TRADE IN CAPITAL GOODS

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ABSTRACT

Innovative activity is highly concentrated in a handful of advanced countries. These same countries are also the major exporters of capital goods to the rest of the world. We develop a model of trade in capital goods to assess its role spreading the benefits of technological advances. Applying the model to data on production and bilateral trade in capital equipment, we estimate the barriers to trade in equipment. These estimates imply substantial differences in equipment prices across countries. We attribute about 25 percent of cross-country productivity differences to variation in the relative price of equipment, about half of which we ascribe to barriers to trade in equipment.

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1 Introduction

International trade can transmit the benefits of technological advances across borders. We assess the importance of this mechanism by studying world production and trade in capital goods.

World R&D activity and world production of capital equipment are highly concentrated in a small number of countries. Moreover, as Figure 1 shows, the countries that are most R&D intensive are also the ones most specialized in making equipment.[1] While only a few countries do much R&D, the benefits may spread around the world through exports of capital goods that embody new technology. A country's productivity then depends on its access to capital goods from around the world and its willingness and ability to make use of them.

We develop a model of trade in capital goods to evaluate this view of the world. The theoretical framework combines Solow's (1960) model of technological change embodied in new capital goods with a model of Ricardian trade similar to Eaton and Kortum (2000).[2]

The model connects a number of empirical observations that have already been made and offers some new ones:

1. It implies a link between cross-country productivity differences and differences in capital accumulation much like the one explored by Mankiw, Romer, and Weil (1992). As pointed out by De Long and Summers (1991), Jones (1994), and Restuccia and Urrutia (2000), however, cross-country differences in real rates of accumulation derive much more from differences in the relative price of capital goods in terms of consumption goods than from differences in savings rates.[3] Given the share of resources set aside for accumulation (the savings rate in Solow parlance), poorer countries are getting much less

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[1]The data are for 1985, as described in Section 2 below, and in the Data Appendix.

[2]Smith (1974) provides a theoretical model of trade in vintage capital. Hulten (1992), Greenwood, Hercowitz, and Krusell (1997), Jovanovic and Rob (1997), and Gilchrist and Williams (2000) apply vintage capital models empirically to closed economies. Castro (2000) extends the Greenwood et al. framework to a continuum of countries to assess the welfare gains in moving from autarky to frictionless trade in equipment.

[3]Jovanovic and Rob (1997) and Chari, Kehoe, and McGratten (1998) also explore the implications of variation in the relative price of capital for cross-country productivity differences.

for their money. A major purpose of our work is to understand the nature of geographic barriers between countries that generate these relative price differences.

2. To the extent impediments to trade in capital goods are at work, they should be reflected in capital goods trade. Hence our model implies a link between productivity and imports of capital goods. This relationship resembles that used by Coe and Helpman (1995), Coe, Helpman, and Hoffmaister (1997), Wang and Xu (1999), and Keller (2000), among others, to relate R&D and international trade to technology diffusion.[4]

3. The model also implies a link between patterns of international trade in capital goods and deviations from the law of one price. We use this relationship to provide a new perspective on and new measures of differences in the cost of capital equipment across countries.

This third link is at the heart of our empirical analysis, but we exploit the first to translate our findings into their implications for productivity.

Since we find geographic barriers to trade in capital equipment to be quantitatively important, they deserve some further discussion. These barriers might reflect costs arising from: (i) marketing overseas, (ii) negotiating a foreign purchase, (iii) transporting goods to foreign locations, (iv) tariffs, (v) non-tariff barriers, (vi) distributing goods in foreign markets, (vii) adapting equipment to foreign conditions and standards, (viii) installation in foreign production facilities, (ix) training foreign workers to use the equipment, and (x) providing parts, maintenance, and customer service from abroad.

Each of these factors raises the cost of buying and using imported equipment, but only some of them would show up in standard measures of the price of equipment. Our approach is to infer the full cost as revealed by where countries buy their equipment. Our trade-based

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[4]Our work demonstrates how impediments to trade in capital goods, many of which are rooted in geography, can affect productivity. It therefore relates to the vast empirical literature on openness and growth, but in particular to Frankel and Romer (1999) who use geography as an instrument for openness.

measures of equipment prices allow us to quantify many of the barriers (both self-inflicted and natural) to adopting foreign technology that have been modeled by Parente and Prescott (1994, 1999), Romer (1994), Holmes and Schmitz (1995), and Acemoglu and Zilibotti (2000), for example.

Our trade-based measures of equipment prices fall quite systematically with development. We estimate equipment to be cheapest in Germany, Japan, the United Kingdom, and the United States, the four major producers. At the other extreme, we estimate equipment to be more than 3.5 times as expensive in Egypt, Iran, Kenya, Morocco, Nigeria, and Zimbabwe.[5] In combination with differences in consumption goods prices (which are systematically higher in developed countries), North-South differences in the relative price of equipment are even more pronounced.

What do our trade-based measures of equipment prices imply for productivity differences? Using a share of capital of 1/3 (split equally between equipment and non-equipment capital), we find that differences in the relative price of equipment account for over 25 percent of productivity differences between developing and developed countries. We attribute a bit less than half of this 25 percent to differences in our measure of the price of equipment itself, with the remainder due to differences in the price of consumption goods (as measured by the United Nations International Comparisons Programme, ICP).[6]

We proceed as follows: Section 2 below lays out the basic facts about production, trade, and prices of capital goods that we seek to explain. Section 3 develops a very stylized two-country model to illustrate how trade in capital goods that embody technical advances can capture

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[5]In contrast, as we discuss below, price measures from United Nations' International Comparisons Programme (ICP), which capture only some of these costs, show no systematic differences in capital goods prices between rich and poor countries. (Systematic differences in the price of capital goods relative to consumption goods in these data, which form the basis of DeLong and Summers analysis, derive almost entirely from variation in the ICP consumption goods prices themselves.)

[6]There is a parallel between our cross-country findings and time-series evidence on the contribution of the declining relative price of equipment, as measured by Gordon (1990), to productivity growth in the United States. Greenwood et. al. (1997) attribute as much as 60 percent of total factor productivity growth to new technology embodied in capital equipment, while Hulten (1992) comes up with a more modest 20 percent, closer to our finding in the cross-country dimension.

many of these facts. Section 4 augments the model to allow for many countries and incomplete specialization in the production of capital goods. The expanded model allows us to infer the prices of capital goods in different countries as revealed in data on trade in equipment. In Section 5, we calculate revealed equipment prices, compare them other measures, and explore their implications for productivity. Section 6 concludes.

2 A Look at the Data

To get an overview of the global market for capital equipment we examine international data on production, trade, investment, and prices. Direct measures of production and trade in capital equipment are not available, so we approximate them by associating capital equipment with the output of the nonelectrical equipment, electrical equipment, and instruments industries.[7] As for measures of investment and prices, we define equipment as expenditure by producers on durable equipment net of transportation equipment. To provide a comparison with the pattern of production and trade in equipment, we have assembled data on production and trade for total manufacturing as well. Details of the data construction are described in the Data Appendix.

