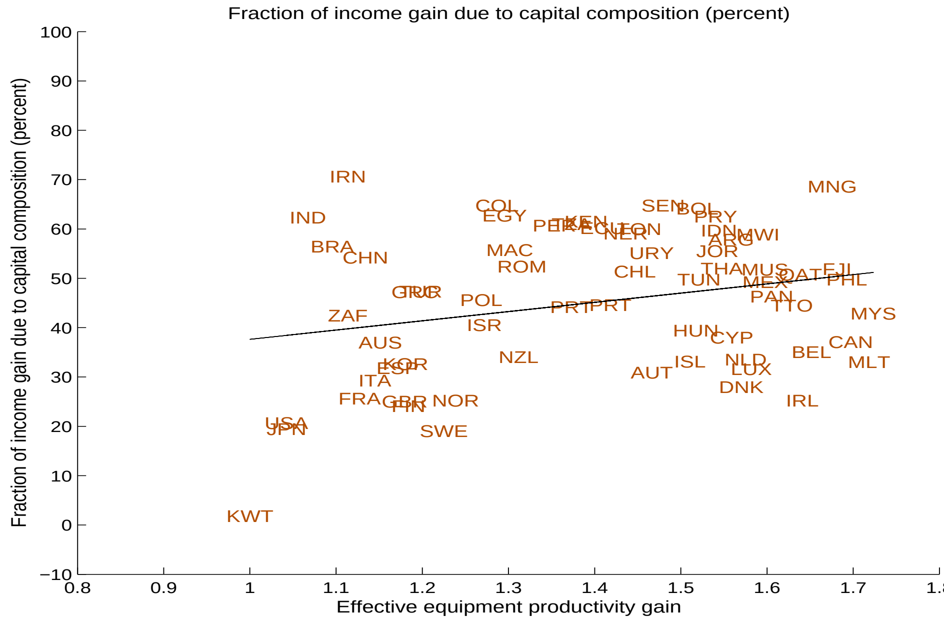
of capital, and therefore, income through a country's equipment home expenditure share. Rich countries have higher average equipment productivity, ${\lambda_i}^{\theta}$, than poor countries. The size of a country's equipment sector is determined by its relative sectoral productivity levels. Accordingly, rich have a larger equipment sector than poor even when there is autarky in equipment. With trade, rich countries specialize in the production of equipment goods for which they have the highest idiosyncratic productivity draws, resulting in higher effective equipment productivity levels. The fall in equipment trade costs from 1985 to 2005 increases the relative size of the equipment sector, leading to lower equipment home expenditure shares and higher effective equipment productivity. This translates into larger equipment capital stocks and higher equipment capital shares in rich countries.

Poor countries, on the other hand, have less equipment in their capital stock because they are inefficient at producing equipment. In autarky, factor mobility across sectors ensures a relatively small equipment sector and, so, little equipment is produced at home. This leads to smaller equipment capital stock and lower equipment capital shares in autarky. The decline in equipment trade barriers from 1985 to 2005 reallocates resources to the production of intermediate goods that are exported to finance imported equipment. This reduces the size of the equipment sector in poor countries and their equipment home expenditure shares decline. As a result, their effective equipment productivity, equipment capital stocks, and so, equipment capital shares increase.

Figure 7 plots the significance of capital along with the gains in effective equipment productivity attributable to 1985-2005 fall in τ_{eij}. The baseline level of US effective equipment productivity is normalized to unity. The correlation in this figure is 0.26. That is, countries that experience larger gains in their effective equipment productivity are the ones that also witness bigger income gains through changes in capital composition. From 1985 to 2005, the effective equipment productivity increases by a factor of 1.7 in rich and by a factor of 1.5 in poor. The rich-poor gap in effective equipment productivity increases marginally.

Overall, a reduction in equipment trade costs reallocates world resources towards more efficient

Figure 7: Capital composition channel and effective equipment productivity gain: 1985-2005



Note: US effective equipment productivity in baseline is normalized to one.

outcomes and increases effective equipment productivity in all countries. The gains in effective productivity have significant implications for incomes: (i) the income gains are large for all countries, and (ii) capital composition is an important channel through which reduced equipment trade costs result in higher incomes for all countries.

Economic growth is accompanied by an equipment intensification of physical capital. Trade speeds up this process. Textbooks on economic growth and development characterize the process of economic growth by rapid capital accumulation. One key feature of rapid capital accumulation has been the rise of equipment capital intensity. Countries that gain the most from equipment trade do so not only because they accumulate more capital but also because they accumulate equipment capital at a faster rate than structures. All countries gain from reductions in equipment trade costs; poor countries gain more through the capital composition channel.

Autarky in equipment: In this experiment, I shut down equipment trade by setting equipment trade barriers, τ_{eij}, at prohibitively high levels. I set the remaining parameters at their calibrated levels and re-compute the world equilibrium. That is, countries still trade intermediate goods, albeit restricted by the calibrated levels of intermediate goods trade costs. With this set of parameters, I re-compute the world general equilibrium.

In the absence of equipment trade, rich can no longer specialize in their comparative advantage good and have to divert resources to their relatively inefficient intermediate goods sector. Less equipment is produced at home and, so, investment in equipment capital declines. As a result, the equipment capital share in the rich falls to 16.5 percent from 34 percent in the baseline (table 2).

Poor countries are also adversely affected. With equipment autarky, they can no longer access the equipment produced in rich countries and the composition of their capital is determined by domestic equipment productivity levels only. The equipment capital share declines to 4.5 percent from 8.4 percent in the baseline. Thus, equipment share in capital reduces to about one-half in both rich and poor. Figure D.5 in appendix D plots the decline in equipment share because of autarky in equipment. Cross-country differences in equipment capital share also increase as the log variance of equipment share nearly doubles to 0.39.

The changes in equipment capital share across countries have implications for incomes. Autarky is costly for all countries (table 3). Income per worker decreases by 20 percent in the rich and 15 percent in the poor. A bulk of these losses are because of the capital composition channel and this channel continues to be more important for poor countries. It accounts for 71 percent of the income loss in the poor and 47 percent in the rich. The figures on contribution of the capital composition channel and equipment effective productivity are in appendix D.

Zero gravity in equipment: In this experiment, I eliminate restrictions to equipment trade by setting τ_{eij}=1 for all i and j, keep other parameters at their baseline calibrated levels, and re-compute the world general equilibrium. This experiment simulates frictionless equipment trade between countries. Equivalently, since $\pi_{ii} = 1$, in this counterfactual world equipment goods flow across borders as they flow within a country. That is, if there are restrictions to goods flow within countries, similar restrictions apply to cross-border equipment trade as well. Intermediate goods trade is restricted by the calibrated levels of trade costs.

