

# Accounting for Development Through Investment Prices<sup>1</sup>

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## **Abstract**

In this paper we explore qualitatively and quantitatively whether observed investment prices can account for the large cross-country income and productivity differences observed in the data. We incorporate an extensive margin in an otherwise standard open economy neoclassical growth model by allowing for entry into the intermediate goods sector. Crucially, entry requires investment of capital. This extensive margin, when combined with a “returns to variety” effect, provides an amplification mechanism from relative investment prices to output. We quantify the model using cross-country data on relative investment prices data. The model can explain up to 5 to 6-fold income differences between the richest and poorest countries in our sample. The model also reduces the exogenous cross-country TFP differences required to explain the observed 33-fold income gaps in the data to between 2 and 4-fold. We view these results as suggestive of the greater importance of the intermediate goods channel and investment prices for explaining the world income distribution than is typically implied by the standard model.

# 1 Introduction

The per capita income gap between the richest and poorest countries of the world are often measured to be 33-fold or more. Concurrently, a systematic feature of the data is that the price of investment goods relative to consumption goods is consistently higher in poorer countries relative to the richer countries. These two facts have induced a number of researchers to investigate the ability of relative investment prices to explain the observed income disparities across countries (see Chari, Kehoe and McGrattan (1997), Jones (1994) and Restuccia and Urrutia (2001)). Using conventional measures for the capital share in the range of 0.3 – 0.4, the standard neoclassical growth model does generate quantitatively accurate variations in measured investment rates across countries.<sup>1</sup> However, the standard model typically translates the observed investment price differences into much smaller differences in per capita income than the 33-fold gaps observed. A corollary of this is that the observed cross-country variations in investment and capital are not enough to explain the measured income disparities. In the neoclassical model, this shows up as huge disparities in measured productivity across countries. Clearly, there appears to be a missing link in the mapping from investment prices to relative incomes. The key goal of this paper is to study a new mechanism that can potentially map the observed investment prices into bigger income differences between countries as well as reduce the implied productivity differences that are required to fully account for the observed income differences.

We formalize a multi-sector model in which intermediate goods are combined to produce the final good. Crucially, we introduce an extensive margin to the intermediate goods sector in an otherwise standard open economy version of the neoclassical growth model. Setting up an intermediate good firm involves a set-up cost, which we label as investment in structures. Thus, intermediate goods production have two cost components – the set-up cost of installing the initial structure, and the variable cost of hiring labor and capital to vary output given the structure. In this environment, higher relative investment prices not only reduce investment in variable capital but also reduce entry into the intermediate goods sector. As a result, economies where relative investment prices are high produce a smaller number of varieties of intermediate goods.

A key feature of the model is that we allow free trade in variable capital goods.<sup>2</sup> The free trade

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<sup>1</sup>Using a broader measure of capital including both physical and human capital one could potentially work with larger capital shares than the typical range. Mankiw, Romer and Weil (1992), Chari, Kehoe and McGrattan (1997), Parente and Prescott (1994), amongst others, use capital shares upwards of 2/3 to explain observed income disparities using investment rates.

<sup>2</sup>Capital goods are indeed a very important part of world trade. See Eaton and Kortum (2003) and references herein.

assumption implies that all countries face the same world prices of variable capital goods. Hence, the domestic price of variable capital in any country, when expressed in terms of its consumption good, depends on the real exchange rate of the country, i.e., on the price of the world numeraire good in terms of the domestic final good. Thus the domestic price of variable capital goods will be higher in countries with relatively cheaper consumption goods. This provides the model with the standard intensive margin of relative investment prices; countries with higher investment prices will employ less variable capital per worker and thereby also produce less. Structures are, however, non-traded. Hence, their domestic price depends both on the price of consumption goods as well as the local cost of producing structures. All else equal, countries where structures are relatively more expensive will invest less in them. This implies less entry into the intermediate goods sector, which is the extensive margin in the model.

The extensive margin of production has two effects on per capita output both of which arise due to a “returns to variety” effect that is embodied in the final goods technology. First, there is a *direct* effect in that higher relative investment prices reduce the number of varieties of intermediates produced in the economy. This reduces output through the “variety” effect over and beyond the standard intensive margin and hence, amplifies the effects of higher relative investment prices.

Second, the “returns to variety” effect also induces an *indirect* effect by magnifying total factor productivity (TFP) differences across countries. In particular, any difference in TFP (which affects all intermediate goods symmetrically) gets magnified as countries that produce more intermediate goods also get an exponential boost to output due to a geometric aggregation of any given TFP difference over all the additional intermediate goods they produce.

The model’s predictions for relative income boils down to a simple expression involving the relative prices of structures, prices of variable capital, and exogenous differences in TFP. We identify the prices of the two types of investment goods individually using the model and the available cross-country data on the relative price of investment goods from the Penn World tables. When these data are put through a calibrated version of the model with a capital share of 0.40, we generate three principal results.

First, the model always maps investment prices into bigger income gaps than the standard neo-classical model. Indeed, observed investment prices could potentially explain up to 5-fold income differences between the richest and poorest countries in our model. However, the model’s direct mapping from relative investment prices to relative incomes depends crucially on the elasticity of substitution between intermediate goods. As the substitution elasticity goes to infinity (interme-

diated goods become perfect substitutes), our model converges to the standard neoclassical model. For substitution elasticities around 3 the observed investment prices induce 5.2-fold or higher income disparities between the richest and poorest countries in our sample. This represents an almost 150 percent increase in the predicted income gap relative to the 2-fold gap predicted by the standard neoclassical growth model using the same investment price data. However, as the substitution elasticity rises to 5 and 10 the predicted income gap declines precipitously to 3 and 2.4. This sensitivity makes it difficult to declare the extensive margin as being completely successful in explaining the observed income gaps since available estimates for the elasticity of substitution between intermediate goods are all over the place with little consensus on any particular estimate.

Second, we compute the productivity differences between the richest and poorest countries that are required to fully account for the observed income gaps in the data. After accounting for the income gaps predicted by relative investment prices, we find that the model only requires TFP differences between 2 and 4 in order to explain the rest of the 33-fold income gaps observed in the data. This stands in sharp contrast to the standard model which implies more than 5-fold TFP differences between the richest and poorest countries for the same investment prices. Expressed as the technological distance in years of the poorest countries from the frontier, this corresponds to a reduction of between 25 and 45 years in the technological distance. We view this result as being indicative of a greater relevance of investment prices for understanding cross-country income differences than the standard model would suggest.

We note our model amplifies the mapping from investment rates to output, but it shares with the standard neoclassical model the mapping from investment prices to investment-output ratios. As Restuccia and Urrutia (2001) document, the standard neoclassical model does a good job explaining the dispersion in investment-output ratios. As the predictions are identical, we know our model is also consistent with investment-output data.

Third, we find that the predicted disaggregated investment prices in the model closely track the corresponding prices in the disaggregated OECD investment price data, lending support to the structure of the model. Lastly, counterfactual experiments using the disaggregated investment prices suggest that both investment goods play a significant role in cross-country income variation, with structures prices being of marginally greater importance. Interestingly, the prices of structures and composite capital goods induce independent cross-country income variation.

Our identification of entry costs as being solely the investment cost of structures provides discipline to the quantitative exercise by linking relative incomes to just the relative price of

investment goods. However, it is also very restrictive in that it precludes a discussion of the contribution of other impediments to firm entry. To examine how far we may be underestimating the role of the intermediate goods channel in explaining cross-country income patterns by focusing exclusively on the cost of structures, we also consider an extension wherein we expand the fixed cost of entry into the intermediate goods sector from just the cost of structures to include other entry costs such as the direct and indirect costs of starting businesses. This is motivated by the fact that the key effects in the model run through the extensive margin of entry into the intermediate goods sector. All costs that impede such entry would work in similar ways. We use cross-country data on the costs of starting businesses from the *Doing Business* survey to show that this view of the entry costs induces 6 to 7-fold income differences between the richest and poorest countries even with relatively high elasticities of substitution of 5. Correspondingly, the implied productivity differences between these countries falls to just 2. We view these results as suggestive of the fact that explanatory power of the intermediate goods channel for explaining the cross-country relative income differences may be much greater than what is implied by our somewhat narrow and unidimensional view of entry costs being solely the investment cost of structures.

While there is a large literature on development accounting, the paper that is closest to our work is Jones (2011). He studies environments where there are linkages and complementarities between intermediate goods and final goods. The key point in Jones's work is that small distortions in some sectors can have a multiplier effect on final output because of linkages between sectors. Jones shows that his model can easily generate 50-fold income differences between low distortion and high distortion economies even with a capital share which is within the empirically plausible range.<sup>3</sup>

Our model differs from Jones in three substantive ways. First, our mechanism works through the extensive margin; distortions affect the number of intermediate goods. Jones's model, on the other hand, works through the intensive margin; distortions affect the intensity with which a given list of intermediate goods are produced. Second, Jones works in a closed economy environment whereas we allow for trade in a set of capital goods. Third, we quantify our model using relative investment prices and characterize the whole distribution of relative incomes. Due to lack of available cross-country data on distortions, Jones is constrained to highlighting the relative income

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<sup>3</sup>Ciccone (2002) is probably the first paper to demonstrate the potential magnification effect of intermediate goods on final output.

implications of different levels of distortions.

Our paper is also related to the work on development accounting which focusses on decomposing cross-country income differences into different components. A key finding of this body of work is that measured differences in inputs are insufficient to account for the large relative income disparities in the data. It follows that productivity differences across countries must be very large.<sup>4</sup> A contribution of our work is to demonstrate that the productivity differences may be much smaller than those implied by the standard model once the effect of investment prices on the extensive margin is accounted for.