We focus on data for 1985 across 34 countries for which we could match data on trade, production, and ICP measures of the price of equipment and consumption goods. The year 1985 is the most recent year in which the price measures are available for a large number of countries outside of the OECD.[8] As shown in Table 1, our sample includes a mix of small and large countries, both developing and developed.

The last column of Table 1 shows how equipment production (value added of the equipment producing industries as a share of GDP) varies dramatically: from a low of 0.1 percent in

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[7]As we discuss in the data appendix, in Germany, Japan, and the United States these three sectors contribute about two-thirds of investment goods overall and over three-fourths of investment goods used in manufacturing. But only around 40 per cent of the output of these industries constitutes final investment goods, with the rest used mainly as intermediates. Whether the output is finished or not makes little difference for our analysis.

[8]Data from the most recent round of the ICP, which includes a much wider cross section of countries for the mid 1990's, may soon be available.

Malawi to a high of 10.5 percent in Germany. Figure 2 shows that OECD countries produce more equipment, on average, as a share of GDP. (Outside of the OECD, as membership stood in 1985, only Hungary, Korea, and Yugoslavia produced much equipment.[9]) But within the OECD the degree of specialization in equipment has surprisingly little do with income and relates much more to R&D as a percent of GDP, as shown in Figure 1.

Turning to international trade in equipment, Figure 3 plots net exports of equipment (as a share of GDP) against specialization in equipment production. The two are highly correlated. The R&D intensive countries that specialize in equipment are also the major net exporters of equipment. Poor countries are net importers of equipment.

Table 2 displays some basic statistics about equipment imports. Comparing the first two columns, we see that the import share for equipment (equipment imports as a percentage of equipment absorption) generally exceeds, often by a substantial amount, the import share for manufactures as a whole. (The one exception is Japan, the country whose manufacturing sector is most skewed toward equipment production.) Equipment appears to be a highly traded category of manufactures. Column 4 shows that each country imports the vast majority of its equipment from just seven large and rich producers.[10]

While developing countries generally import most of their equipment, their purchases are nevertheless strongly biased toward domestic producers. To examine this bias and other geographic effects, we group countries into four broad regions. Table 3 provides some detail about where each country purchases equipment (from itself or from one of the seven main equipment exporters). The geographic effects are striking. Germany dominates the export of equipment to almost all European destinations while the United States and Japan are both major suppliers to the Pacific. In Africa, former colonial and cultural ties continue to play a role. Kenya,

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[9]Hungary and Korea both joined the OECD in 1996.

[10]These seven are: France, Germany, Italy, Japan, Sweden, United Kingdom, and United States. Moreover, as a rule the top five sources of equipment imports for each country are drawn from these seven. The few exceptions to this rule seem to be the result of proximity: India and Korea are both top-five sources for Bangladesh, Austria is a top-five source for Hungary, Turkey for Iran, Korea for Japan, Australia for New Zealand, and Korea and Canada for the United States.

Malawi, and Nigeria buy the most from the United Kingdom, while Mauritius and Morocco import the most from France.[11] As for home bias, note that only six countries import more equipment from any one of the seven big exporters than they purchase from themselves.

Table 4 presents measures of equipment investment and prices. The first column is equipment investment in local prices as a share of GDP in local prices. The investment share, i.e. the savings rate as it applies to equipment, varies much less across countries than does the equipment production share. This fact should not come as a surprise given the relationship in Figure 3: If the investment share varied a lot, we would not have seen such a strong comovement between equipment production and net exports of equipment.[12]

As Figure 4 illustrates, what variation there is in the equipment investment share displays little relationship to a country's level of development. The well-known positive relationship between the *real* investment rate and GDP per capita arises from differences in the *relative* price of investment goods. As shown in Figure 5, the price of equipment relative to the price of consumption goods bears a striking negative relation to GDP per capita.[13] The time-series analog is the fall in relative price of equipment over time documented by Gordon (1990).

For understanding trade in capital equipment it is crucial to distinguish the price of equipment from the relative price of equipment (i.e. the price of equipment relative to the price of consumption). Although the relative price is what matters for converting the savings rate into a real investment rate, it is the price of investment itself that is relevant for deciding where to buy equipment. The last two columns of Table 4 present both the denominator and

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[11]Mauritius was settled by the French in the early 1700's, but was under some level of British control from the early 1800's until its independence in 1968.

[12]Ignoring intermediates, net exports of equipment are equal to equipment production less equipment investment. Intermediates complicate the relationship in two ways. First, since intermediates are used in the production of equipment, in examining specialization we measure equipment production as the value added (rather than the gross production) of equipment producing industries. Second, the output of equipment producing industries (and trade in what we have labeled equipment) includes a substantial amount of equipment type goods (such as engines and bearings) that are actually used as intermediates.

[13]Restuccia and Urrutia (2000) document these two basic relationships across a much wider range of countries. Collins and Williamson (2000) document them for a smaller number of countries but over a much broader time span.

numerator of the relative price of equipment as measured by the ICP. While the relative price of equipment is substantially lower in richer countries, the reported price of equipment itself is, if anything, higher in such countries. Figure 6 illustrates. The ICP measure of equipment prices certainly varies across countries, but the numbers do not show that it is systematically higher in the net importers than in the net exporters of equipment. This last result is surprising: Home-bias and regionalism suggest that geographic barriers in capital goods trade are substantial, which would normally imply lower prices in exporting countries.[14]

We can summarize our discussion so far with seven apparent facts extracted from various data sources:

1. According to production data, a small group of R&D intensive countries are the most specialized in equipment production.

2. According to trade data, poor countries import much of their equipment, most of which comes from just a few large exporters.

3. According to trade data, equipment is traded more than manufactures as a whole, yet this trade still displays home bias and other effects of geography.

4. According to national accounts, in local prices, equipment investment as a share of GDP shows little relation to development.

5. According to ICP measures, the price of equipment relative to the price of consumption goods declines dramatically with development, so that, in combination with fact 4, poor countries appear to have a lower real investment rate.

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[14]The *variability* across countries in the price of equipment is certainly consistent with the existence of large trade costs. Heston, Summers, Aten, and Nuxoll (1995) examine this variability in ICP prices in more detail. In particularly they look at how cross-country variability in the price structure differs between goods that are tradable and those that are not. Although they find a bit less variability in the prices of the tradable goods, they admit that the law of one price is far from holding among tradables. They conclude with a plea for a closer examination of how trade influences prices: "The extent and character of a country's international trade certainly affects the price structure of its tradables versus that of its nontradables, and this is a prime area to focus on." We hope to be pushing in that direction here.

6. According to Gordon (1990), the relative price of equipment in the United States has declined dramatically over time.

7. According to the ICP, the price of equipment itself is slightly lower in poor countries.

3 A Textbook Model

A simple model of growth and North-South trade can capture items 1, 2, 4, 5, and 6 from our list of seven above. We will deal with 3 by incorporating a more realistic model of trade in Section 4. The last one, which remains a puzzle for either model, is explored in Section 5.