With zero gravity, equipment goods are not lost in transit, and the quantity of world equipment goods increases. This leads to overall higher equipment investment levels and larger equipment capital stock, compared to the baseline. All countries experience an increase in their equipment capital share, and rich gain more than do poor. The share of equipment increases to 49 percent in the rich from 34 percent in the baseline, and the poor's equipment capital share increases from 8.4 percent to 19.3 percent. Figure D.6 in appendix D plots the increase in the equipment capital share. The correlation between the increase in share of equipment and income per worker is 0.43. Cross-country differences in the equipment capital share also decline. The log variance of the share of equipment reduces by 40 percent to 0.12.

With more equipment capital, income rises in all countries. Overall, income per worker increases by 18 percent in the rich and by 63 percent in the poor. Capital composition is an important channel through which equipment trade determines incomes. The change in the capital composition term accounts for 17 percent of income gain in the rich and 23 percent in the poor. The significance of the capital composition channel is presented in figure D.6. Capital composition channel is more important for poor countries: the correlation in this figure is -0.22 (see appendix D for the figure on equipment effective productivity gain in this experiment).

7 Conclusion

In this paper, I first examine the role of equipment trade in determining capital composition across countries and unearth a non-trivial role for trade. I have argued that rich countries have a higher share of equipment in capital because they are more productive in equipment, and through equipment trade they reap efficiency gains that accompany specialization in the goods of comparative advantage. Poor countries, on the other hand, have a lower share of equipment because they are inefficient at producing equipment and face large costs to export their comparative advantage good in exchange for imported equipment. I quantify a new channel through which trade affects incomes: composition of capital. Reductions in equipment trade costs alter capital composition across countries and result in income gains for all. Poor countries gain predominantly via changes in capital composition channel and rich countries gain through increases in level of capital and TFP.

While my model explains capital composition and measures the impact of trade on capital composition and incomes reasonably, obviously I have not told the whole story. As noted previously, capital composition is affected by the abundance of complementary factors, a channel that is absent in my framework. Also, my framework abstracts from investment-specific technological change and cross-country differences in the quality of equipment and structures capital. Much remains to be said about implications of these for capital composition, and the role of trade in these mechanisms.

References

Affendy, Arip M., Lau Sim Yee, and Madono Satoru. 2010. “Commodity-industry Classification Proxy: A Correspondence Table Between SITC revision 2 and ISIC revision 3.” *Journal of International Economic Studies* March (24):185–202.

Alvarez, Fernando and Robert E. Lucas. 2007. “General Equilibrium Analysis of the Eaton-Kortum Model of International Trade.” *Journal of Monetary Economics* 54 (6):1726–1768.

Bems, Rudolfs. 2008. “Aggregate Investment Expenditures on Tradable and Nontradable Goods.” *Review of Economic Dynamics* 99 (6):1166–1187.

Burstein, Ariel, Javier Cravino, and Jonathan Vogel. 2013. “Importing Skill-Biased Technology.” *American Economic Journal: Macroeconomics* 5 (2):32–71.

Caselli, Francesco. 2005. “Accounting for Cross-Country Income Differences.” In *Handbook of Economic Growth*, edited by Philippe Aghion and Steven Durlauf, Handbook of Economic Growth, chap. 9. Elsevier, 679–741.

Caselli, Francesco and Daniel J. Wilson. 2004. “Importing Technology.” *Journal of Monetary Economics* 51:1–32.

Deaton, Angus and Bettina Aten. 2017. “Trying to Understand the PPPs in ICP 2011: Why Are the Results So Different?” *American Economic Journal: Macroeconomics* 9 (1):243–264.

Dornbusch, Rudiger, Stanley Fischer, and Paul A. Samuelson. 1977. “Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods.” *American Economic Review* 67 (5):823–839.

Eaton, Jonathan and Samuel Kortum. 2001. “Trade in Capital Goods.” *European Economic Review* 45:1195–1235.

———. 2002. “Technology, Geography, and Trade.” *Econometrica* 70 (5):1741–1779.

Gollin, Douglas. 2002. “Getting Income Shares Right.” *Journal of Political Economy* 110 (2):458–474.

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell. 1997. “Long-Run Implications of Investment-Specific Technological Change.” *American Economic Review* 87 (3):342–362.

Greenwood, Jeremy, Juan M. Sanchez, and Cheng Wang. 2013. “Quantifying the Impact of Financial Development on Economic Development.” *Review of Economic Dynamics* 16 (1):194–215.

Herrendorf, Berthold and Ákos Valentinyi. 2012. “Which Sectors Make Poor Countries So Unproductive?” *Journal of the European Economic Association* 10:323–341.

Heston, Alan, Robert Summers, and Bettina Aten. 2009. "Penn World Table Version 6.3." Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Hsieh, Chang-Tai and Peter J. Klenow. 2007. "Relative Prices and Relative Prosperity." *American Economic Review* 97 (3):562–585.

Krusell, Per, Lee E. Ohanian, José-Víctor Ríos-Rull, and Giovanni L. Violante. 2000. "Capital-skill Complementarity and Inequality: A Macroeconomic Analysis." *Econometrica* 68 (5):1029–1053.

Mutreja, Piyusha. 2014. "Equipment and Structures Capital: Accounting for Income Differences." *Economic Inquiry* 52 (2):713–31.

Mutreja, Piyusha, B. Ravikumar, and Michael J. Sposi. 2016. "Capital Goods Trade, Relative Prices and Economic Development." Working paper, Federal Reserve Bank of Dallas.

Parro, Fernando. 2013. "Capital-Skill Complementarity and the Skill Premium in a Quantitative Model of Trade." *American Economic Journal: Macroeconomics* 5 (2):72–117.

Raveh, Ohad and Ariell Reshef. 2016. "Capital imports composition, complementarities, and the skill premium in developing countries." *Journal of Development Economics* 118:183–206.

Restuccia, Diego and Carlos Urrutia. 2001. "Relative Prices and Investment Rates." *Journal of Monetary Economics* 47 (1):93–121.

Simonovska, Ina and Michael E. Waugh. 2014. "The Elasticity of Trade: Estimates and Evidence." *Journal of International Economics* 92 (1):34–50.

UNIDO. 2013. *International Yearbook of Industrial Statistics 2013*. Edward Elgar Publishing.

Waugh, Michael E. 2010. "International Trade and Income Differences." *American Economic Review* 100 (5):2093–2124.