There is a growing literature exploring the implications of entry for standard macroeconomic models. Bilbiie, Ghironi, and Melitz (2007) argue that entry provides a powerful propagation mechanism in real business cycle models. Jaimovich (2007) and Barseghyan and DiCecio (2008) show that endogenous entry can lead to a multiplicity of equilibria. To our knowledge, we are the first to explore the implications of the extensive margin for cross-country income differences using investment prices.

Since a key motivation for our work is the observed variation in the relative price of investment goods, one key observation is in order before we proceed. Hsieh and Klenow (2007) have argued that most of the variation in the relative price of investment goods in the PWT dataset is due to variations in the price of consumption across countries rather than variations in the price of investment goods. They interpret this result as suggesting that explanations of the world income dispersion that hinge on investment distortions in the form of import tariffs, taxes etc., are unlikely to be true. Instead, they argue the challenge is to explain the reasons for the low productivity of the investment goods sector in the poorer countries. Our model is consistent with Hsieh-Klenow in that it takes a technological view of the observed differences in prices. In particular, investment prices in the model differ across countries because the non-traded component of investment uses a technology that requires different amounts of the consumption good in different countries. Hence, there is cross-country variation in investment prices when expressed in terms of the domestic consumption good.

The next section develops the model while section 3 presents the key analytical implications for the cross-country facts of interest. Section 4 presents the quantitative results while we conduct some counterfactual experiments involving the prices of individual capital goods in Section 5.

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<sup>4</sup>A non-exhaustive list of papers in this context is Klenow and Rodrigues (1997), Hall and Jones (1999), and Parente and Prescott (2000).

Section 6 re-does the quantification of the model with an expanded notion of entry costs to include the costs of starting businesses and presents the results. The last section concludes. Some key derivations and proofs are contained in the appendix.

## 2 Model

In this section we outline the model. We start with the economic environment that we study and then provide details of the competitive equilibrium of the model.

### 2.1 Environment

We consider a world economy with  $J$  countries. We first describe the economy of a given country  $j \in J$ . We use a superscript to denote country-specific parameters: all non-indexed parameters are taken to be identical across countries.

In each country  $j \in J$  there are  $L_t^j$  identical households. Each household supplies one unit of labor inelastically and consumes  $c_t^j$  units of the final good. Households value a stream of consumption according to

$$U^j = \sum_{t=0}^{\infty} \beta^t u(c_t^j) \quad (1)$$

where  $\beta \in (0, 1)$  is the intertemporal discount rate and utility function  $u(c)$  has the standard properties.

The final good  $Y_t^j$  is produced by combining together a set  $\Omega_t^j = [0, m_t^j]$  of intermediate goods according to the technology:

$$Y_t^j = \left[ \int_{\omega \in \Omega_t^j} \left( x_t^j(\omega) \right)^\rho d\omega \right]^{1/\rho}, \quad (2)$$

where the parameter  $\rho \in (0, 1)$  determines the elasticity of substitution across intermediate goods and  $x_t^j(\omega)$  is the amount of intermediate good  $\omega$  used in production in country  $j$ . More specifically,  $\sigma = 1/(1 - \rho)$  is the elasticity of substitution across intermediates goods. In the following we shall use  $\sigma$  throughout by making the appropriate transformation of expressions involving  $\rho$ .

The set of intermediate goods is endogenous as we allow for entry and exit in the sector. Let us start, though, with the production of existing intermediate goods  $\omega \in \Omega_t^j$ . The production

technology for intermediate goods is given by

$$x_t^j(\omega) = A_t^j \left( \hat{k}_t^j(\omega) \right)^\alpha \left( l_t^j(\omega) \right)^{1-\alpha}$$

with  $\hat{k}_t^j(\omega)$  and  $l_t^j(\omega)$  being the composite capital and labor inputs respectively used in firm  $\omega$ . It turns out to be convenient to work with composite capital per worker in a firm rather than composite capital per firm. Hence, we define  $k_t^j(\omega) \equiv \hat{k}_t^j(\omega) / l_t^j(\omega)$ . The production of the intermediate good  $\omega$  is then given by

$$x_t^j(\omega) = A_t^j \left( k_t^j(\omega) \right)^\alpha l_t^j(\omega). \quad (3)$$

The parameter  $\alpha \in (0, 1)$  equals the share of working capital expenses in the variable cost. The term  $A_t^j$  determines the total factor productivity in the production of intermediate goods: we allow this term to vary between countries.

To start production of a new intermediate good requires an initial investment of the capital good we call structures. This initial investment is a sunk cost: it depreciates fully on exit. In order to avoid scale effects in the model, we assume that the units of structures are necessary to start production are proportional to the population,  $L_t^j$ .<sup>5</sup> We can thus relate the measure of active intermediate goods  $m_t^j$  to the stock of structures in the economy,  $M_t^j = m_t^j L_t^j$ . It must be emphasized that the investment in structures occurs only at entry: there are no fixed costs associated with *continuing* production. Exit of firms from the intermediate goods sector is exogenous and occurs with probability  $\chi$ .

We now turn to the production of new composite capital. Let  $I_t^j$  denote the investment in the composite capital good in country  $j$ . New composite capital goods are produced by combining together specific capital goods from all countries according to the CES technology

$$I_t^j = \left[ \sum_{c \in J} (N_{jt}^c)^\eta \right]^{1/\eta} \quad (4)$$

where  $N_{jt}^c$  denotes specific capital produced in country  $c \in J$  and used in country  $j$  at date  $t$ . Parameter  $\eta \in (0, 1)$  governs the elasticity of substitution between specific capital goods from

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<sup>5</sup>The presence of the indivisible investment in structures implies that this model, in general, will give rise to scale effects: countries with bigger populations will face lower per unit costs of structures and, hence, will end up with higher per capita output. While this scale effect often arises in this class of models there is very little evidence to support its presence in the data. On a related note, if the costs were not scaled to  $L$  the model would exhibit increasing returns due to the fixed cost.

different countries. The total stock of composite capital  $K_t^j$  in country  $j$  follows the law of motion

$$K_t^j = (1 - \delta) K_{t-1}^j + I_t^j \quad (5)$$

where  $\delta \in [0, 1]$  is the depreciation rate.

To produce one unit of the specific capital good of country  $j$  requires  $v_t^j$  units of the final good. We assume that countries differ in their ability to produce specific capital goods. Specific capital goods are the only traded goods in the world economy. The production of new structures is also linear: one unit of new structures costs  $f_t^j$  units of the final good. This can too vary across countries.

We are now ready to summarize all the uses of the final good  $Y_t^j$  in the aggregate resource constraint

$$Y_t^j = C_t^j + f_t^j \left[ m_{t+1}^j - m_t^j (1 - \chi) \right] L_t^j + v_t^j \sum_{c \in J} N_{ct}^j. \quad (6)$$

The resource constraint includes the cost of investment in new structures,

$$f_t^j \left[ m_{t+1}^j - m_t^j (1 - \chi) \right] L_t^j$$

as well as the total cost of producing the country  $c$  specific capital demanded by all countries,

$$v_t^j \sum_{c \in J} N_{ct}^j.$$

We can also rewrite the resource constraint (6) in per capita terms as

$$y_t^j = c_t^j + f_t^j \left[ m_{t+1}^j - m_t^j (1 - \chi) \right] + v_t^j \sum_{c \in J} n_{ct}^j \quad (7)$$

where  $y, c$  and  $n$  denote the per capita counterparts of  $Y, C$  and  $N$ .

## 2.2 Competitive Equilibrium

We now describe a competitive equilibrium. We focus on the determination of prices and the real exchange rate. In each country we use the final good as numeraire. In making cross-country comparisons of goods however, we use the real exchange rate, which measures the price of the world numeraire good in terms of the domestic final good.

*Households.* Households own the stock of domestic composite capital as well as all claims to domestic firms. Each period the households rent out labor and the composite capital to domestic firms, and trades one-period domestic bonds  $b_t$  in order to maximize utility as given by (1) subject to the flow budget constraint

$$c_t^j + p_{kt}^j \left[ K_{t+1}^j - (1 - \delta) K_t^j \right] / L_t^j + q_t^j b_{t+1}^j \leq w_t^j + r_t^j K_t^j / L_t^j + d_t^j + b_t^j$$

where  $p_{kt}^j$  is the price of new composite capital goods,  $q_t^j$  is the price of the domestic bond,  $w_t^j$  and  $r_t^j$  are the rental rates of labor and the composite capital good respectively, and  $d_t^j$  are total dividends received.

The necessary first order conditions give the price of the bond,

$$q_t^j = \beta \frac{u'(c_{t+1}^j)}{u'(c_t^j)}.$$

We assume bonds are in zero net supply (that is, they are not internationally traded) and we drop them from the competitive equilibrium definition.

From the household optimization problem we also derive

$$u'(c_t^j) = \beta u'(c_{t+1}^j) \left[ \frac{p_{kt+1}^j (1 - \delta) + r_{t+1}^j}{p_{kt}^j} \right] \quad (8)$$

which is the basic Euler equation governing the optimal consumption-saving decision by households.

*Final good producers.* The final goods sector is competitive. Profit maximization by final goods firms implies

$$p_{xt}^j(\omega) = \left( Y_t^j / x_t^j(\omega) \right)^{\frac{1}{\sigma}} \quad (9)$$

where  $p_{xt}^j(\omega)$  is the price of the intermediate good of the variety  $\omega$ . This is the standard inverse CES demand function.

*Structures and specific capital firms.* We assume both sectors are perfectly competitive so the prices of structure and specific capital goods equal their marginal costs  $p_{ft}^j = f_t^j$  and  $p_{nt}^j = v_t^j$  respectively. Because the pricing equations are trivial we drop them and use the technology parameters  $f_t^j$  and  $v_t^j$  directly.