There are two homogenous goods: a capital good K and a consumption good C. We allow international trade in both goods but, for simplicity, rule out international borrowing or lending. To account for international price differences, we introduce trade frictions in the form of iceberg costs: For good $l = K, C$ the exporter must ship $d^l > 1$ units in order for one unit to arrive at the export destination.

Our specification of production technologies is motivated by the fact that equipment production is concentrated in research intensive economies. In $i = N, S$ (North, South) we assume $Q_i^K = A_i F(K_i^K, L_i^K)$ and $Q_i^C = F(K_i^C, L_i^C)$, where Q is output and F is constant returns to scale in labor L and capital K. The term A_i captures capital goods technology. We give the North a technological advantage in capital goods by setting $A_N > A_S$. (The technology term A_i could reflect either the quality of the capital goods that country i makes or its efficiency in producing capital goods of a given quality. Our language adopts the quality interpretation. Under this interpretation capital is always measured in efficiency units.)

At any moment there are fixed endowments of labor $L_i = L_i^K + L_i^C$ and capital $K_i = K_i^K + K_i^C$ for $i = N, S$. (The total capital stock reflects the history of capital goods purchases, taking into account the quality of each vintage and subsequent depreciation, which we turn to in Section 3.2.)

Since there is not strong evidence to the contrary, we make the simplifying assumption that

F is common across sectors and countries. The appendix reports that the labor share in value added is slightly higher in the equipment sectors than in other manufacturing industries. If anything, this factor intensity would imply a direction of trade opposite to what we observe.[15]

3.1 Trade

We want the model to capture the observation that production of capital goods is concentrated in rich countries, yet these countries also engage in other activities. Thus, we focus on the equilibrium in which the South specializes in C while the North produces both goods, exporting the capital good K and importing the consumption good C. In order to provide explicit conditions for this pattern of specialization to emerge as an equilibrium outcome we need to specify the demand side of the model. This in turn requires us to specify the behavior of the economy over time, which we do in the next section.

We assume perfect competition in the output market, the labor market, and the rental market for capital. We can then easily solve for prices. Using the C good in the South as numeraire, $P_S^C = 1$. Since the North imports C from the South, its price on arrival is $P_N^C = d^C$. Since the North is incompletely specialized and the capital good is produced in quantity A_N using the same bundle of inputs that would produce a unit of C, it follows that $P_N^K = P_N^C/A_N = d^C/A_N$. Since the South imports the capital good, $P_S^K = d^K P_N^K = d^K d^C/A_N$. Hence in combination the two trade frictions leave the South facing a higher relative price of equipment.[16]

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[15]As we show in the appendix there is evidence that equipment production is more skill-intensive (to the extent that the share of nonproduction workers captures skill-intensity). We interpret this skill-intensity as reflecting the importance of R&D to equipment. A slightly more complicated variant of our model would ascribe the North's specialization in equipment to the North's skill-abundance and equipment's skill-intensity. This variant would imply the same relative price differences as our simpler Ricardian version while allowing for some Southern equipment production.

[16]The reason for the difference in relative prices between the North and the South emerges for reasons similar to the Balassa-Samuelson explanantion (Balassa, 1964; Samuelson, 1964). To relate our framework to theirs imagine setting d^C to infinity and d^K to 1. No trade takes place in equilibrium but its possibility forces capital to have the same price in both locations. To offset its productivity disadvantage, production costs in the South would need to be lower by a factor A_S/A_N. These lower costs translate into a lower price of the consumption good in the South. Moving away from these extremes, but leaving some barrier to trade in the consumption good, the logic carries over to our model.

Since the South makes only C, its income is simply:

$$Y_S = F(K_S, L_S) = L_S f(k_S),$$

where $k_i = K_i/L_i$ and $f(k) = F(K/L, 1)$. In the North, by cost minimization, each sector will have the same capital labor ratio k_N. Income in the North is thus:

$$Y_N = P_N^K A_N L_N^K f(k_N) + P_N^C L_N^C f(k_N) = d^C L_N f(k_N).$$

The ratio of national incomes Y_N/Y_S corresponds to the ratio of national-currency GDP's translated into a common currency using the exchange rate. If price levels and country sizes differ, it is more meaningful to compare GDP after dividing by each country's population and its price for the consumption good: $y_i = (Y_i/P_i^C)/L_i = f(k_i)$ for $i = N, S$. This measure of real output per capita corresponds to real GDP per capita in international prices as calculated by Summers and Heston (1991).[17]

As it stands, the model is consistent with a number of observations: (i) exports of capital goods from North to South, (ii) a higher relative price of capital P_i^K/P_i^C in the South (by the factor $d^K d^C$), and (iii) a higher absolute price of the C good in the North (by the factor d^C). The model also predicts a higher absolute price of capital in the South (by the factor d^K). As discussed earlier, the ICP data in Figure 6 are at odds with this last prediction. We return to this point in Section 5.

3.2   Growth

So far we have described the world economy at any moment, taking as given capital stocks in each county (and positing an equilibrium in which the North produces both goods while the South buys all its capital from the North). We now turn to how this economy evolves over time in order to endogenize capital stocks (and also check when our assumed pattern of specialization is an equilibrium outcome).

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[17]Summers and Heston (1991) actually take into account differences in the prices of a bundle of consumption and investment goods. Greenwood et. al. (1997) make a convincing argument for why, in the context of a model like the ours, the proper deflator is simply the price of the consumption good.

Investment and depreciation govern the evolution of the capital stock according to the equation $\dot{K}_{it} = I_{it} - \delta K_{it}$, where I is investment and δ the depreciation rate. Spending on capital goods is $P_{it}^K I_{it}$. The driving force for long-term growth is technical progress in the production of capital, which lowers P_{it}^K over time. (We assume that labor forces L and iceberg geographic barriers d do not change over time, the second implying that trade frictions eat up a constant share of factor services).

We assume that technological change proceeds at a constant rate in the North, so that $\dot{A}_N/A_N = g > 0$. (To sustain the North's technological lead, we restrict $\dot{A}_S/A_S \leq g$.) Trade thus ensures that the relative price of the capital good P_{it}^K/P_i^C falls at rate g in both the North and the South, with the level remaining higher in the South.

We analyze the steady state of the model in which consumption everywhere grows at the same rate g_y as income. Since we have balanced trade (no international borrowing or lending), it follows from the national income identity that expenditure on investment must also grow at rate g_y. Since the price of capital falls at rate g, real investment and the capital stock grow at rate $g_y + g$. Assuming a Cobb-Douglas production function $f(k) = k^\alpha$ (where α is capital's share), $g_y = \alpha(g_y + g)$ or $g_y = \frac{\alpha}{1-\alpha}g$.