Appendix

A Derivations

Price indices and trade shares: In this section, I derive the expressions for the price index and trade share of equipment. The expressions for the price index and trade share of intermediate goods can be derived in a similar manner. The derivations below follow the ones in Alvarez and Lucas (2007).

To derive an expression for the aggregate equipment price index, I use following properties of an exponential distribution:

1) $u \sim \exp(\psi)$ and $\kappa > 0 \Rightarrow \kappa u \sim \exp(\psi/\kappa)$.

2) $u_1 \sim \exp(\psi_1)$ and $u_2 \sim \exp(\psi_2) \Rightarrow \min\{u_1, u_2\} \sim \exp(\psi_1 + \psi_2)$.

The producers in the equipment sector minimize their costs of production. This implies the following price for each equipment good $e \in [0,1]$ that has idiosyncratic productivity of z_{ei} in country i and is produced domestically:

$$p_{eii}(e) = V_e \left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha} \right)^{\gamma_e} P_{mi}^{1-\gamma_e} z_{ei}^{\theta},$$

where $V_e = (\alpha\gamma_e)^{-\alpha\gamma_e}((1-\alpha)\gamma_e)^{(\alpha-1)\gamma_e}(1-\gamma_e)^{\gamma_e - 1}$ is a collection of constant terms. Perfect competition implies that price of good e in country i, when purchased from country j, is given by:

$$p_{eij}(e) = V_e \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} z_{ej}^{\theta}.$$

Country i purchases each individual equipment good from the least cost supplier. So, the price of good e is

$$p_{ei}(e)^{1/\theta} = (V_e)^{1/\theta} \min_j \left[\left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{1/\theta} z_{ej}^{\theta} \right].$$

Since $z_{ej} \sim \exp(\lambda_{ej})$, it follows from property 1 that

$$\left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{1/\theta} z_{ej} \sim \exp\left(\left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej} \right).$$

Then, property 2 implies that

$$\min_j \left[\left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{1/\theta} z_{ej} \right] \sim \exp\left(\sum_j \left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej} \right).$$

Another application of property 1 leads to:

$$p_{ei}(e)^{1/\theta} \sim \exp(\phi_{ei})$$
$$\phi_{ei} = (V_e)^{-1/\theta} \sum_j \left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej} \tag{7}$$

This implies

$$P_{ei}^{1-\eta} = \phi_{ei} \int p_{ei}{}^{\theta(1-\eta)} \exp\left(-\phi_{ei} p_{ei}\right) dp_{ei}.$$

Letting $\omega_i = \phi_{ei} p_{ei}$, the above expression modifies to:

$$P_{ei}^{1-\eta} = (\phi_{ei})^{\theta(\eta-1)} \int \omega_i^{\theta(1-\eta)} \exp(-\omega_i) d\omega_i.$$

Let $U = \Gamma(1 + \theta(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the Gamma function. Therefore,

$$P_{ei} = UV_e \left[\sum_j \left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej} \right]^{-\theta} \tag{8}$$

To derive the trade share, π_{eij}, note that π_{eij} is the fraction of country i's total spending on equipment goods that are sourced from country j. Because of the distributional assumption and the law of large numbers, this fraction is also the probability that j is a least cost supplier of equipment to i:

$$\begin{aligned} \pi_{eij} &= \Pr\left\{ p_{eij}(e) \leq \min_v \left[p_{eiv}(e) \right] \right\} \\ &= \frac{\left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej}}{\sum_v \left\{ \left(r_{ev}^{\alpha\mu} r_{sv}^{\alpha(1-\mu)} w_v^{1-\alpha} \right)^{\gamma_e} P_{mv}^{1-\gamma_e} \tau_{eiv} \right\}^{-1/\theta} \lambda_{ev}}, \end{aligned} \tag{9}$$

where I use property 2 and the following property of exponential distribution: $u_1 \sim \exp(\psi_1)$ and $u_2 \sim \exp(\psi_2) \Rightarrow \Pr(u_1 \leq u_2) = \frac{\psi_1}{\psi_1 + \psi_2}$.

Equilibrium relative prices: Here, I derive the equilibrium expression for relative prices that are used in the calibration of the model: P_{ei}/P_{mi}, P_{ei}/P_{ci}, and P_{si}/P_{ci}. These derivations follow the ones in Mutreja, Ravikumar, and Sposi (2016). In equilibrium, aggregate price indices are given by:

$$P_{ei} = UV_e \left[\sum_j \left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_e} P_{mj}^{1-\gamma_e} \tau_{eij} \right\}^{-1/\theta} \lambda_{ej} \right]^{-\theta}$$

$$P_{mi} = UV_m \left[\sum_j \left\{ \left(r_{ej}^{\alpha\mu} r_{sj}^{\alpha(1-\mu)} w_j^{1-\alpha} \right)^{\gamma_m} P_{mj}^{1-\gamma_m} \tau_{mij} \right\}^{-1/\theta} \lambda_{mj} \right]^{-\theta}$$

$$P_{si} = V_s \left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha} \right)^{\gamma_s} P_{mi}^{1-\gamma_s}$$

$$P_{ci} = V_c \frac{1}{A_{ci}} \left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha} \right)^{\gamma_c} P_{mi}^{1-\gamma_c}$$

Using equations (8) and (9):

$$\pi_{eii} = \frac{\left\{\left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha}\right)^{\gamma_e} P_{mi}^{1-\gamma_e}\right\}^{-1/\theta} \lambda_{ei}}{(UV_e)^{1/\theta} P_{ei}^{-1/\theta}}$$

$$\Rightarrow \frac{P_{ei}}{P_{mi}} = UV_e \left(\frac{r_{ei}^{\mu} r_{si}^{1-\mu}}{w_i}\right)^{\alpha\gamma_e} \left(\frac{w_i}{P_{mi}}\right)^{\gamma_e} \left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta} \tag{10}$$

Using aggregate price of structures and final good,

$$\frac{P_{ei}}{P_{ci}} = \frac{UV_e}{V_c} A_{ci} \left(\frac{r_{ei}^{\mu} r_{si}^{1-\mu}}{w_i}\right)^{\alpha(\gamma_e-\gamma_c)} \left(\frac{w_i}{P_{mi}}\right)^{\gamma_e-\gamma_c} \left(\frac{\lambda_{ei}}{\pi_{eii}}\right)^{-\theta}$$

$$\frac{P_{si}}{P_{ci}} = \frac{V_s}{V_c} A_{ci} \left(\frac{r_{ei}^{\mu} r_{si}^{1-\mu}}{w_i}\right)^{\alpha(\gamma_s-\gamma_c)} \left(\frac{w_i}{P_{mi}}\right)^{\gamma_s-\gamma_c} \tag{11}$$