*Intermediate good producers.* The intermediate goods sector is monopolistically competitive

and subject to entry. We will focus on a symmetric equilibrium: we drop the index  $\omega$  for the intermediate goods.

Technology (3) is constant returns to scale, so cost minimization implies that total costs are  $s_t^j x_t^j$ , where

$$s_t^j = \frac{(r_t^j)^\alpha (w_t^j)^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha} A_t^j} \quad (10)$$

is the marginal cost.

We can substitute the cost function and the inverse demand function facing the intermediate goods firm into its profit function to derive the optimal price that the firm charges for its product:

$$p_{xt}^j = \left( \frac{\sigma}{\sigma-1} \right) s_t^j. \quad (11)$$

This is the familiar mark-up pricing rule with the mark-up over marginal cost being given by  $\frac{\sigma}{\sigma-1}$ . Revenues net of variable cost  $\pi_t^j = (p_{xt}^j - s_t^j) x_t^j$  are then

$$\pi_t^j = \left( \frac{1}{\sigma-1} \right) s_t^j x_t^j.$$

*Entry in the intermediate sector.* There is free entry into the intermediate sector. However, entrants need  $L_t^j$  units of structures to start up production. The present discounted value of the flow profits of a firm that chooses to enter at date  $t$  is

$$V_t^j = \sum_{s=t}^{\infty} (1-\chi)^{s-t} q_{ts}^j \pi_s^j$$

where we have used the bond price for  $s$  periods ahead,  $q_{ts}^j$ , to discount future profits.

Hence there will be entry as long as the present value of profits is higher than the sunk cost entry, given by  $p_{ft}^j L_t^j = f_t^j L_t^j$ . The free entry condition can be written then as

$$V_t^j \leq f_t^j L_t^j \quad (12)$$

with strict equality if there is positive entry.

*Composite capital sector.* Perfectly competitive firms produce new units of the composite

capital good using (4). The profit function is given by

$$p_{kt}^j I_t^j - \varepsilon_t^j \sum_{c \in J} \left( \frac{v_t^c N_{jt}^c}{\varepsilon_t^c} \right)$$

where  $\varepsilon_t^c$  is the real exchange rate between country  $c$  and some (unindexed) country whose final good acts as numeraire in the international markets. Hence the ratio  $\varepsilon_t^j / \varepsilon_t^c$  is the price of one unit of final good in country  $c$  in terms of the final good of country  $j$ . All prices in the world market are taken as given. Recall that  $p_{kt}^j$  is the domestic good price of composite capital while  $I_t^j$  is new production of composite capital in country  $j$ .

Profit maximization implies that the inverse demand for specific capital from country  $c$  by a firm in country  $j$  is given by

$$\left( \frac{I_t^j}{N_{jt}^c} \right)^{1-\eta} = \frac{\varepsilon_t^j v_t^c}{\varepsilon_t^c p_{kt}^j}. \quad (13)$$

We assume that trade is balanced each period. Since specific capital goods are the only traded goods in this economy we have

$$v_t^j N_t^j = \varepsilon_t^j \sum_{c \in J} \left( \frac{v_t^c N_{jt}^c}{\varepsilon_t^c} \right). \quad (14)$$

where  $N_t^j = \sum_{c \in J} N_{ct}^j$ .

We state the definition of competitive equilibrium in per capita terms as they will be the exclusive focus of our analysis.

*Competitive equilibrium definition.* A competitive equilibrium is a price system

$$\left\{ q_t^j, p_{kt}^j, r_t^j, w_t^j, p_{xt}^j, \varepsilon_t^j \right\}_{t \geq 0, j \in J}$$

and an allocation

$$\left\{ c_t^j, y_t^j, x_t^j, k_t^j, l_t^j, i_t^j, n_t^j, m_t^j \right\}_{t \geq 0, j \in J}$$

such that for all countries  $j \in J$  and periods  $t \geq 0$ :

1. Households maximize (1) subject to the flow budget constraints,
2. Firms maximize profits,
3. All markets clear, and
4. The resource constraint holds (7).

### 2.3 The Steady State

We now solve for the key equilibrium relationships in the model in steady state.<sup>6</sup> Here and below we suppress time subscripts for notational convenience since we are describing the steady state. We start by using the inverse demand function for specific capital from country  $c$  (see equation (13)) to get

$$n_c^j = \left( \frac{p_k^c}{\varepsilon^c v^j} \right)^{\frac{1}{1-\eta}} i^c.$$

Substituting this expression into the production function for the composite capital good in country  $c$  and suitably manipulating the resulting expression gives

$$\varepsilon^c = p_k^c \left[ \sum_{j \in J} \left( \frac{v^j}{\varepsilon^j} \right)^{\frac{\eta}{\eta-1}} \right]^{\frac{1-\eta}{\eta}}.$$

For ease of notation, we relabel the price of the composite capital good,  $p_k^c$ , as  $z^c$ , as we will be identifying it directly from the data. We have thus

$$z^c = \varepsilon^c \left[ \sum_{j \in J} \left( \frac{v^j}{\varepsilon^j} \right)^{\frac{\eta}{\eta-1}} \right]^{\frac{\eta-1}{\eta}}. \quad (15)$$

Clearly,  $\left[ \sum_{j \in J} \left( \frac{v^j}{\varepsilon^j} \right)^{\frac{\eta}{\eta-1}} \right]^{\frac{\eta-1}{\eta}}$  is a world price index for a basket of specific capital goods which is common to all countries. Hence, the relative price of the composite capital good across any two countries is given by the ratio of their real exchange rates:

$$\frac{z^j}{z^i} = \frac{\varepsilon^j}{\varepsilon^i}.$$

Intuitively, since the basket of goods that is used to produce the composite capital good is identical across countries and this basket is freely available to all countries at the same world price, differences in the *domestic* basket price of the composite capital good across countries can only arise due to differences in the real exchange rate across countries, i.e., differences in the rate at which the world numeraire good can be converted into domestic final goods. Recall that all world prices are denominated in terms of the world numeraire good. Summarizing, trade in specific

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<sup>6</sup>For simplicity we abstract from growth. It is easy to characterize a balanced growth path given constant growth rates in the technology for intermediate and capital goods. Along the balanced growth path all countries experience the same growth rate and cross-country income differences remain constant.

capital goods pins down the relative price of the composite capital good, exactly as if the latter were freely traded.<sup>7</sup>

Before proceeding further, it is worth noting that the real exchange rate  $\varepsilon^c$  for each country can be determined through the joint solution of a set of equations involving the demand for specific capital goods from each country, the balanced trade condition, and the production technology for new composite capital goods. These set of equations induce a solution for  $\varepsilon^c$  as a function of the underlying cost of producing specific capital goods  $v$ , TFP technologies  $A$ , and the cost of structures  $f$  across all countries. Since we are interested in evaluating the role of investment prices in income differences, we shall proceed later by taking the real exchange rate from the data instead of solving for all the trade flows in the model. See Appendix B for further details.

In a symmetric equilibrium the final output of any economy is given by

$$Y^j = (m^j)^{\frac{1}{\sigma-1}} A^j (k^j)^\alpha L^j.$$

This expression follows by setting  $x^j = x^j(\omega)$  for all  $\omega$  in the production function (2). In per capita terms,

$$y^j = (m^j)^{\frac{1}{\sigma-1}} A^j (k^j)^\alpha. \quad (16)$$

The term  $(m^j)^{\frac{1}{\sigma-1}}$  in equation (16) reflects the “returns to variety” effect in the model. It arises due to the CES aggregator for final goods.

In the appendix we show that the steady state composite capital to structure ratio is given by

$$\frac{K^j}{M^j} = \frac{f^j}{z^j} \alpha (\sigma - 1) \beta \left[ \frac{1 - \beta(1 - \chi)}{1 - \beta(1 - \delta)} \right]. \quad (17)$$

This gives the optimal mix of composite and structural capital as a function of the ratio of their relative prices.

The appendix also shows that in steady state

$$m^j = \left[ \frac{(z^j)^\alpha (f^j)^{1-\alpha} \sigma [1 - \beta(1 - \chi)]^{1-\alpha} [1 - \beta(1 - \delta)]^\alpha}{A^j \alpha^\alpha \beta^\alpha (\sigma - 1)^\alpha} \right]^{\frac{\sigma-1}{2-\sigma+\alpha(\sigma-1)}}. \quad (18)$$

We can substitute this expression for  $m^j$  along with equation (17) into the expression for

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<sup>7</sup>Modeling specific capital goods as tradeable, though, ensures that trade flows are positive and uniquely determined across countries. As we shall show below however, the quantitative implications of the model for cross-country relative incomes are robust to the assumption on trade.

output (equation 16) to derive output as a function of productivity and capital goods prices:

$$\begin{aligned} \log y^j &= \left[ \frac{\sigma - 1}{\sigma - 2 - \alpha(\sigma - 1)} \right] (\log A^j - \alpha \log z^j) \\ &\quad - \left[ \frac{1}{\sigma - 2 - \alpha(\sigma - 1)} \right] \log f^j + \text{constant}. \end{aligned} \quad (19)$$

As long as  $\sigma - 2 > \alpha(\sigma - 1)$ , per capita output will be decreasing in the capital prices  $z^j$  and  $f^j$  and increasing in total factor productivity  $A^j$ . This condition will be satisfied by our parameterization of the model (see Section 4 below) and is necessary in order to have a stable steady state. Note that the only sources of cross-country income dispersion are the relative prices of capital goods and total factor productivity. In other words, the relationship (19) holds for each country as parameters  $\{\sigma, \alpha, \beta, \chi, \delta\}$  are assumed to be constant across countries.