Making the Solow assumption that each country spends a fraction s_i of its income on capital goods, the capital stocks per worker evolve according to:

$$\dot{k}_{it} = s_i \frac{P_i^C}{P_{it}^K} k_{it}^\alpha - \delta k_{it}.$$

The steady-state level of income per capita at time t is:

$$y_{it} = \left(\frac{s_i}{\left(\delta + \frac{g}{1-\alpha}\right)\left(P_{it}^K/P_i^C\right)} \right)^{\alpha/(1-\alpha)}. \tag{1}$$

Since the relative price of capital P_{it}^K/P_i^C is higher in the South by a factor of $d^C d^K$, its income is lower by a factor of $\left(d^C d^K\right)^{\alpha/(1-\alpha)}$ given equal savings rates s. In both the North and the South the relative price of capital P_{it}^K/P_i^C is falling at rate g, generating the same growth rate

of income in each.[18]

Being more neoclassical, we can specify intertemporal preferences of the form:

$$U_i = \int_0^\infty e^{-\rho_i t} \ln C_{it} dt,$$

where ρ_i is the discount rate in country i and C_{it} is consumption in country i at time t. In this case we can relate the steady-state savings rate to underlying parameters of preferences and technology as follows:

$$s_i = \frac{P_{it}^K I_{it}}{Y_{it}} = \frac{\alpha(\delta + \frac{g}{1-\alpha})}{\rho_i + \delta + \frac{g}{1-\alpha}},$$

If discount factors are the same across countries so are savings rates.

Assuming similar savings rates, the model can now capture some additional observations: (i) the North is richer than the South, (ii) the relative price of capital falls over time, (iii) countries grow in parallel (i.e. poor countries do not generally grow either faster or slower), (iv) real investment rates, $I_{it}/(Y_{it}/P_i^C) = s_i P_i^C/P_{it}^K$, are higher in rich countries even though savings rates are similar.[19]

Equation (1) makes explicit the distinction between the savings rate and the real investment rate. In this model, and in the data, it is differences in the relative price of capital, not differences in the savings rate, that drive the correlation between output per capita and the real investment rate.[20]

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[18]We now state two conditions to ensure that our presumed pattern of specialization is in fact an equilibrium. First, we need to make sure that the South does not find it profitable to produce capital. The South's unit cost of producing capital would be $1/A_S$, which needs to be compared to the cost of importing capital, $P_S^K = d^C d^K/A_N$. The South will not produce any capital if $A_N/A_S > d^C d^K$, which we now assume. Second, we need to make sure that the North has labor left over to produce some C after supplying the world with new capital goods. The quantity of capital goods required to supply the South is $d^K s_S Y_S/P_S^K$ (including export costs) and to supply the North is $s_N Y_N/P_N^K$. If the North devoted all its resources to capital goods production it would make $A_N L_N k_N^\alpha$ units. After rearranging, the condition for the North to be incompletely specialized is $s_S Y_S < (1 - s_N)Y_N$. We assume a set of parameters that guarantee this inequality.

[19]Mankiw, Romer, and Weil (1992) assume that technology is freely mobile and explain productivity differences by differences in real investment rates. But since real investment rates vary because of relative prices rather than preferences, some explanation for price variation is needed. Our model shows how cross-country differences in capital goods technology, combined with trade frictions, naturally generate the correlation between real investment rates and productivity that these authors and others observe.

[20]An interesting property of the model is that it delivers parallel growth whether or not there is any technological change in the South. This outcome arises from trade rather than from diffusion of technology, as in Eaton and Kortum (1996, 1999). But, as in models of technology diffusion from the North to the South,

4 An Empirical Model

Although it captures most of the basic facts, a problem in taking the textbook model to the data is its failure to explain why countries buy capital goods from a variety of sources. While exports of capital goods are concentrated among a small number of sources, countries still buy capital goods from a wide range of countries, including themselves. The obvious explanation is that capital goods are in fact highly heterogeneous. In order to take this heterogeneity into account we follow the framework we developed in Eaton and Kortum (2000). It turns out that this approach allows us to infer something about the price of capital goods in different countries from where they buy and sell them.

In adding this greater detail to the capital goods sector we simplify the analysis by treating cross-country variation in consumption goods prices as given. Having solved for what goes on in the capital goods sector we can return to the textbook model to consider the implications for labor productivity.

4.1 Heterogenous Capital Goods

We assume that there are a continuum of types of capital goods indexed by $j \in [0,1]$. The available capital services of each type j, which we denote $K_t(j)$, reflects the history of purchases of type j capital by date t, taking into account the quality of each vintage and subsequent depreciation. Different types of capital services combine to form the overall capital stock:

$$K_t = \left[\int_0^1 K_t(j)^{(\sigma-1)/\sigma} dj \right]^{\sigma/(\sigma-1)},$$

where $\sigma > 0$ is the elasticity of substitution between the services of different types of capital.

We assume that at any time t a country can buy capital of type j from any of a number of sources. Country $i \in \{1, ..., N\}$ provides capital of type j with quality $z_{it}(j)$ at a production

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it is technological change in the North that ultimately drives productivity growth in the South. Consistent with Young (1995), the model would show no TFP growth as long as capital is measured in quality units. Nonetheless, it is technological change that ultimately drives capital accumulation (even if it does not show up in TFP growth).

cost c_i. (Now N represents the number of countries and we switch to using production costs in country N as numeraire, treating relative costs as constant over time.) We continue to assume that there are costs to getting the capital good up and running in a foreign destination, treating them as iceberg costs that are constant over time. Delivering one unit of the good in destination n requires shipping $d_{ni} \geq 1$ units from source i, normalizing $d_{ii} = 1$. (Since we now treat the price of consumption goods P_i^C as given we no longer need d^C. We thus drop the K superscript on the d^K's.)

Buying capital good j from country i, country n faces a cost $p_{nit}^K(j) = c_i d_{ni} / z_{it}(j)$ per quality unit of capital. But with perfect competition it would actually buy good j only from the source that provides the lowest effective cost, $p_{nt}^K(j) = \min_i \{p_{nit}^K(j)\}$.[21]

In general, calculating this minimum across a number of potential sources is analytically intractable. To proceed, we assume that the qualities $z_{it}(j)$ are realizations of random variables z_i drawn independently from the extreme-value distribution:

$$\Pr[z_i \leq z] = \exp(-T_{it} z^{-\theta}).$$

Here $T_{it} \geq 0$ represents the stock of technological knowledge in country i accumulated by time t, which raises the overall level of quality; $\theta \geq 1$ reflects (inversely) the variability of quality. We assume that this stock of knowledge grows in each country at a constant rate $g_T > 0$. (Hence T_i plays a role similar to A_i in the textbook model, except T_i governs a country's average quality across the range of capital goods, not its actual quality for each good.) While the agents in the economy make their decisions based on realized values, we need to keep track only of the moments of the distribution from which they are drawn.

Under our assumption about the z's, the cost in country n of buying good j from country i is drawn from the distribution:

$$\Pr[p_{nit}^K \leq p] = 1 - \exp(-T_{it} c_i^{-\theta} d_{ni}^{-\theta} p^{\theta}).$$

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[21]In Bernard, Eaton, Jensen, and Kortum (2000), we show how the approach generalizes quite simply to allow for imperfect competition.

The minimum across all possible sources i is consequently drawn from:

$$\Pr[p_{nt}^K \leq p] = 1 - \exp(-\Phi_{nt} p^\theta)$$

where:

$$\Phi_{nt} = \sum_{i=1}^{N} T_{it} c_i^{-\theta} d_{ni}^{-\theta}.$$

As we show next, the parameter Φ_{nt} relates both to the price index for capital goods in country n and to country n's import shares, providing a link between the two.