Using trade share and price index of intermediate goods,

$$\pi_{mii} = \frac{\left\{\left(r_{ei}^{\alpha\mu} r_{si}^{\alpha(1-\mu)} w_i^{1-\alpha}\right)^{\gamma_m} P_{mi}^{1-\gamma_m}\right\}^{-1/\theta} \lambda_{mi}}{(UV_m)^{1/\theta} P_{mi}^{-1/\theta}}$$

$$\Rightarrow \frac{w_i}{P_{mi}} = (UV_m)^{-\frac{1}{\gamma_m}} \left(\frac{r_{ei}^{\mu} r_{si}^{1-\mu}}{w_i}\right)^{-\alpha} \left(\frac{\lambda_{mi}}{\pi_{mii}}\right)^{\frac{\theta}{\gamma_m}}$$

Using this in expressions (10) and (11) leads to the equations in (6).

Composition of capital: The equilibrium capital-output ratios are a function of the respective relative prices:

$$\frac{k_{ei}}{y_i} = \frac{\alpha\mu}{\frac{1}{\beta} - (1-\delta_e)} \frac{1}{P_{ei}/P_{ci}}$$

$$\frac{k_{si}}{y_i} = \frac{\alpha(1-\mu)}{\frac{1}{\beta} - (1-\delta_s)} \frac{1}{P_{si}/P_{ci}}$$

Using the expressions for relative prices derived above leads to the expression for capital-output ratios and equipment capital share in (3).

Income per worker: The income per worker is defined as

$$y_i = \frac{w_i}{P_{ci}} + \frac{r_{ei}}{P_{ci}} + \frac{r_{si}}{P_{ci}}$$

Using the first order conditions from firm optimization,

$$y_i = \frac{1}{1-\alpha} \frac{w_i}{P_{ci}}$$

Using the expression for price of final good, derived above, along with first order conditions from firm optimization leads to the following expression:

$$y_i = (1-\alpha)^{(1-\alpha)\gamma_c} \alpha\mu^{\alpha\mu\gamma_c} \alpha(1-\mu)^{\alpha(1-\mu)\gamma_c} V_c \; k_{ei}^{\alpha\mu\gamma_c} \; k_{si}^{\alpha(1-\mu)\gamma_c} \; \left(\frac{w_i}{P_{mi}}\right)^{1-\gamma_c}$$

Combining this with the following expression of intermediate goods home expenditure share and firm optimization first order conditions,

$$\pi_{eii} = UV_m \frac{\left(r_{ei}^{\alpha\mu\gamma_m} r_{si}^{\alpha(1-\mu)\gamma_m} w_i^{(1-\alpha)\gamma_m} P_{mi}^{1-\gamma_m}\right)^{-\frac{1}{\theta}} \lambda_{mi}}{P_{mi}^{-\frac{1}{\theta}}}$$

results in the following expression for income per worker:

$$y_i = \Lambda \, A_{ci} \left(\frac{\lambda_m}{\pi_{mii}}\right)^{\frac{\theta(1-\gamma_c)}{\gamma_m}} \; \left(k_{ei}^{\mu} k_{si}^{1-\mu}\right)^{\alpha}$$

where $\Lambda = (1-\alpha)^{-(1-\alpha)} \alpha\mu^{-\alpha\mu} \alpha(1-\mu)^{-\alpha(1-\mu)} \frac{1}{V_c} UV_m^{\theta - \frac{(1-\gamma_c)}{\gamma_m}}$ is a collection of constants.

B Data

The data set comprises prices, national accounts, production, trade, and capital stocks for a cross-section of 65 countries in 2005. The list of countries is in table C.1. This sample includes both rich and poor countries and accounts for 78 percent of world GDP in 2005.[21]

Goods categories: The goods categories here are consistent with the definitions in the System of National Accounts 1993.[22] Equipment corresponds to ISIC revision 2 categories 381-385, i.e., fabricated metal products, electrical and non-electrical machinery, transport equipment, communication equipment, office machinery, and professional and scientific equipment. ICP also identifies these as “machinery & equipment”.[23] Structures include residential and non-residential buildings.[24]

Prices: Data on the price of equipment and structures are from the International Comparison Program.[25] The price of equipment corresponds to the purchasing power parity (PPP) price of “Machinery & equipment”, world price equal to 1. The price of structures is the PPP price of “Construction”; world price equal to 1. For the price of final good, I use data on variable ”PC” from the Penn World Tables version 6.3. The price of intermediate goods uses prices from the benchmark ICP data. It is constructed by aggregating PPP prices across all goods except durable goods and services.

The equipment and structures capital stocks employed in this paper are based on PPP data from Penn World Tables version 6.3 (see Mutreja, 2014, for details). Thus, to maintain consistency with the data on capital stocks, prices and other PPP data have been taken from Penn World Tables version 6.3.

National Accounts: Income per worker is from Penn World Tables version 6.3 (Heston, Summers, and Aten, 2009) as the variable RGDPWOK. Using real GDP per capita (RGDPL), real income per worker (RGDPWOK), and population (POP) from the Penn World Table version 6.3 (Heston, Summers, and Aten, 2009), I calculate $\frac{\text{RGDPL*POP}}{\text{RGDPWOK}}$ to arrive at data on the labor force.

Production: Data on manufacturing production is from INDSTAT4 2013, a database maintained by UNIDO (2013). This database is organized according to ISIC revision 3 classification.[26] To extract equipment production data from this database, I identify the categories in 4 digit ISIC revision 3 that correspond to categories 381-385 in ISIC revision 2. The ISIC revision 3 categories

[21]World GDP is computed from the Penn World Tables version 6.3 (Heston, Summers, and Aten, 2009)

[22]SNA 1993 is available at http://unstats.un.org/unsd/nationalaccount/sna1993.asp.

[23]The ICP documentation is available at http://siteresources.worldbank.org/ICPINT/Resources/270056-1255977254560/6483625-1291755426408/7604122-1363984715044/15_Chapter_14.pdf.

[24]In SNA, residential buildings but not consumer durables are considered as as part of the production boundary.

[25]ICP is available at http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html

[26]Available at http://unstats.un.org/unsd/cr/registry/regcst.asp?cl=2

are 2811, 2812, 2813, 2893, 2899, 291*, 292*, 30**, 31**, 321*, 322*, 323*, 331*, 332*, 3420, 351*, 352*, 353*, and 3599. Intermediate goods correspond to manufactured goods other than equipment.