### 3 Cross-Country Implications: Quantities and Prices

We now turn to an evaluation of the quantitative implications of this model. Our primary focus is on the model's implications for output per capita. From the previous section the output of country  $c$  relative to any reference country, say country  $r$ , is given by

$$\frac{y_i}{y_r} = \left( \frac{A_i}{A_r} \right)^{\frac{\sigma-1}{\sigma-2-\alpha(\sigma-1)}} \left( \frac{z_r}{z_i} \right)^{\frac{\alpha(\sigma-1)}{\sigma-2-\alpha(\sigma-1)}} \left( \frac{f_r}{f_i} \right)^{\frac{1}{\sigma-2-\alpha(\sigma-1)}}.$$

We can simplify the above expression in terms of the share of capital income. Recall that profits of intermediate goods firms are used to pay for structures. The profit share of revenues in the intermediates goods sector is  $1/\sigma$ . Hence, in terms of the share of final output, a fraction  $1/\sigma$  accrues to structures while a share  $\alpha$  of the remaining  $1 - 1/\sigma$  accrues to composite capital. Thus, the share of output going to capital in our model is

$$\kappa = \frac{1}{\sigma} + \alpha \left( 1 - \frac{1}{\sigma} \right) = \frac{1 + \alpha(\sigma - 1)}{\sigma}.$$

We have then that

$$\frac{y_i}{y_r} = \left( \frac{A_i}{A_r} \right)^{\frac{\sigma-1}{\sigma(1-\kappa)-1}} \left( \frac{z_r}{z_i} \right)^{\frac{\alpha(\sigma-1)}{\sigma(1-\kappa)-1}} \left( \frac{f_r}{f_i} \right)^{\frac{1}{\sigma(1-\kappa)-1}}. \quad (20)$$

Hence, in order to quantify the relative income predicted by the model we need to identify the price of composite capital  $z$  and the price of structures  $f$  across countries.

Given our assumption that capital goods are traded, the price of composite capital goods across countries satisfies

$$\frac{z_r}{z_i} = \frac{\varepsilon_r}{\varepsilon_i}$$

as shown in the previous section. Since  $\varepsilon$  denotes the real exchange rate, one can determine the relative price of composite capital by using the ratio of the price of consumption in the two countries (expressed in terms of the same basket). Data on the price of consumption across countries is readily available from the Penn World Tables.

Determining the price of structures across countries is more complicated. The relative price of investment that is available from the Penn World Tables gives the price of a basket of capital goods, not just structures. Unfortunately we do not have reliable price data on disaggregated capital goods across countries.<sup>8</sup> We get around this problem by using the structure of the model to identify the prices of structures and composite capital individually from the relative price of investment series.

To proceed we consider the problem facing an artificial firm which produces aggregate capital  $h$  using as inputs structures  $m$  and composite capital  $k$ . Define aggregate capital as

$$h = \left[ m^{\frac{1}{\sigma-1}} k^\alpha \right]^{\frac{\sigma-1}{1+\alpha(\sigma-1)}}$$

where we drop the country superscript for ease of notation. The definition is necessary in order to have constant returns to scale for the artificial firm.<sup>9</sup> Output per capita is now given by

$$y = Ah^{\frac{1+\alpha(\sigma-1)}{\sigma-1}}.$$

The parameter condition  $\sigma - 2 > \alpha(\sigma - 1)$  ensures there are decreasing returns to aggregate capital. The artificial firm's problem is given by

$$\max P^h h - fm - zk$$

where  $P^h$  is the price of aggregate capital. Combining the first order conditions for this problem,

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<sup>8</sup>An exception is the 2005 PPP benchmark study conducted by the OECD and the 1996 benchmark study for the Penn world table. In Section 5, we use both dataset and show that our model's predictions for disaggregated categories of investment goods prices match up with the data. See also Eaton and Kortum (2003) and Bems (2008) for a discussion of trade in capital goods.

<sup>9</sup>Without constant returns to scale, the price of aggregate capital would depend on the quantities.

solving out for  $k$  and  $m$  in terms of  $f$  and  $z$  and substituting them back into the expression for  $H$  gives

$$h = \left[ \left( \frac{f}{z} \right) \alpha (\sigma - 1) \right]^{\frac{\alpha(\sigma-1)}{1+\alpha(\sigma-1)}} m.$$

Finally, we can use the first order condition for  $m$  in the above to get

$$P^h = G \left[ z^{\alpha(\sigma-1)} f \right]^{\frac{1}{1+\alpha(\sigma-1)}}$$

where  $G$  is a constant. Thus, the aggregate price index is a geometric average of  $z$  and  $f$  with constant weights. Note that the relative price of variable capital and structures are the only source of cross-country variation in  $P^h$ .

To see the implications of this for the model's cross-country predictions, note first that the expression for the investment goods price index can be used to derive the ratio of structures prices between the reference country  $c$  and country  $i$ :

$$\frac{f_r}{f_i} = \left( \frac{P_r^h}{P_i^h} \right)^{1+\alpha(\sigma-1)} \left( \frac{z_i}{z_r} \right)^{\alpha(\sigma-1)}. \quad (21)$$

Substituting this expression into the relative income term (20) gives

$$\frac{y_i}{y_r} = \left( \frac{A_i}{A_r} \right)^{\frac{\sigma-1}{\sigma(1-\kappa)-1}} \left( \frac{P_r^h}{P_i^h} \right)^{\frac{\sigma\kappa}{\sigma(1-\kappa)-1}}. \quad (22)$$

Hence, the relative incomes across countries becomes solely a function of the ratio of relative price of investment and the productivity ratios across countries. This is very similar to the one-sector neoclassical model except for the exponent on the arguments.<sup>10</sup> We expand on this below.

## 4 Quantitative Results

Equation (22) above can be used to illustrate two key differences in the quantitative implications of our model relative to the standard neoclassical model. Consider a simplified version of the neoclassical model where  $P^x$  units of the final good produce one unit of capital. Further assume

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<sup>10</sup>Equation (22) also makes clear that the predictions for relative incomes arising from the model are robust to whether or not we consider open or closed economies, i.e., whether or not we allow for trade in capital goods. The relevant relative income term is always a function of the relative price of investment goods. However, the assumption of an open economy does have some ancillary data implications for the individual relative prices of the two types of capital goods – structures and composite capital. As we show in Section 5, we find support for the openness assumption made in the model.

that the final good is produced using a production function  $Y = AK^\kappa L^{1-\kappa}$ . It is easy to check that the steady state relative income between countries *rich* and *poor* in the standard model is given by

$$\frac{y_{rich}}{y_{poor}} = \left( \frac{A_{rich}}{A_{poor}} \right)^{\frac{1}{1-\kappa}} \left( \frac{P_{poor}^h}{P_{rich}^h} \right)^{\frac{\kappa}{1-\kappa}}. \quad (23)$$

This is closely analogous to the expression for relative incomes for our model, (22):

$$\frac{y_{rich}}{y_{poor}} = \left( \frac{A_{rich}}{A_{poor}} \right)^{\frac{\sigma-1}{\sigma(1-\kappa)-1}} \left( \frac{P_{poor}^h}{P_{rich}^h} \right)^{\frac{\sigma\kappa}{\sigma(1-\kappa)-1}}.$$

Comparing equations (23) and (22) shows that the expressions for relative income in the two models are quite similar except for the parameter  $\sigma$ . In particular, as  $\sigma$  rises the predictions of our model converge towards the neoclassical model with the two becoming identical in the limiting case of  $\sigma = \infty$ , i.e., when intermediate goods are perfect substitutes. This is intuitive since individual intermediate goods lose any special role in the productive process when they are perfect substitutes for other intermediate goods – whatever can be done by one can be done equally well by other intermediates. Hence, all the action reduces to movement on the intensive margin alone.

As an alternative way of building intuition for our results, note from equation (16) that the true share of reproducible goods in the model is  $\theta = \frac{1}{\sigma-1} + \alpha$  (the sum of the coefficients on  $M$  and  $k$ ). The share of output going to capital on the other hand is  $\kappa = \frac{1+\alpha(\sigma-1)}{\sigma}$ . Hence,  $\frac{\theta}{\kappa} = \frac{\sigma}{\sigma-1} > 1$ . This mark-up of the true share of reproducible goods reflects the price mark-up in the model. To see this, recall that the price to marginal cost ratio in the model is  $1/\rho$  (see equation (11)). Using the definition of  $\sigma$  this implies that the price mark-up in the model is  $\sigma/(\sigma-1)$ . The gap between what capital is paid and what the true share allows an increase in the true share while keeping the measured share of capital at realistic levels. As an example, suppose  $\kappa = 0.4$  and  $\sigma = 5$ . This implies a price mark-up of 25 percent. The implied  $\alpha$  from the definition of  $\kappa$  is  $1/4$ . With these values the true share of reproducible inputs rises to  $\theta = 0.5$  even though  $\kappa$  remains unchanged at 0.4. Note that  $\theta$  goes to  $\alpha$  as  $\sigma$  goes to infinity, i.e., as goods become perfect substitutes.

The terms for relative income in equations (22) and (23) are very similar. The key difference is in the value of the exponent on the two terms on the right hand side. The key parameter in equation (23) is  $\kappa$  which is the share of capital in total output. Work by Gollin (2002) and others indicates that the capital share is somewhere between 0.3 and 0.4 in most countries. In

the following we shall set the capital share parameter  $\kappa = 0.4$  for all our quantitative exercises.