4.2 Bilateral Trade and the Price of Capital

With the heterogeneity of capital goods all described in terms of distributions, we can now aggregate over types to obtain results for aggregates. Assuming $\theta > \sigma - 1$, the exact price index for new capital goods (per efficiency unit) is:

$$P_{nt}^K = \gamma \Phi_{nt}^{-1/\theta}, \tag{2}$$

where γ is a constant.[22]

This expression shows how the states of technology and production costs in countries where n buys its capital goods, and the cost of overcoming geographic barriers, translate into an effective price index for capital in country n. The fraction of the continuum of capital goods that country n buys from country i is just:

$$\pi_{ni} = \frac{T_{it} c_i^{-\theta} d_{ni}^{-\theta}}{\Phi_{nt}},$$

country i's share in Φ_{nt}. (Since T's all grow at the same rate, trade shares are constant over time.)

As we show in Eaton and Kortum (2000), the price index P_{nt}^K applies not only to all capital goods in country n, it also applies to what country n buys from each source i. (Sources that are more advanced, lower cost, or closer exploit their advantage by selling a wider range of

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[22] As shown in Eaton and Kortum (2000), $\gamma = [\Gamma((\theta + 1 - \sigma)/\theta)]^{1/(1-\sigma)}$. Although it enters the equation for the constant γ, the elasticity of substitution σ can be ignored in what follows.

goods, so that in the end the costs of their goods have the same distributions as any others.)
This result allows us to equate π_{ni} to the share of capital produced in country i in n's total
expenditures on capital goods.

If country n allocates a share s_n of its income toward purchasing new capital goods, its
expenditure on capital goods at time t is:

$$X_{nt}^K = s_n Y_{nt}.$$

Imports of capital goods from country i as a share of GDP are then

$$\frac{X_{nit}^K}{Y_{nt}} = \pi_{ni} s_n. \tag{3}$$

We treat s_n as constant over time, but allow it to vary across countries. (As in our textbook
model, variation across countries in the savings rate would be the result of differences in the
discount rate.) The price *index* of capital P_{nt}^K is now given by (2). In a steady state the price
of capital falls at rate $g = g_T/\theta$, the same g as in the textbook model, only now referring
to an average over a continuum of capital goods. Taking variation across countries in the
price P_n^C of the C good as given, we can still apply equation (1) from the textbook model
above. Hence the expanded model can replicate the stylized facts above without insisting
on complete specialization anywhere. Furthermore, the trade cost parameters d_{ni} enable the
model to capture the home-bias and other geographic factors that are so apparent in Table 3.

4.3   Empirical Implications

We base our empirical implementation of the model on three equations plucked from above.
(In what follows we drop time subscripts since we will always be applying the model to a cross-
section of observations in 1985.) The first links import shares of capital goods to technologies,
production costs, and trade barriers:

$$\frac{X_{ni}^K}{X_n^K} = \frac{T_i c_i^{-\theta} d_{ni}^{-\theta}}{\Phi_n}. \tag{4}$$

The second links capital goods prices to technologies, production costs, and trade barriers:

$$P_n^K = \gamma \Phi_n^{-1/\theta} = \gamma \left[\sum_{i=1}^{N} T_i c_i^{-\theta} d_{ni}^{-\theta} \right]^{-1/\theta}. \tag{5}$$

The third links productivity to the savings rate and the relative price of capital goods:

$$y_n = \left(\frac{s_n}{(\delta + \frac{g}{1-\alpha})(P_n^K/P_n^C)} \right)^{\alpha/(1-\alpha)}. \tag{6}$$

In combination, these equations bring out the role of trade in conveying the exporter's technological prowess to the importer in the form of lower capital goods prices.[23]

Our empirical strategy is as follows: First we use equations (4) and (5) to infer what we can from trade data about how capital goods prices vary across countries. Then we use (6) to examine the relationship between the log of productivity and the log of the inferred price of capital goods series, after expressing it relative to the price of consumption goods.

It may appear somewhat magical (or suspicious) that we can infer anything about the price of capital goods simply from data on trade volumes. There are two trade ratios that indicate low capital goods prices in country i. First, observing country i with big market shares around the world indicates that i is a competitive supplier of capital goods. It should therefore be able to supply its domestic market at a low price. Second, observing country i importing a lot relative to home purchases indicates that i has not erected costly barriers to imported capital goods. Either indicator on its own could be misleading. For example, if country i is a large producer of capital goods it may appear closed simply because it has less need to import. But

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[23]Substituting (5) into (6), perturbing the technology parameters T_i (ignoring any effect on the c_i's), and using (4) to simplify, we get:

$$\%\Delta y_n = \frac{\alpha}{(1-\alpha)\theta} \sum_{i=1}^{N} \frac{X_{ni}^K}{X_n^K} \%\Delta T_i, \tag{7}$$

where $\%\Delta x$ is the percentage perturbation in variable x. Percentage changes in technology in country i translate into productivity gains in country n with a coefficient that depends on the market share of country i in n's capital good purchases. Very similar equations, with the percentage change of country i's R&D stock used in place of $\%\Delta T_i$, have been estimated by Coe and Helpman (1995) for the OECD and by Coe, Helpman, and Hoffmaister (1997) for developing countries. Even closer to the functional form here is Keller's (2000) specification. We want to exploit the cross-country rather than time variation in these equations, so we proceed quite differently.

the two indicators together allow us to weight the roles of competitiveness and openness to infer prices.

An artificial example helps formalize this intuition. Say that there are no trade barriers in selling to country N. (i.e., $d_{Ni} = 1$ for all i). In this case (4) implies that country i's export share in N is $X_{Ni}^K / X_N^K = T_i c_i^{-\theta} / \Phi_N$. Our measure of country $i's$ openness is $X_i^K / X_{ii}^K = \Phi_i / T_i c_i^{-\theta}$. The product of these two indicators is Φ_i / Φ_N. Plugging this expression into the price index (5) yields:

$$\frac{P_i^K}{P_N^K} = \left[\frac{X_{Ni}^K}{X_N^K} \frac{X_i^K}{X_{ii}^K} \right]^{-1/\theta}.$$

We can infer the direction of price variation from countries' import shares multiplied by their market shares in country N. To infer the amplitude of the variation we need to take a stand on the parameter θ.

Of course, in actual practice there is no such impartial country N, as in our example. But by estimating a simple equation for bilateral trade in capital goods we can achieve essentially the same thing, as we now show.

5   Estimation and Results

We begin by showing how we can estimate equation (4). Next we show how the parameter estimates, when substituted into equation (5), have implications for capital equipment prices, which we compare with ICP measures of those prices. Finally, we take the trade-based measure of equipment prices, along with ICP measures of consumption goods prices and investment rates, and feed them into equation (6). The result is a prediction about the role of capital equipment in explaining productivity differences across countries.