To have the largest country coverage possible, I supplement production data with information from more aggregated INDSTAT2 2013, which is organized at 2-digit level. Most countries are taken from the year 2005. In the case of missing data for 2005 in both INDSTAT4 and INDSTAT2, if information is available for any of the years 2000-04 and 2006 in INDSTAT4, I take data from the year closest to 2005 and convert into 2005 values by using growth rates of total manufacturing output over the same period.

Trade Flows: Bilateral trade data for 2005 is from UN Comtrade (http://comtrade.un.org). UN Comtrade data are organized according to SITC revision 2 level. In order to identify SITC revision 2 categories for equipment goods, I employ the SITC revision 2 - ISIC revision 3 correspondence in Affendy, Sim Yee, and Satoru (2010). Trade in intermediate goods corresponds to manufactured goods trade other than the trade equipment.

Trade Shares: Following Bernard, Eaton, Jensen and Kortum (2003), I construct bilateral trade shares as follows:

$$\pi_{eij} = \frac{\text{Country } i\text{'s equipment imports from country } j}{\text{Home equipment production + equipment imports from sample - equipment exports to world}}$$

Trade shares for the intermediate goods sector are constructed similarly.

Capital composition: The data on capital composition, and equipment and structures capital stocks are from Mutreja (2014).

Countries in 1985 sample: Australia, Austria, Canada, Denmark, Finland, France, Greece, Hungary, India, Iran, (Islamic Republic of), Ireland, Italy, Japan, Kenya, Luxembourg, Malawi, Mauritius, Netherlands, New Zealand, Norway, Philippines, Portugal, Republic of Korea, Spain, Sweden, Trinidad and Tobago, Turkey, United Kingdom, United Republic of Tanzania, United States of America, Portugal and Egypt.

C Tables

Table C.1: Productivity parameters

Country	Isocode	$\frac{\lambda_{eUS}^{\theta}}{\lambda_{ei}^{\theta}}$	$\frac{\lambda_{mUS}^{\theta}}{\lambda_{mi}^{\theta}}$	$\frac{A_{cUS}}{A_{ci}}$
Argentina	ARG	1.17	5.71	3.35
Australia	AUS	1.17	1.22	1.13
Austria	AUT	0.86	1.60	1.05
Belgium	BEL	1.16	2.55	2.24
Bolivia	BOL	2.41	9.05	1.94
Brazil	BRA	1.30	2.48	1.32
Canada	CAN	1.30	4.03	1.39
Chile	CHL	1.62	2.92	1.51
China	CHN	2.75	3.46	2.19
China (Macao SAR)	MAC	1.67	2.14	2.39
Colombia	COL	1.96	4.45	1.74
Cyprus	CYP	1.99	2.95	1.68
Denmark	DNK	0.97	1.64	1.10
Ecuador	ECU	3.77	4.67	1.95
Fiji	FJI	1.46	6.83	1.71
Finland	FIN	1.43	1.07	1.20
France	FRA	0.94	1.07	1.00
Greece	GRC	1.64	1.79	1.36
Hungary	HUN	0.96	2.69	1.12
Iceland	ISL	1.96	1.54	1.71
India	IND	1.88	3.02	1.66
Indonesia	IDN	1.97	7.00	1.88
Iran (Islamic Republic of)	IRN	2.57	3.59	1.98
Ireland	IRL	0.95	1.79	1.14
Israel	ISR	2.16	1.96	1.63
Italy	ITA	1.68	1.19	1.28
Japan	JPN	1.93	1.16	1.37
Jordan	JOR	3.26	3.92	1.99
Kenya	KEN	0.95	5.29	1.61
Luxembourg	LUX	1.02	2.14	1.90
Malawi	MWI	5.06	8.09	7.22
Malaysia	MYS	3.99	6.38	2.37
Malta	MLT	1.90	3.94	1.88
Mauritius	MUS	0.84	4.40	1.74
Mexico	MEX	0.98	4.18	1.08
Mongolia	MNG	5.88	16.76	9.06
Netherlands	NLD	0.63	2.07	1.27
New Zealand	NZL	0.89	1.38	1.07
Norway	NOR	1.33	1.02	1.34
Panama	PAN	4.86	7.03	2.48
Paraguay	PRY	1.22	7.45	1.64
Peru	PER	3.36	4.14	1.78
Philippines	PHL	2.30	7.95	2.13
Poland	POL	1.52	2.34	1.31
Portugal	PRT	2.04	2.39	1.44
Qatar	QAT	2.47	4.01	2.43
Republic of Korea	KOR	2.94	1.64	1.84
Romania	ROM	1.62	2.79	1.52
Senegal	SEN	1.89	5.01	2.32
South Africa	ZAF	0.92	1.44	1.21

Continued on Next Page...

Table C.1 – Continued

Country	Isocode	$\frac{\lambda_{eUS}^{\theta}}{\lambda_{ei}^{\theta}}$	$\frac{\lambda_{mUS}^{\theta}}{\lambda_{mi}^{\theta}}$	$\frac{A_{cUS}}{A_{ci}}$
Spain	ESP	0.97	1.28	1.02
Sweden	SWE	0.59	0.89	0.88
Thailand	THA	3.69	5.55	2.24
Tonga	TON	2.29	6.66	3.05
Trinidad and Tobago	TTO	1.52	3.21	1.40
Turkey	TUR	1.69	2.05	1.40
United Kingdom	GBR	0.84	1.01	1.02
United Republic of Tanzania	TZA	2.83	5.15	2.12
United States of America	USA	1.00	1.00	1.00
Uruguay	URY	1.45	3.71	1.52
Puerto Rico	PRT	2.04	2.29	1.49
Niger	NER	1.69	7.14	1.73
Egypt	EGY	1.36	3.88	1.96
Kuwait	KWT	5.07	2.07	2.20
Tunisia	TUN	1.47	3.07	1.96