In our discussion of disparities between the richest and poorest countries we shall use the values of the 95th percentile country of the world income distribution as the proxy number for the richest countries and the 5th percentile as the stand-in for the poorest countries. We shall use the 1996 data from the Penn World Tables for all our quantitative exercises. In 1996  $\frac{y_{95}}{y_5} = 32.7$ , i.e., the per capita income of the 95th percentile country of the world income distribution was 32.7-fold greater than the per capita income of the 5th percentile country. Moreover,  $\frac{P_5^h}{P_{95}^h} \approx 3$ , i.e., relative investment prices in the 5th percentile country were approximately 3 times higher than in the 95th percentile country. Plugging a capital share of 0.4 along with  $\frac{P_{poor}^h}{P_{rich}^h} = 3$  into (23) while keeping the  $A$ 's constant across countries gives  $\frac{y_{rich}}{y_{poor}} = 2.08$ . A corollary of this is that for the model to generate 32.7-fold income differences one needs a productivity gap  $\frac{A_{rich}}{A_{poor}} = 5.2$ .

What are the corresponding numbers from our model? To quantify the model we need an estimate for  $\sigma$  along with the capital share number. The parameter  $\sigma$  represents the elasticity of substitution between intermediate goods and, as equation (22) makes clear, is the key parameter of the model. Available estimates of the elasticity of substitution between intermediate goods from micro studies report a vast array of values with estimates ranging from 3 to 10 or more. Typically the estimated values are sensitive to the particular industry, the time frame of the study and the level of aggregation with the estimates being higher the more disaggregated the study.<sup>11</sup> At the aggregate level, researchers have often used the average level of the price mark-up over marginal cost to calibrate this parameter. Recall that our model implies that the price to marginal cost ratio is  $1/\rho$  (see equation (11)). Using the definition of  $\sigma$  this implies that the price mark-up in the model is  $\sigma/(\sigma - 1)$ . Estimates for this mark-up for the USA range between 10 and 20 percent implying  $\sigma$  between 5 and 10.

Given these wide variety of estimates, here we shall illustrate the predicted income disparities and the required TFP gaps in the model for three different values of  $\sigma$  : 3, 5 and 10. This range spans the range of estimates reported in the literature. We keep the capital share fixed at  $\kappa = 0.40$  by varying  $\alpha$  appropriately. As before, we set  $\frac{P_{poor}^h}{P_{rich}^h} = 3$  which is the approximate average value of the investment price mark-up in the poorest countries (the 5th percentile relative to the 95th

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<sup>11</sup>There there are a number studies that have estimated these elasticities at the industry level. For example, see Goldberg and Verboven (2001) for estimates from the European auto industry. McDaniel and Balistrery (2002) provide a nice review of studies that estimate these substitution elasticities using trade data. It is worth noting though that most of the micro studies estimate the elasticity of *consumption* substitution across goods while our structure is concerned with the elasticity of *production* substitution across intermediate goods. While the two specifications have the same aggregate reduced-form implication, the micro underpinnings are different.

percentile) in the data. Table 1 illustrates the contrast between the models.

**Table 1. Contrasting Income and TFP predictions**

$\sigma$	Data	Standard model		Armenter-Lahiri	
	$\frac{y_{rich}}{y_{poor}}$	$\frac{y_{rich}}{y_{poor}}$	$\frac{A_{rich}}{A_{poor}}$	$\frac{y_{rich}}{y_{poor}}$	$\frac{A_{rich}}{A_{poor}}$
3	32.7	2.08	5.2	5.2	2.1
5	32.7	2.08	5.2	3.0	3.3
10	32.7	2.08	5.2	2.4	4.3

Two features stand out from Table 1. First, for the same given relative price of investment goods, our model always produces larger income differences than the standard neoclassical model (typically between 1.5 and 2.5-fold bigger). This highlights the fact that the model produces a bigger role for investment prices in explaining cross-country income gaps relative to the standard model. Second, the model’s prediction for the relative income gaps between countries is very sensitive to the parameter value for  $\sigma$ . Thus, raising the elasticity of substitution between intermediates from 3 to 5 to 10 reduces the predicted income gap between the richest and the poorest countries from 5.2 to 3 to 2.3. This high sensitivity makes it hard to assess precisely the quantitative performance of investment prices in generating large gaps in relative incomes across countries especially given the wide range of estimates reported in the literature. For low elasticities (under 3) the model can indeed generate large income disparities across countries. In this range the magnification effect of intermediate goods is particularly large due to the high productive value of each distinct intermediate good. For elasticities of substitution greater than 5 however, each intermediate good is a close substitute of other intermediates. Even though poorer countries with higher investment prices produce fewer varieties, they can compensate by producing more of the intermediate goods that they have, i.e., they can offset the loss of varieties reasonably well by adjusting along the intensive margin.<sup>12</sup>

Perhaps more interestingly, the implied total factor productivity differences between the richest and poorest countries that are needed to explain 33-fold income differences range between 2.1 and 4.3. These numbers are significantly smaller than the 5.2 required in the standard model. Where is the reduction coming from? It comes through an indirect effect. Small TFP differences get

<sup>12</sup>It is worth noting that Jones (2008), who shows large magnification effects due to intermediate goods, assumes that the elasticity of substitution between intermediate goods is always less than one.

magnified in the model due to the extensive margin and the “returns to variety” effect. A country with a lower relative investment price produces more intermediates. The positive effect of this on output gets magnified if the country also has higher TFP since the higher exogenous productivity gets added geometrically over the entire list of additional intermediates produced. Clearly, this indirect effect on productivity also produces a bigger role for investment prices in explaining the cross-country income facts relative to the standard model.

We view the reduction in the TFP difference across countries implied by our model as a major improvement over the neoclassical model. To put the difference in perspective, note that at an average productivity growth rate of 2 percent per year, a 5.2-fold increase in productivity levels requires around 84 years. If productivity differences across countries are solely due to differences in technology levels, a 5.2-fold productivity gap between the richest and the poorest countries of the world would imply that the poorest countries are using technology levels that were being operated in the USA 85 years back (i.e., around 1910)!! A 2.1-fold productivity difference on the other hand implies that technology levels in the poorest countries are about 38 years behind the frontier – an almost 45-year reduction in the implied technological distance of the poorest countries from the frontier. Clearly, productivity differences do not arise solely due to technology differences. However, the example is illustrative of the potentially extreme implications of the standard neoclassical model and why we consider our model to be an improvement.<sup>13</sup>

We next subject the model to a second test. In particular we evaluate the cross-country fit of the entire income distribution generated by the model relative to the data. We express each country’s income relative to the U.S.A.. We use income and relative investment price data on 186 countries for the year 1996 from the Penn World Tables 6.1. We quantify equation (22) for each country  $i$  by substituting in  $\frac{P_i^h}{P_{US}^h}$ . For our baseline calibration we set  $\sigma = 5$  and the capital share  $\kappa = 0.4$ . Recall that  $\sigma = 5$  corresponds to a price mark-up of 20 percent.

Figure 1 plots the result. On the horizontal axis are the relative income numbers in the data while the vertical axis gives the corresponding numbers predicted by the model. We have drawn in a 45-degree line to permit an easy visual examination of the fit of the model. The scatter of points are mostly above the 45-degree line indicating that the model is overpredicting relative incomes relative to the data, i.e., it is underpredicting the income gaps. However, the correlation between the predicted and data relative income series is still a relatively high 0.7.

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<sup>13</sup>Note that this back-of-the-envelope calculation is comparing technology levels using an assumed annual TFP growth rate of 2 percent. This is not the same as assuming an output growth of 2 percent per annum.

On a related theme, the correlation between the relative income predicted by our model and the implied relative TFP (the residual needed to explain the observed relative income left unexplained by the model) is 0.26 which is quite low. Hence, while we are indeed missing important determinants of relative incomes, these missing components are not systematically related to the channels identified in the model. Indeed, for  $\sigma = 3$ , the correlation between relative income and TFP drops to almost zero.

#### 4.1 Is it Investment?

As we saw above, relative to the standard neoclassical growth model, our model generates a magnification of the output gaps across countries for the same relative price of investment across countries. Restuccia and Urrutia (2001) have shown that the neoclassical model performs well in mapping the observed investment prices into predicted investment-output ratios. A key question then is whether the magnification effect in our model is occurring due to counterfactually high investment-output ratios. We address this issue next by showing that the aggregate investment behavior in our model is the same as in the standard model. Thus our mechanism amplifies the mapping from investment-output ratios to income per worker, but leaves the mapping from relative prices to investment-output ratios unchanged from the standard neoclassical model.

In the standard neoclassical model, savings rate and thus the ratio of investment expenditures to output is constant across countries,

$$\frac{P_I^a I^a}{Y^a} = \frac{P_I^b I^b}{Y^b}$$

where  $P_I^a$  and  $P_I^b$  are the relevant investment prices (in terms of the final good) for each country.<sup>14</sup>

We show below that our model also predicts that investment expenditures to output is constant across countries. Thus, in the standard neoclassical model as well as in ours, the ratio of investment to output is then given by  $\frac{I^a/Y^a}{I^b/Y^b} = \frac{P_I^b}{P_I^a}$ .