5.1   Estimating the Bilateral Trade Equation

Normalizing equation (4) by the importer's home sales and taking logs:

$$x_{ni}^K = \ln \frac{X_{ni}^K}{X_{nn}^K} = \ln \frac{T_i c_i^{-\theta}}{T_n c_n^{-\theta}} - \theta \ln d_{ni}. \tag{8}$$

We have observations on the left-hand side variable for 1122 country pairs. (Observations of x_{ni}^K for $n = i$ are not informative.)

To specify the right-hand side we proceed as follows: We define $S_i = \ln T_i - \theta \ln c_i$ to get:

$$x_{ni}^K = S_i - S_n - \theta \ln d_{ni}. \tag{9}$$

Here S_i indicates country i's "competitiveness" in equipment production, i.e. its state of technology adjusted for its input costs. We capture the S_i as the coefficients on export-country dummies.

To handle the d_{ni}'s we use proxies for geographic barriers suggested by the gravity literature. In particular, we relate the impediments in moving goods from i to n to proximity and language. Since $d_{nn} = 1$, we have, for all $i \neq n$:

$$\ln d_{ni} = d_k + b + l + m_n + \delta_{ni},$$

where the dummy variable associated with each effect has been suppressed for notational simplicity. Here d_k ($k = 1, \ldots, 6$) is the effect of the distance between n and i lying in the kth interval, b is the effect of n and i sharing a border, l is the effect of n and i sharing a language, and m_n ($n = 1, ..., 34$) is an overall destination effect. The error term δ_{ni} captures geographic barriers arising from all other factors. The six distance intervals (in miles) are: [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,maximum]. We assume that the error δ_{ni} is orthogonal to the other regressors (source country dummies and the proxies for geographic barriers listed above).[24]

Imposing this specification of geographic barriers, equation (9) becomes:

$$x_{ni}^K = S_i - S_n - \theta m_n - \theta d_k - \theta b - \theta l + \theta \delta_{ni}. \tag{10}$$

An issue in estimating equation (10) is how to handle observations in which x_{ni}^K is not reported, which occurs with about one-fourth of the bilateral pairs. The absence of a reported value

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[24]The distance and border dummies were constructed using information from Haveman (2000).

could reflect zero trade, a level falling below some threshold, or a choice by an importer to report only data aggregated over several sources.[25] We assume that each importer has a threshold level of imports below which it does not separately report a country as a source of any of its imports. We therefore estimate the model as a Tobit, with import-country specific censoring points λ_n. Since we do not observe λ_n directly, we use the maximum likelihood estimator, $\widehat{\lambda}_n = \min_i \{x_{ni}^K\}$, where for each importer n the minimum is taken over all sources i appearing in the data.

Tables 5, 6, and 7 show the results of the Tobit estimation of equation (10), both for total manufactures and for equipment trade.[26] The parameter estimates are useful primarily as an intermediate input for inferring price differences. Nonetheless, they are of some independent interest.

For one thing, they provide insight into why equipment is traded more than manufactures as a whole, as shown in Table 2. On the one hand, the geography parameters themselves are quite similar between total manufactures and equipment. On the other hand, exporter competitiveness S_i varies across countries much more for equipment than for total manufactures. Hence equipment is traded more not because geographic barriers are weaker, but because the forces of comparative advantage are stronger.

The estimated importer-specific barriers reported in Table 7 turn out to play a major role in generating differences in the price of equipment across countries than geography itself: The range of variation in $\widehat{\theta m_n}$ (11.85, attained between Germany and Egypt) exceeds the range in variation generated by distance and language (4.9, attained by the difference between a country pair separated by the largest distance and between a country pair separated by the smallest distance and sharing a language).

Our purpose in this paper is not to explain the determinants of cross-country differences in barriers to equipment imports. However, to get some sense of what might be driving these

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[25]See Feenstra et. al. (1997) for a discussion.

[26]Maximum likelihood estimation of the model used the INTREG command in STATA.

differences we find it worthwhile to relate them to two other country characteristics, one reflecting policy and the other capacity to absorb advanced technology from abroad.

The World Bank (1999) provides a measure τ_n of the average ad valorem duty across all tariff lines for manufactured products (World Bank, 1999).[27] A tariff τ_n on equipment imports should raise θm_n by $\theta \ln(1+\tau_n)$. An OLS regression of the estimated $\widehat{\theta m_n}$ on $\ln(1+\tau_n)$ (across the 28 countries for which we have complete data) yields an estimated θ of 9.2 with a standard error of 3.1 (the R^2 of the regression is 0.25). This estimate of θ is quite similar to the 8.3 value that Eaton and Kortum (2000) find using very different observations (retail prices of 50 manufactured goods across 19 OECD countries) and a very different methodology.

A country's level of human capital may provide some indication of its ability to exploit foreign technology. In fact, a regression of the estimated $\widehat{\theta m_n}$ on (the inverse of) Barro and Lee's (1993) measure of the average years of schooling in country n, H_n, yields an R^2 of 50 per cent.[28] Higher educational attainment is associated with lower barriers. Moreover, when both variables are included, human capital takes away all the explanatory power of tariffs.

5.2 Implications for Equipment Prices

We now use the estimated parameters from the bilateral trade equation to infer how equipment prices differ across countries. Inserting our estimates of exporter competitiveness $\widehat{S}_i$ and of geographic barriers $\widehat{\theta m_n} + \widehat{\theta d_k} + \widehat{\theta b} + \widehat{\theta l}$ into the right hand side of equation (11) yields the log of our trade-based measure of equipment prices, up to the unknown parameter θ:

$$\theta \ln \widehat{P_n^K} = -\ln \left(\sum_{i=1}^{N} \exp \left[\widehat{S}_i - (\widehat{\theta m_n} + \widehat{\theta d_k} + \widehat{\theta b} + \widehat{\theta l}) \right] \right). \tag{11}$$

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[27]This measure has advantages over a measure of tariff revenues since tariffs on some products may be so high as to discourage all purchases. Two shortcomings of the measure are that it is not specific to capital equipment and it is not available for 1985 but rather for various years in the late 1980's and early 1990's (and for different years in different countries). It was not available at all for Egypt, Iran, Kenya, Morocco, Pakistan, or Yugoslavia.

[28]We filled in a missing value for Nigeria with data from Kyriacou (1991).

We have ignored an additive constant which will be eliminated when we choose any normalization of the price index.[29]

Figure 7 plots the log of the ICP measure of equipment prices (from the second to the last column of Table 4) against our trade-based measure from equation (11). Our measure and the ICP measure bear little relationship. Both indicate Nigeria and Egypt to have among the highest equipment prices. But according to the trade-based measure Japan and the United States (the two largest producers) have the lowest equipment prices while the ICP reports very high prices for these two.

What is behind the contradictory messages sent by the ICP measure and trade-based measure of equipment prices? One possibility, of course, is that ICP equipment prices tell the true story while our model has led us to misinterpret what the bilateral trade data has to say, if anything, about price differences.[30] There are reasons to think, however, that the ICP measure fails to pick up a systematically higher true cost of equipment in poor countries.

One possibility is that the ICP price measures do not adequately reflect the lower quality of equipment used in poor countries.[31] That quality may in fact be lower is suggested by Navaretti, Soloaga, and Takacs's (2000) finding that poorer countries tend to import a higher share of used equipment.