D Figures

Figure D.1: Share in world equipment production

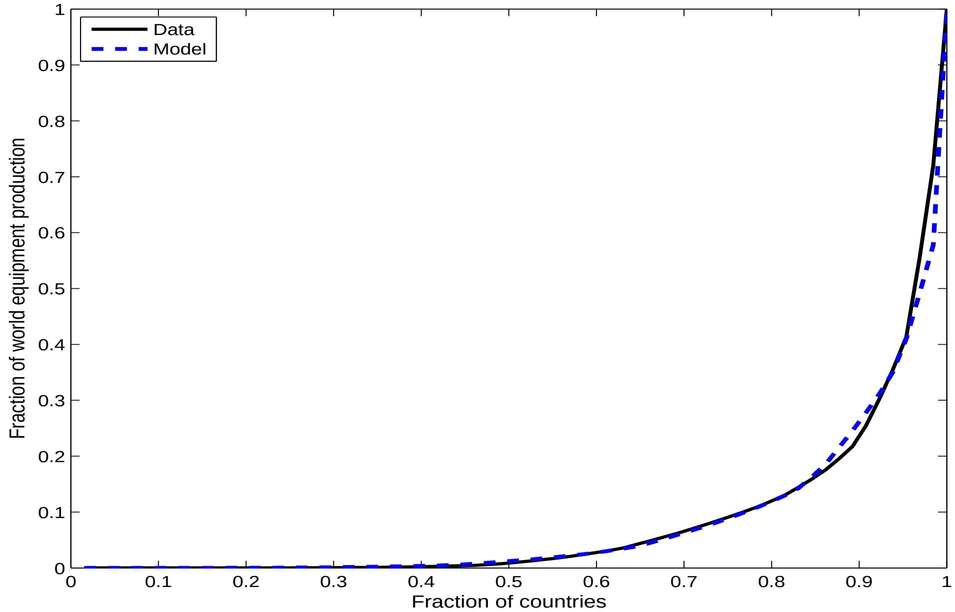


Figure D.2: Capital-output ratios (model versus data)

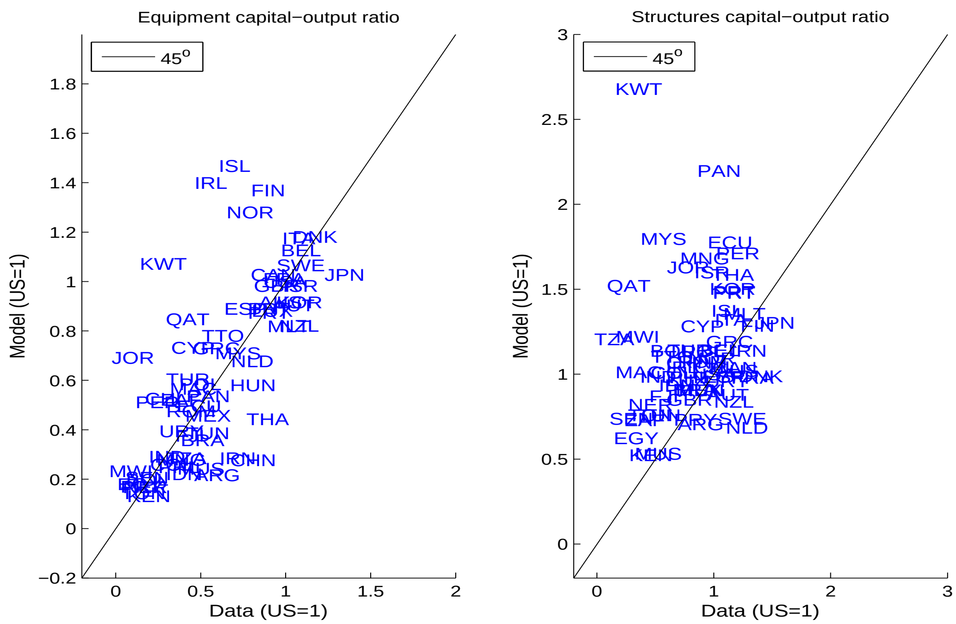


Figure D.3: Capital per worker (model versus data)