We start by deriving the investment-output ratio in our model. The resource constraint for country  $j$  is

$$y_t^j = c_t^j + f^j \left( m_{t+1}^j - (1 - \chi) m_t^j \right) + v^j n_t^j$$

where  $n^j = \sum_c n_c^j$  denotes the per-capita production of country  $j$  specific capital goods. From the

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<sup>14</sup>In order to break this result in either model is necessary to postulate variation in the intertemporal discount rate, depreciation rates, or the income share of capital. Since savings rate are not systematically correlated with income, the literature does not venture in these sources of heterogeneity.

perspective of the national accounts, investment should be equal to output minus consumption since trade is balanced. Thus total investment in country  $j$  is

$$f^j \left( m_{t+1}^j - (1 - \chi) m_t^j \right) + v^j n_t^j.$$

From the zero-profit condition associated with the composite capital sector we have that  $v^j n_t^j = z^j i_t^j$ . In steady state investment relates to stocks by the depreciation rate,  $f^j \left( m_{t+1}^j - (1 - \chi) m_t^j \right) = \chi f^j m^j$  and  $i_t^j = \delta k^j$ . Thus in steady state we can write total investment expenditures in country  $j$ , in terms of the final good, as

$$\chi f^j m^j + \delta z^j k^j.$$

Depreciation rates are constant across countries, thus the ratio of investment expenditures to output will vary across countries if the ratio of equipment capital expenditures to output,  $\frac{z^j k^j}{y^j}$ , or structures expenditures to output,  $\frac{f^j m^j}{y^j}$ , varies across countries. We next show they do not.

We start with the ratio  $\frac{z^j k^j}{y^j}$ . From the first-order condition associated with intermediate producer of good  $\omega$  we obtain

$$\frac{r^j k^j(\omega)}{p^j(\omega) x^j(\omega)} = \alpha \left( \frac{\sigma - 1}{\sigma} \right).$$

Clearly the ratio holds for the industry as a whole. Noting that the final good sector is perfectly competitive, we have that  $\int p^j(\omega) x^j(\omega) d\omega = y^j$ . Thus

$$\frac{r^j k^j}{y^j} = \alpha \left( \frac{\sigma - 1}{\sigma} \right).$$

The Euler equation associated with the accumulation of equipment, evaluated at steady state, relates the rental rate  $r^j$  with the equipment price,  $z^j$ , according to

$$r^j = z^j [\beta^{-1} - (1 - \delta)].$$

Thus we obtain that

$$\frac{z^j k^j}{y^j} = [\beta^{-1} - (1 - \delta)]^{-1} \alpha \left( \frac{\sigma - 1}{\sigma} \right).$$

There is no variation across countries in the parameters on the right hand side. Thus  $\frac{z^j k^j}{y^j}$  is equalized across countries.

To close the argument, recall from equation (17) that

$$\frac{K^j}{M^j} = \frac{f^j}{z^j} \alpha (\sigma - 1) \beta \left[ \frac{1 - \beta (1 - \chi)}{1 - \beta (1 - \delta)} \right]$$

in steady state. Transforming the variables to per capita, we obtain that  $\frac{f^j m^j}{y^j}$  is also constant across countries.<sup>15</sup>

We have thus showed that our model, like the standard neoclassical model, does not predict differences in the ratio of investment expenditures to output across countries. In fact, both models make the same prediction for the ratio of investment to output across countries. As documented by Restuccia and Urrutia (2001), the neoclassical model fits the data on investment to output ratios fairly well, and hence so does our model. Clearly, the magnification of output gaps across countries arises not due to differences in saving and investment but rather due to the varieties effect.

We interpret these results as suggestive that the model does a decent job of fitting the data. Moreover, we view the relatively small TFP gaps implied by the model as being a significant improvement over the standard model which typically requires large TFP differences to fit the relative income data – differences that are often viewed as being unreasonably large. Overall, we view our results as indicative of a much bigger role for investment prices in explaining the world income distribution than what is suggested by the standard neoclassical model.

## 5 Disaggregated Investment Prices: Some Implications

We showed in Section 3 that the production structure of the model implies that the aggregated price of investment goods is a geometric average of the prices of structures and composite capital. Crucially, the cross-country relative income predictions of the model are solely a function of the relative aggregate investment prices across countries. This aspect of the model carries over to a model without trade in specific capital goods. Hence, the relative income implications of the model are invariant to whether we consider an open or a closed economy. What then does the open economy assumption buy for this model? Given the structure of the model, we would like to gain some insight into the sources of the cross-country variations in relative incomes: do they arise

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<sup>15</sup>We should also note that Bems (2008) finds no systematic relationship between the expenditure share of structures and income across countries. This finding is consistent with our model which predicts that  $\frac{f^j m^j}{y^j}$  is constant across countries.

mostly due to variations in non-traded structures prices or due to traded capital goods? With the answer in hand we can then conduct some counterfactual exercises to evaluate the relative income implications of reductions in the prices of structures and composite capital individually.

However, to do any of this we need to identify the prices of structures and composite capital individually. While data is available for the price of investment goods across countries, we typically do not have reliable disaggregated data on structures and equipment capital good prices. We solved this identification problem by assuming the only capital goods that are traded are the country-specific capital goods used to produce the composite capital good in each country. This assumption allowed us to identify the prices of the composite capital goods across countries using their real exchange rates. The prices of structures were then identified as well. Hence, the openness assumption allowed identification of the disaggregated investment prices.

Before we can use these disaggregated prices to conduct the experiments of interest listed above, we need some test of the strength of our identification strategy. The way to test the identification strategy is to compare the individual investment prices implied by the model with those reported in the data. There are two cross-country data sets that report both disaggregated prices for investment categories. Specifically, individual investment prices for "Machinery and Equipment" and "Construction" are reported for 30 countries in the OECD PPP 2005 benchmark study and for a broader set 115 countries by the Penn World Tables 1996 PPP benchmark study. Both studies also provide data on GDP per capita and on the PPP prices for consumption and total gross investment. We view "Machinery and Equipment" as being the data equivalent of composite capital in the model and "Construction" as being the closest counterpart of structures in the model. Unfortunately, the construction category also includes residential investment. Hence, we have to take the mapping from data to the model with added caution for the price of structures. Nonetheless, we proceed by comparing the model implied prices with the data prices using both data sets. While the OECD study is more recent and has potentially more reliable data, the PWT data set provides a check of the robustness of our identification to a broader set of countries than just the OECD set.<sup>16</sup>

Table 2 reports key features of the data on PPP prices of consumption, investment, equipment and construction and relative income ( $P_c, P_i, P_{eqp}, P_{const}$  and  $\frac{y}{y_{US}}$  respectively). It also compares the properties of the reported price series in the OECD and PWT data sets. Three features of

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<sup>16</sup>Total investment also includes "Other capital goods," for which the OECD does not collect price data. Examples in this catch-all category are agricultural investment, mineral exploration, and intangible assets.

the data are noteworthy. First, PPP equipment prices are much less dispersed than construction prices, and are significantly less correlated with income per capita than construction prices. In fact, the cross-country variance of equipment prices is 11-fold lower than the corresponding variation in construction prices in both data sets.<sup>17</sup> The lower variance of equipment prices across countries relative to the variance of construction prices is consistent with our identification assumption that equipment is traded across countries while structures are not. Second, PPP consumption prices display significant variation and are correlated with income. This fact corroborates Hsieh and Klenow (2007) who have argued that most of the cross-country variation in the price of investment to consumption goods is due to variations in the price of consumption. Third, the OECD data exhibits less volatility on all the reported series relative to the PWT data. This is to be expected primarily due to the fact that the OECD data consists of both fewer countries as well as countries that are richer and more similar in nature as well as, presumably, more reliable regarding data collection. Hence, measurement error is likely to be a lesser issue for the OECD data.

**Table 2: Investment Prices in the data**

	$P_c$	$P_i$	$P_{eqp}$	$P_{const}$	$\frac{y}{y_{US}}$
<i>OECD 2005, 30 countries</i>					
Correlation with $\frac{y}{y_{US}}$	0.71	0.60	0.06	0.59	1.00
Variance	0.08	0.05	0.01	0.11	0.08
<i>PWT 1996, 110 countries</i>					
Correlation with $\frac{y}{y_{US}}$	0.83	0.46	0.20	0.38	1.00
Variance	0.16	0.17	0.09	1.02	0.08

We map the PPP price of investment relative to consumption and the cross-country PPP consumption prices in the data to the composite capital and structures prices predicted by the model using equation (21). Figure 2 plots the equipment relative price in the data against the prediction in the model for both the data sets, i.e., it plots  $\frac{P_{eqp,i}/P_{c,i}}{P_{eqp,US}/P_{c,US}}$  against  $\frac{z_i}{z_{US}}$ . The left panel plots the scatter for the OECD while the right panel gives the scatter plot for the PWT data. The number for each country is computed relative to the average for all the countries in the relevant data set. The fit is remarkably tight with the correlation being 0.98 for the OECD data and 0.80 for the PWT data. This reflects the fact that consumption prices account for

<sup>17</sup>Some of these variation, especially in the PWT data set, is clearly due to residential prices. A series of small island countries appear to be outliers and we drop them from our analysis.

most of the dispersion in relative equipment prices — exactly as our assumption regarding trade dictates. Figure 3 plots actual and predicted structure prices for the two data sets. Once again the fit is quite good, although it is looser than for equipment, especially for the PWT data. The correlation for the OECD is 0.88 but only 0.48 for the PWT. The relatively weaker fit for structures prices from the PWT data is perhaps not surprising, since the purchasing power parity comparisons across countries are more problematic for non-traded goods, and such problems are compounded by the inclusion of residential investment and the quality of the data in some of the poorer non-OECD countries.

Overall, we view the high correlations between relative equipment prices in the data and the model as well as the low cross-country variance of equipment prices as being broadly supportive of our identification strategy which relied on trade in composite capital goods. Moreover, we believe that the identification is robust since it finds support in two independent data sets involving both relatively richer countries in the OECD as well as a broader set of rich and poor countries in the PWT data set. Hence, we now use the model to conduct a few decomposition exercises along with some counterfactual experiments. Given our fit is better in the OECD data, we shall use restrict ourselves to OECD countries from now on.