Another possibility is that the ICP ignores many components of the cost of equipment (learning about it, learning how it works, adapting it to local conditions, maintaining it, etc.) that are in fact higher in poor countries. The finding that a low level of skills is associated with barriers to capital goods imports suggests that such costs, not reflected in prices, could

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[29]Since we only estimate the model on 34 countries rather than the entire world, our estimates are subject to sampling error. But since we have most of the big exporters, this error should be small.

[30]For example, Kravis and Lipsey (1988) argue that tradables tend to be cheaper in poor countries because wholesale and retail activities there cost less.

[31]This explanation parallels developments in measures of U.S. capital goods prices over time. Earlier measures, which ignored most quality improvements, showed little decline. But Gordon (1990), after controlling for quality change, found a dramatic fall in the relative price of capital equipment, averaging between 3 and 4 percent annually since 1950.

be substantial.[32]

To extract a properly scaled trade-based price measure from (11) we need to take a stand on θ. We set $\theta = 8.3$ as estimated in Eaton and Kortum (2000). Using this value of θ, we denote the trade-based measure $\hat{P}^K$. Table 8 shows both the ICP measure for P^K as well as our trade-based measure $\hat{P}^K$, both normalized to their U.S. value. Even though the ICP and our trade-based price measures of equipment prices bear little relationship, with $\theta = 8.3$ the variation in the two measures is similar (in that the range of variation along the horizontal axis in Figure 7 is about 8 times the range of variation along the vertical axis). More significantly, however, our measure, unlike the ICP's, correlates very well with development.

Aside from allowing us to use trade data to infer variation in equipment prices across countries, the model also tells us where countries are getting their technology. As expressions (4) and (5) imply, the share that a source country i occupies in the total purchases of a destination country n also reflects country i's contribution to lower equipment prices. One simple counterfactual is to ask what would happen if destination country n were cut off from source country i. The answer is that the price of capital goods there would rise by a factor of $(1 - \pi_{ni})^{-1/\theta}$. As can be seen from Table 3, among developing countries n, the value of π_{ni} is never more than 28 percent (the share of France in Morocco's absorption of equipment). Using this large value for π_{ni} we find that the price of capital would rise by only 4 percent in Morocco if it could no longer import equipment from France. No particular exporter is critical as a supplier in that importers could reallocate their imports among different suppliers at a moderate cost. Shutting down all imports of capital equipment by country n should make prices rise by a factor $(\pi_{nn})^{-1/\theta}$. The last column in Table 8 shows the resulting equipment price levels. For most countries the rise is modest, although it can go as high as 80 percent.[33]

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[32]See Navaretti, Soloaga, and Takacs (2000) and Mayer (2000).

[33]In Malawi, which is particularly dependent on imports, we find that autarky would force prices to rise over 80 percent. Other countries, which rely less on imports, start with higher price levels. Iran, for example, (whose equipment price we estimate at 3.6 times the U.S. level) suffers only an 8 percent increase in equipment prices if trade in equipment is eliminated altogether. Other countries rely heavily on imports but are fairly capable of producing for themselves. Sweden would experience over a 20 percent rise in prices if imports were cut off,

5.3 Implications for Productivity

We now ask how far cross-country differences in our trade-based measure of equipment prices go in explaining cross-country productivity differences. Equation (6) relates the steady-state output per worker y_n implied by our theory to the savings rate and the relative price of capital. Taking logarithms of this expression yields:

$$\ln y_n = a + \frac{\alpha}{1-\alpha} \ln \frac{s_n}{P_n^K / P_n^C}. \tag{12}$$

The elasticity of productivity with respect to real equipment investment rate is $\alpha/(1-\alpha)$.

We explore the relationship given by (12) on two fronts. We first investigate it econometrically, following DeLong and Summers (1991). In doing so we explore the implications of adding nonequipment capital. This econometric approach not only provides insight into the strength of the relationship between our measure of relative equipment price and productivity, in principle, it provides evidence on the elasticity. We also take outside estimates of the elasticity to assess how far real equipment investment (using our measure of equipment prices) can go in accounting for cross-country productivity differences.

To measure y_n we use GDP per capita adjusting for years of schooling.[34] We collect remaining factors affecting GDP per capita, such as disembodied technological differences, into a multiplicative error term ε_n. In terms of (schooling-adjusted) output per capita y_n^*, equation (12) becomes, in logs:

$$\ln y_n^* = a + \frac{\alpha}{1-\alpha} \ln \frac{s_n}{P_n^K / P_n^C} + \ln \varepsilon_n. \tag{13}$$

We employ two measures of the real equipment investment rate, one based on the ICP measure of equipment prices and one employing our trade-based measure. Throughout, we measure s_n

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but even so, its prices would be only 30 percent higher than those in the United States.

[34]Following Bils and Klenow (1998), we divide GDP per capita by $e^{.09H_i}$ where H_i is average years of schooling across the 25 year and older population in country i. This correction attempts to account for differences in the skill of labor across countries. The schooling data for 1985 is from Barro and Lee (1993) with missing values filled in for Egypt, Morocco, and Nigeria using data from Kyriacou (1991).

as the equipment investment rate based on local currency values and P_n^C as the ICP measure of the consumption goods price index.

An OLS regression using equation (13), with the real equipment investment rate derived from the ICP price measure, yields a slope of 0.95 with an R^2 of 0.46. (Table 9 shows all of the regression results.) With our trade-based measure the regression slope falls to 0.63, but the relationship tightens substantially with the R^2 rising to 0.67. This rise in R^2 indicates that our trade-based measure is more highly correlated with GDP per capita. The reason that the slope falls is the greater variation in the trade-based measure of real equipment investment.

To explore (13) in more detail, we run OLS regressions with separate coefficients on the savings rate, the price of equipment, and the price of consumption. The third and fourth rows of Table 9 report the results. Using the ICP measure of equipment prices, we find that variation in the price of consumption drives the relationship between productivity and the real investment rate. Variation in the price of capital itself has little explanatory power. But when we use our trade-based measure of equipment prices, the coefficients on the price of equipment and the price of consumption have about the same absolute magnitude with opposite signs, as they should.[35]

So far we have ignored the distinction between equipment and other types of capital (implicitly assuming that the real investment rates for each move in parallel). Following Greenwood et. al. (1997) we now generalize the production function to $F(K^e, K^s, L) = (K^e)^{\alpha_e}(K^s)^{\alpha_s}L^{1-\alpha_e-\alpha_s}$, where K^s is the stock of structures and K^e is the stock of equipment (with α_e and α_s the corresponding shares). The steady-state productivity equation becomes:

$$\ln y_n^* = \ln \eta - \frac{\alpha_e}{1-\alpha} \ln \frac{P_n^K}{P_n^C} - \frac{\alpha_s}{1-\alpha} \ln \frac{P_n^s}{P_n^C} + \ln \varepsilon_n, \tag{14}$$

where P_n^K is the price of equipment, P_n^s is the price of structures, $\alpha = \alpha_e + \alpha_s$, and η is a

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[35]The similarity of these coefficients also lends some support to our choice of $\theta = 8.3$. Had we used a value of θ only half as large, the coefficient on the predicted equipment price would have been only half as large as the coefficient on the price of consumption.

complicated constant.[36] (Implicit in the derivation are the assumptions that the savings rate is constant across countries and that the price of structures, unlike the price of equipment, remains fixed over time in terms of the price of consumption goods.)