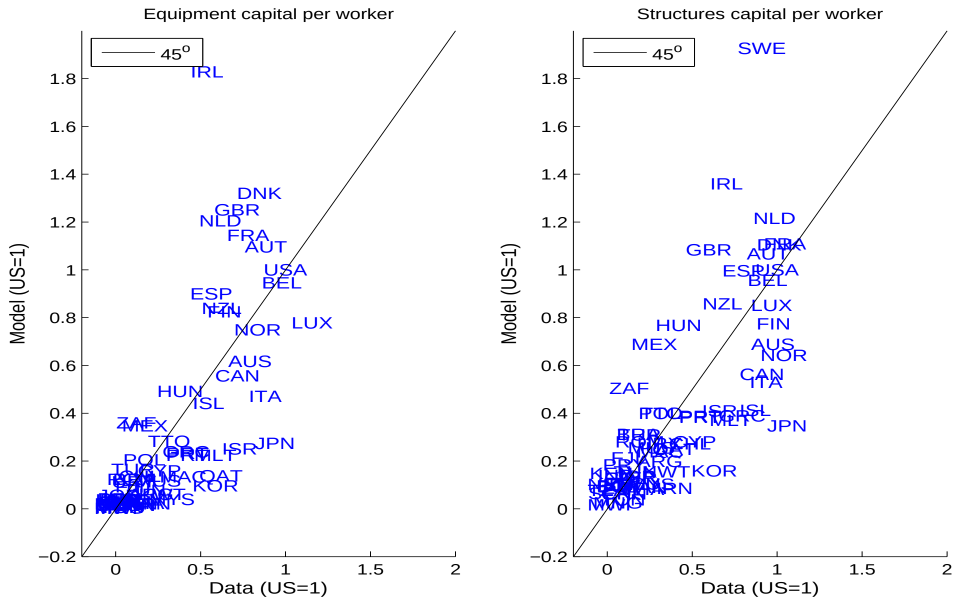


Figure D.4: World income distribution

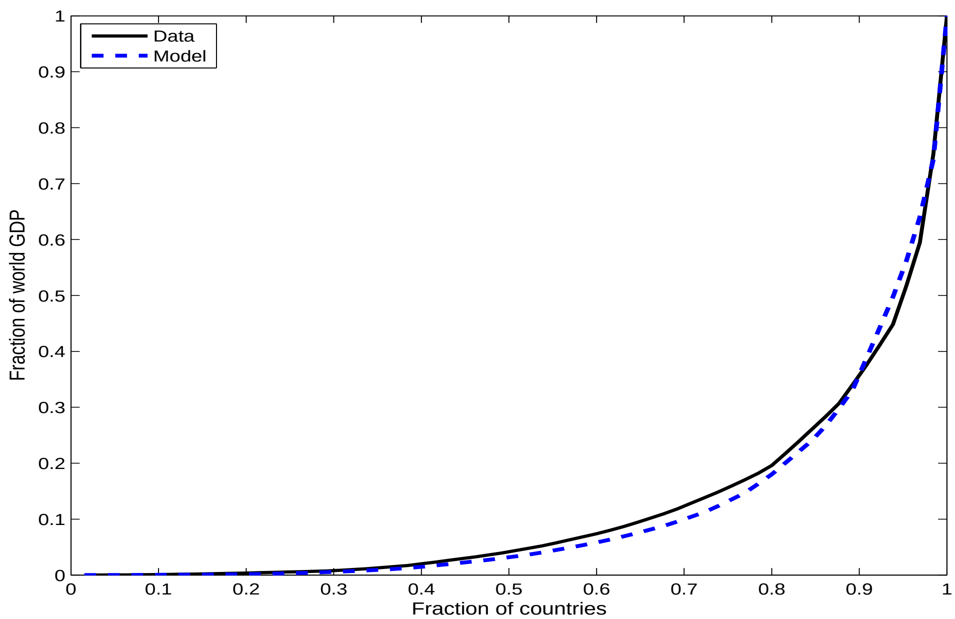


Figure D.5: Autarky in equipment

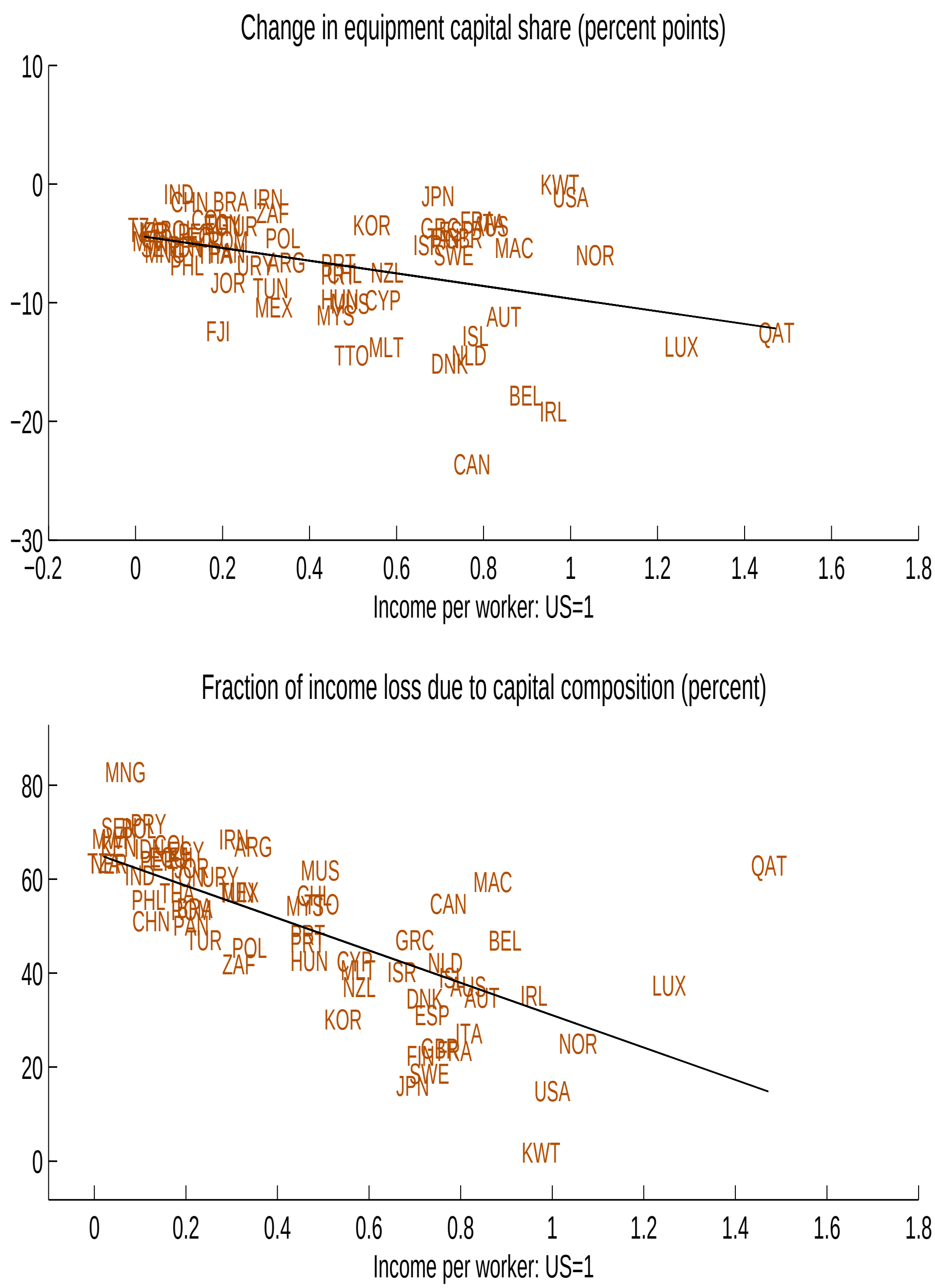


Figure D.6: Zero gravity in equipment, $\tau_{eij} = 1$

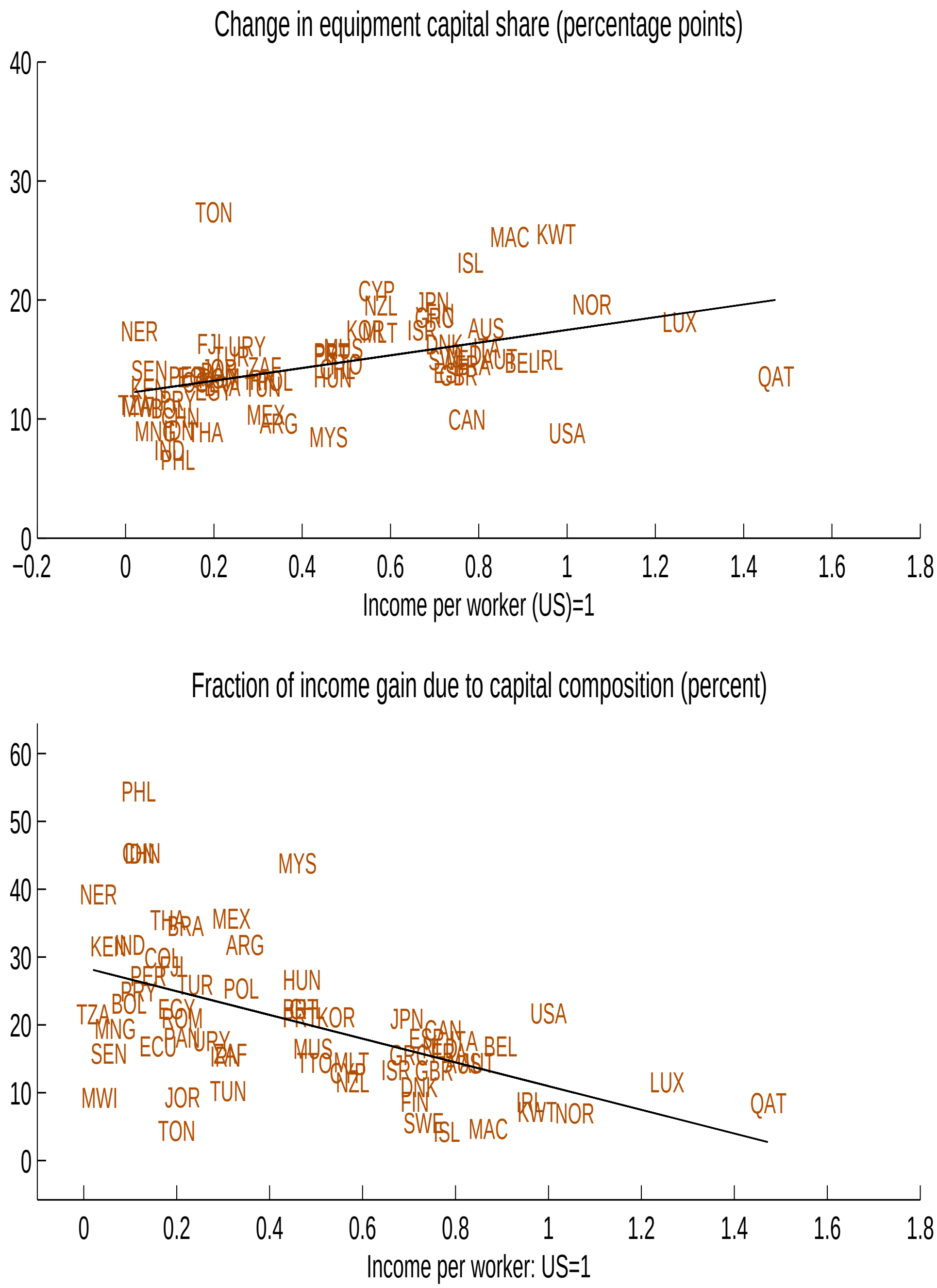
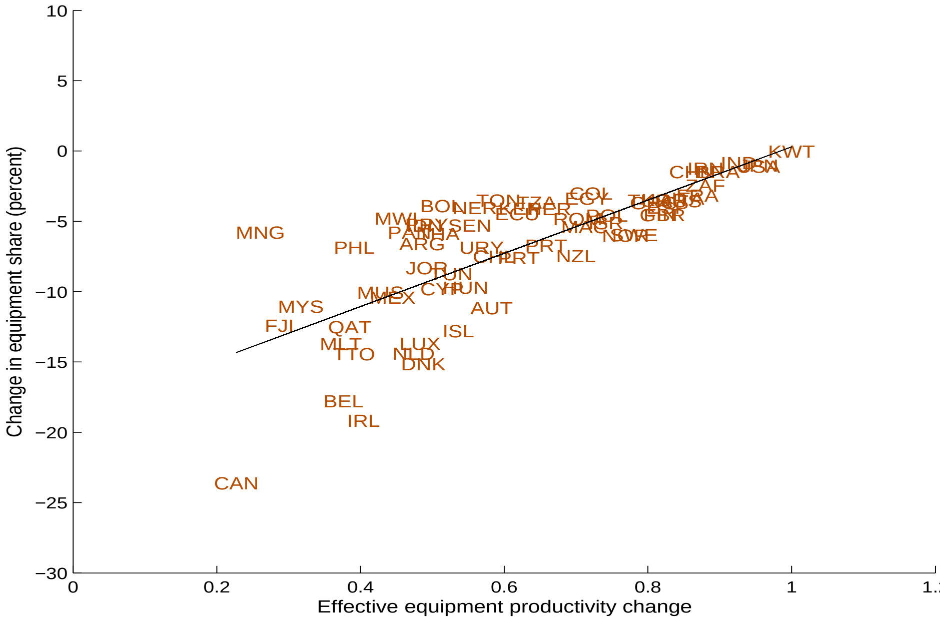
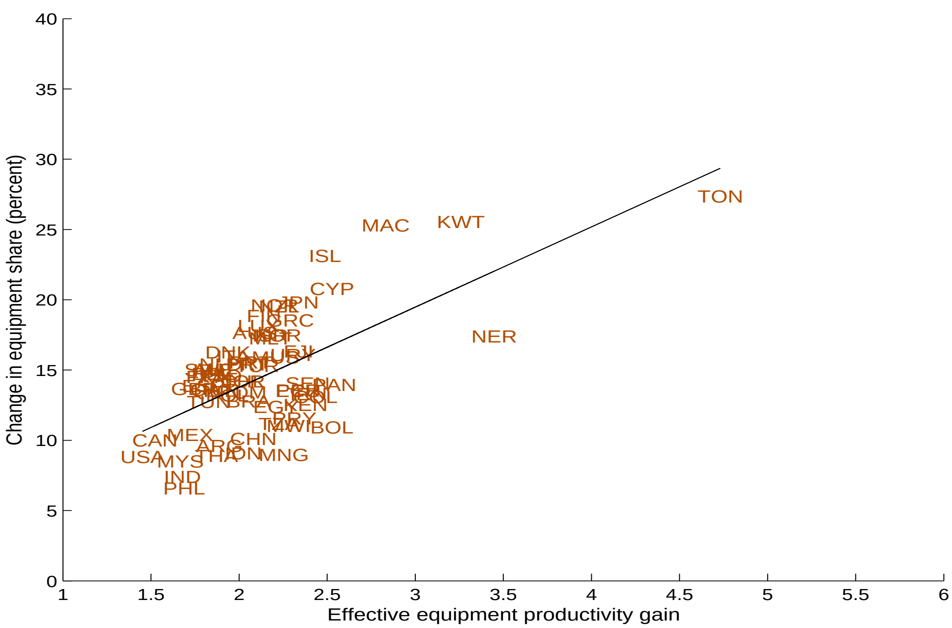


Figure D.7: Equipment capital share and effective equipment productivity: autarky in equipment



Note: US effective equipment productivity in baseline is normalized to one.

Figure D.8: Equipment capital share and effective equipment productivity: zero gravity in equipment



Note: US effective equipment productivity in baseline is normalized to one.