The first experiment of interest to us is a variance decomposition exercise: what percent of the cross-country variation in relative incomes generated by the model is due to variations in structures prices and what percent arises due to composite capital prices? A standard variance decomposition exercise reveals that 38 percent of the relative income variation is due to variations in composite capital prices  $z$ , 58 percent is due to variations in non-traded structures prices  $f$  and the covariance between the two accounts for a small 4 percent. Splitting the covariance equally between the two, we conclude that the cross-country variation in incomes is quite evenly split between structures (60 percent) and equipment  $z$  accounts for 40 percent. The correlation between the equipment and structure prices  $z$  and  $f$  is almost close to zero  $-0.02$  indicating that the identification strategy is capturing independent sources of variations.

We then conducted two counterfactual experiments. First, we computed the relative incomes from the model by setting the relative price of structures in every country at the level of the corresponding price in the USA. We then repeated the exercise by setting the relative price of composite capital to the US level. It is important to clarify the nature of this exercise. Essentially, we are trying to determine the effect on the cross-country income distribution if the prices of capital goods were equated across countries. The relative price of structures in the model are

determined solely from the technological parameters  $f$ . The relative price of equipment  $z$  on the other hand is a function of the ratio of the real exchange rates across countries. Appendix ?? shows that the real exchange rate  $\varepsilon$  is itself a function of the productivity parameters  $v$ ,  $f$  and  $A$ . Hence, equating say structures prices across countries will have equilibrium effects on the relative prices of equipment due to the implied effect on  $\varepsilon$ . In the experiment where we equate structures prices across countries, we continue to take the  $\varepsilon$ 's from the data. Hence, in order to interpret the computed output effects as equilibrium effects requires the additional assumption that we are simultaneously changing the  $A$ 's and  $v$ 's across countries to offset the effect of the change in  $f$  so as to keep  $\varepsilon$  unchanged. Analogously, for the experiment of equating equipment prices across countries, there exist underlying changes  $v$  and  $A$  in order to equate  $\varepsilon$  across countries without changing the  $f$ 's.

Figure 4 plots the resulting world income distribution relative to the distribution generated by the actual prices. The top panel shows the effect of structures prices while the bottom panel plots the effect of composite capital prices. Both panels are generated using the baseline parameter value  $\sigma = 5$ . As the figure makes clear, on average, a reduction in either price to the US level raises the predicted levels of relative incomes relative to the model. The average increase induced by changing the structures price to the US level is 51 percent while the corresponding increase induced by the composite capital price is a marginally higher 56 percent.

The experiments above suggest that both structures and composite capital prices are independently important in understanding the cross-country income dispersion with structures prices being, perhaps, marginally more important quantitatively.

## 6 An Expanded View of Entry Costs

We have thus far taken a very circumscribed view of the fixed entry costs,  $f$ , as being the cost of structures required to start up production of a new production unit. This is clearly very narrow. While linking entry costs solely to the investment cost of structures has the benefit of imposing discipline on our quantitative assessment of the channel, it is very restrictive and, possibly, provides an underestimate of the explanatory power of the intermediate goods channel. The cost of starting up a new production line or, more generally, the cost of starting up a new business includes other costs such as the direct and indirect costs of acquiring business permits and licenses, costs of mobilizing capital, project appraisal costs and, non-trivially, the time lags

involved.

There is by now a large descriptive literature which documents that one of the largest differences between the richest and poorest countries is the cost of starting businesses. The World Bank has been collecting and publishing estimates of the cross-country distribution of these and related costs for almost a decade now under its *Doing Business* project. They report data on a number of dimensions of these costs including the direct official cost of setting up a new business, the cost of acquiring permits as well as the time lags involved. The 2009 data set provides survey based estimates from 181 countries. The reported direct costs of starting a business range from 433 percent of per capita income in Zimbabwe and 435 percent of per capita income in the Democratic Republic of Congo to 0.5 percent in Canada and 0.7 percent in the US and the UK. D'Erasmus and Moscoso Boedo (2010) have recently used the survey numbers from *Doing Business* to compile a consolidated cost of entry number for each country in the sample including both direct costs and the imputed goods cost equivalent of the time costs of setting up a business. They find that the cost of entry ranges between a high of 612 times per capita income to a low of 0.26 times per capita income.<sup>18</sup>

These range of estimates suggest that the actual cost of starting a new production unit to produce goods may be much higher than the costs of structures (relative to consumption) which is only higher by a factor of 3 in the poorest countries relative to the richest countries. Note that the per capita incomes in the poorest countries is about \$700 while it is around \$25000 in the richest countries (in PPP terms). Using only the direct cost measures, suppose the direct costs in the poorest countries averages around 200 percent of per capita income and around 0.5 percent in the richest. In dollar terms the costs would be then be \$1400 in the poorest countries and \$125 in the richest. Hence, the start-up cost in the poorest countries relative to the richest would be  $\frac{f_{poor}}{f_{rich}} \approx 11$ . Adding on the time cost as in D'Erasmus and Moscoso Boedo (2010) would make it significantly larger.

What effect do these numbers have on the predicted relative income gaps from our model of intermediate goods? Clearly, these additional costs would not be picked up in the price of investment. However, they would be part of the cost of starting up a new intermediate good. Hence, the higher these costs the fewer the number of intermediate goods that would be produced.

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<sup>18</sup>It is worth noting that the World Bank collects this data by running an experiment in which they try to operate the same notional firm in all countries and assess the costs of doing so. This method controls for differences in size and other structural features of the sampled countries. The data is freely available from the website <http://www.doingbusiness.org>.

To see this, recall that the income of a country  $i$  relative to reference country  $r$  is given by

$$\frac{y_i}{y_r} = \left( \frac{A_i}{A_r} \right)^{\frac{\sigma-1}{\sigma(1-\kappa)-1}} \left( \frac{z_r}{z_i} \right)^{\frac{\alpha(\sigma-1)}{\sigma(1-\kappa)-1}} \left( \frac{f_r}{f_i} \right)^{\frac{1}{\sigma(1-\kappa)-1}}$$

Figure 5 plots the effect on  $\frac{y_{rich}}{y_{poor}}$  of varying  $\frac{f_{poor}}{f_{rich}}$  holding constant  $\frac{z_{poor}}{z_{rich}}$  and  $\frac{A_{rich}}{A_{poor}}$ . The figure has been drawn for  $\frac{z_{poor}}{z_{rich}} = 3.4$  (the approximate value of the relative price of machinery and equipment in the poorest countries in 1996). Moreover, we have set  $\frac{A_{rich}}{A_{poor}} = 1$  for generating the plot. We retain our baseline parametrization of  $\sigma = 5$  and  $\kappa = 0.4$ .

The figure shows that for  $\frac{f_{poor}}{f_{rich}} = 10$  the predicted income gap from the model is  $\frac{y_{rich}}{y_{poor}} = 5.8$ . For  $\frac{f_{poor}}{f_{rich}} = 20$  the predicted income gap rises to 8.2. The figure also plots the  $\frac{A_{rich}}{A_{poor}}$  required to generate a 32.7-fold income gap given the income gaps generated by the composite capital costs  $z$  and the entry costs  $f$ . For  $\frac{f_{poor}}{f_{rich}} = 10$  the required productivity gap  $\frac{A_{rich}}{A_{poor}} = 2.4$  while for  $\frac{f_{poor}}{f_{rich}} = 20$  it falls to  $\frac{A_{rich}}{A_{poor}} = 2$ .

We view these results as corroborative evidence suggestive of the fact that the intermediate goods channel is potentially a much more powerful explanation for the large measured income gaps in the data than what one might think. Barriers to entry are often not directly measured in investment prices but have a first order impact on productivity and output due to their depressing effect on intermediate goods production and specialization. Entry barriers are often considered to be a major hurdle for development and growth. Our model provides a candidate rationalization for this view.

## 7 Conclusion

The standard neoclassical growth model attributes a large fraction of the observed income disparity between the richest and poorest countries of the world to productivity differences. Differences in measured inputs, while substantial, are not large enough to account for the income disparity given measured factor shares. This has proved to be a stumbling block for using the dispersion in relative investment prices across countries to account for the observed cross-country income differences. In this paper we have augmented the standard model to allow for an extensive margin in the production process as well as a “returns to variety” effect. In particular, we have formalized an environment where higher investment prices not only reduce the total amount of investment in variable capital (the standard intensive margin on capital) but also reduce the number of firms

and products in the economy. We have shown that the extensive margin magnifies the effect of higher relative investment prices on per capita output through two channels. First, the fewer varieties produced due to higher investment prices *directly* reduces output through the “returns to variety” effect. Second, there is an *indirect* effect in that any pre-existing productivity difference between countries gets magnified as the differential productivity gets aggregated over the entire set of additional goods produced in the richer countries.

At conventional levels for the capital share, we find that our model can account for up to 5-fold income differences between the richest and poorest countries of the world though this fit is sensitive to the assumed parameter value for the elasticity of substitution between intermediate goods. However, our model reduces the TFP gaps required to explain the observed income differences to between 2 and 4-fold with this reduction being relatively robust to the changing the elasticity of substitution parameter. These results suggest a much bigger role for relative investment prices in accounting for cross-country income dispersion relative to the standard model. We view this feature of our model as a significant improvement over the standard model.

A key component of our environment is that entry into the intermediate goods sector involves a set-up cost. In the quantitative section of the model we take a narrow view of this set-up cost as being the cost of acquiring and installing a business fixed structure. More generally, one could view this set-up cost as including a number of other costs of setting up businesses including things like acquiring licenses, paying business agents, costs of conducting business surveys and plans, political contributions as well as outright bribes. We have shown that augmenting the measure of entry costs to incorporate these alternative measures can significantly raise the predicted income gaps generated by the model and correspondingly reduce the required TFP gaps to explain the large observed income gaps even with relatively high elasticities of substitution between intermediate goods. We view this as suggestive of the quantitative importance of the intermediate goods channel for explaining the cross-country income facts.

## References

- [1] Barseghyan, Levon and Ricardo DiCecio, 2008, “Endogenous Productivity and Multiple Steady States,” Federal Reserve Bank of St. Louis, Working Paper 2008-023A.

- [2] Bems, Rudolfs, 2008, "Aggregate Investment Expenditures on Tradable and Non-Tradable Goods," *Review of Economic Dynamics* 11, pp. 852-883.
- [3] Bilbiie, F., F. Ghironi, and M. Melitz, 2007, "Endogenous Entry, Product Variety, and Business Cycles," Working paper.
- [4] Chari, V. V., Patrick J. Kehoe and Ellen R. McGrattan, 1997, "The Poverty of Nations: A Quantitative Investigation," Federal Reserve Bank of Minneapolis, Research Department Staff Report 204.
- [5] Ciccone, A., 2002, "Input Chains and Industrialization," *Review of Economic Studies* 69, pp. 565-587.
- [6] D'Erasmus, Pablo and Hernan Moscoso Boedo, 2010, "Financial Structure, Informality and Development," mimeo, University of Maryland.
- [7] Eaton, Jonathan, and Samuel Kortum, 2003, "Trade in Capital Goods," *European Economic Review*.
- [8] Goldberg, P. and F. Verboven, 2001, "The Evolution of Price Dispersion in the European Car Market," *Review of Economic Studies* 68, pp. 811-848.
- [9] Gollin, Douglas, 2002, "Getting Income Shares Right," *Journal of Political Economy* 110, pp. 458-474.
- [10] Hall, Robert E. and Charles I. Jones, 1999, "Why Do Some Countries Produce So Much More Output Per Worker Than Others?", *Quarterly Journal of Economics* 114, pp. 83-116.
- [11] Hsieh, Chang-Tai and Pete Klenow (2007), "Relative Prices and Relative Prosperity", *American Economic Review* 97, pp. 562-585.
- [12] Jaimovich, Nir, 2007, "Firm Dynamics and Markup Variations: Implications for Sunspot Equilibria and Endogenous Economic Fluctuations," *Journal of Economic Theory*, 137, 300-325.
- [13] Jones, Charles I., 1994, "Economic Growth and the Relative Price of Capital," *Journal of Monetary Economics* 34, 359-382.

- [14] Jones, Charles I., 2011, "Intermediate Goods and Weak Links in the Theory of Economic Development," *American Economic Journal: Macroeconomics* 3, pp. 1-28.
- [15] Klenow, Pete, and Andrés Rodríguez, 1997, "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" NBER Macroeconomics Annual 1997, B. Bernanke and J. Rotemberg ed., Cambridge, MA: MIT Press, 73-102.
- [16] Mankiw, G., D. Romer and D. Weil, 1992, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics* 107, pp. 407-437.
- [17] McDaniel, C., and E. Balistrery, 2002, "A Discussion on Armington Trade Substitution Elasticities," mimeo, Office of Economics Working Paper 2002-01-A, U.S. Trade Commission.
- [18] Parente, Stephen L. and Edward C. Prescott, 1994, "Barriers to Technology Adoption and Development", *Journal of Political Economy* 102, pp. 298-321.
- [19] Parente, Stephen L. and Edward C. Prescott, 2000, Barriers to Riches, MIT Press, Cambridge, Massachusetts..
- [20] Restuccia, Diego, and Carlos Urrutia, 2001, "Relative Prices and Investment Rates," *Journal of Monetary Economics* 47, pp. 93-121.

Figure 1: **Relative Income: Model and Data**

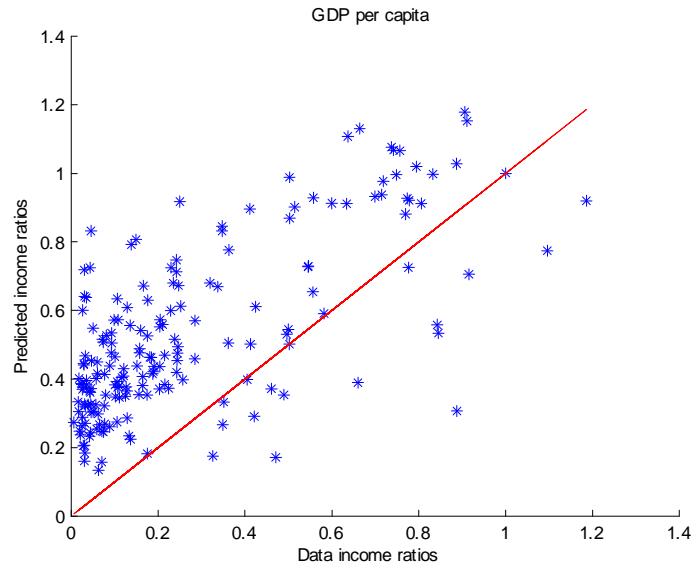
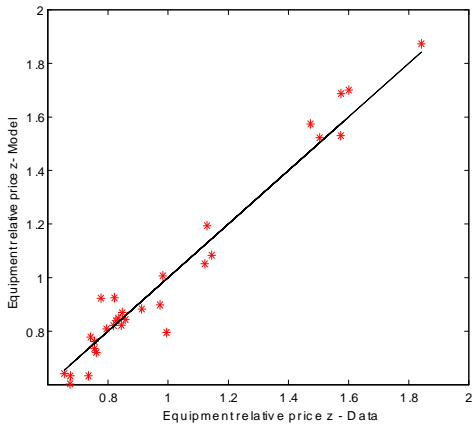
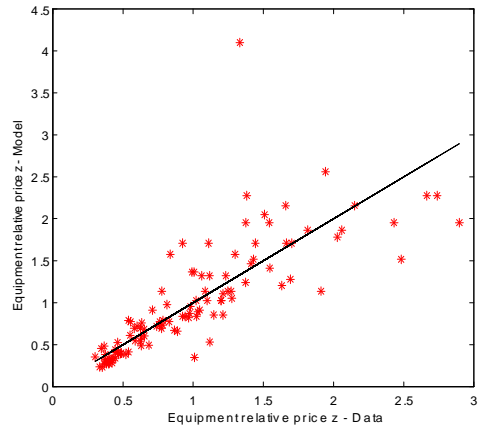


Figure 2: **Equipment prices: Model and Data**

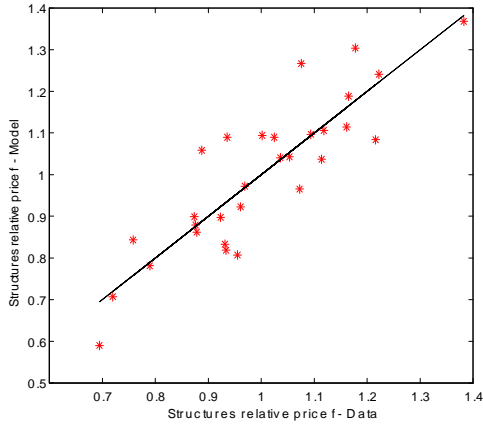


(a) OECD data: Correlation 0.98

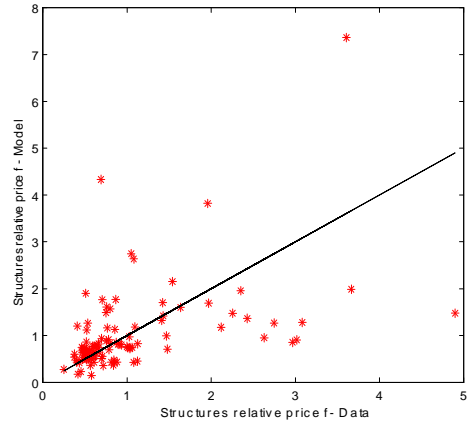


(b) PWT data: Correlation 0.80

Figure 3: Structures prices: Model and Data



(a) OECD data: Correlation 0.88



(b) PWT data: Correlation 0.48

Figure 4: Counterfactual Experiments

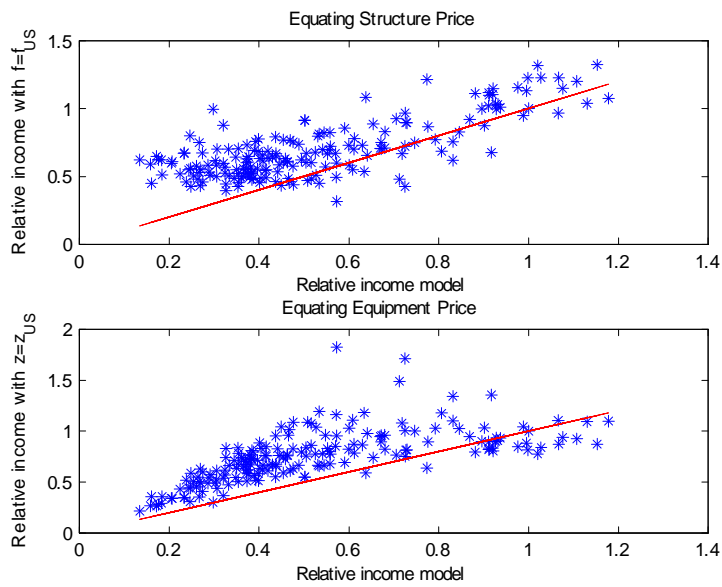


Figure 5: Effect of Broader Entry Costs