If the relative price of structures is highly correlated with the relative price of equipment, its inclusion in the regression should lower the coefficient on the relative price of equipment. We estimate equation (14) using ICP data on the relative price of capital structures and our predicted price of equipment relative to the ICP data on the price of consumption goods. The results are shown in the last row of Table 9. The inclusion of the relative price of structures has almost no impact on the equipment price coefficient, and the coefficient on structures prices is not significantly different from zero.

To summarize the findings of the regression analysis, using our predicted equipment price we estimate that the elasticity of steady-state productivity with respect to the relative equipment price is between 0.6 and 0.7. Although these estimates are more reasonable than those obtained using the ICP measure of equipment prices, they are nevertheless too large. Given estimates of the share of equipment and structures in production, it is hard to justify a coefficient larger than $\alpha_e/(1 - \alpha) = (1/6)/(2/3) = 1/4$, in line with Greenwood et. al. (1997). An obvious explanation for the larger coefficients in the regressions is a negative correlation between the unobserved efficiency of labor ε and the relative price of equipment. It is quite likely that countries where equipment is cheap are also more productive for other reasons as well. They might, for example, benefit from more advanced levels of disembodied technology.

In light of this estimation problem we now simply impose an elasticity based on measured shares in production, setting $\alpha_e/(1 - \alpha) = 1/4$ in equation (14). We then use the equation to account for differences in productivity levels. (Based on the results above, we ignore variation

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[36]The constant is given by

$$\eta = (\kappa^e)^{-\alpha_e/(1-\alpha)} (\kappa^s)^{-\alpha_s/(1-\alpha)},$$

where the value of the equipment capital to output ratio is $\kappa^e = \alpha_e/[\rho + \delta^e + (1 - \alpha_s)g/(1 - \alpha)]$ and structures capital output ratio is $\kappa^s = \alpha_s/[\rho + \delta^s + \alpha_s g/(1 - \alpha)]$.

in the relative price of structures.)

By analogy to growth accounting (where, due to growth, observations tend to be ordered roughly in terms of the level of productivity) we order countries by the level of y_n^*. We denote the set of 10 low productivity countries by Ω_S (Malawi, Kenya, India, Philippines, Nigeria, Zimbabwe, Bangladesh, Pakistan, Egypt, and Sri Lanka). Similarly, we denote the set of 10 high productivity countries by Ω_N (Australia, Japan, Norway, United States, Sweden, Germany, Austria, Canada, Italy, and France). Our accounting is then based on:

$$\sum_{n\in\Omega_N} \ln y_n^* - \sum_{n\in\Omega_S} \ln y_n^* = -\frac{1}{4}\left(\sum_{n\in\Omega_N} \ln P_n^K - \sum_{n\in\Omega_S} \ln P_n^K\right) + \frac{1}{4}\left(\sum_{n\in\Omega_N} \ln P_n^C - \sum_{n\in\Omega_S} \ln P_n^C\right) + \epsilon, \tag{15}$$

where ϵ is the difference in productivity between the two groups not explained by relative equipment prices.

We find that differences between the two groups in consumption goods prices P^C (on the right hand side) explain 14 percent of the productivity difference between the two groups (on the left). Using the ICP measure of equipment prices we find that differences in P^K explain -3 percent of the productivity differences. With our trade-based measure we can explain 12 percent, in line with the explanation provided by differences in consumption goods prices. Together, differences in the relative price of equipment using our trade-based measure account for 26 percent of the difference in productivity.

How big is 26 per cent? A basis for comparison is the contribution of the declining relative price of equipment over time to U.S. productivity growth. While, as discussed above, Greenwood et. al., attribute almost 60 percent of U.S. productivity growth to falling equipment prices, Hulten (1992) puts the number at 20 percent. Note, however, that while international trade in equipment can reduce the cross-country variation in equipment prices, there is no such mechanism to reduce the differences in prices that arise over time due to technological change. Thus, we should expect that difference in the relative price of equipment explain less across countries than over time.

6   Conclusion

Our analysis of trade in capital goods relates productivity differences to differences in equipment prices, and in turn relates these prices to barriers inhibiting trade in equipment. The model allows us to infer differences in equipment prices across countries from data on bilateral trade in these goods. Estimating the model for a sample of 34 countries implies price differences that are much greater across countries and more tightly tied to GDP per capita than standard price measures. Our working hypothesis is that standard measures are not fully accounting for quality differences, and ignore many indirect costs that may vary across countries, such as the cost of learning how to operate imported equipment.

While our trade-based measure of equipment prices goes a lot further in explaining GDP differences than the prices typically used in the empirical growth literature, obviously we have not told the whole story. Indeed, if capital goods price differences alone were sufficient to explain all differences in GDP per capita, they would have to be enormous given the modest share of capital equipment in output. Nonetheless, we have made some progress on this front. More important, we have gone further than earlier work in connecting equipment trade, productivity, and price differences across countries.

References

Acemoglu, Daron and Fabrizio Zilibotti (2000), "Productivity Differences." forthcoming in *Quarterly Journal of Economics*.

Balassa, Bela (1964), "The Purchasing Power Parity Doctrine: A Reappraisal." *Journal of Political Economy 72*: 584-596.

Barro, Robert and Jong-Wha Lee (1993), "International Comparisons of Educational Attainment." *Journal of Monetary Economics 32*: 363-394.

Berman, Eli, John Bound, and Stephen Machin (1998), "Implication of Skill-Biased Technological Change: International Evidence." *Quarterly Journal of Economics 113*: 1245-1280.

Bernard, Andrew B., Jonathan Eaton, J. Bradford Jensen, and Samuel Kortum (2000), "Plants and Productivity in International Trade." *NBER Working Paper No. 7688*.

Bils, Mark and Peter Klenow (1998), "Does Schooling Cause Growth of the Other Way Around?" *NBER Working Paper No. 6393*.

Castro, Rui (2000), "Economic Development under Alternative Trade Regimes." mimeo, University of Montreal.

Chari, V. V., Patrick J. Kehoe, and Ellen R. McGratten (1998), "The Poverty of Nations: A Quantitative Investigation." Federal Reserve Bank of Minneapolis.

Coe, David T. and Elhanan Helpman (1995), "International R&D Spillovers." *European Economic Review 39*: 859-887.

Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister (1997), "North-South Research and Development Spillovers." *Economic Journal 107*: 134-149.

Collins, William J. and Jeffrey G. Williamson (2000), "Capital Goods Prices and Investment: 1870-1950." mimeo, Harvard University.

De Long, J. Bradford and Lawrence H. Summers (1991), "Equipment Investment and Economic Growth." *Quarterly Journal of Economics 106*: 445-502.

Eaton, Jonathan, and Samuel Kortum (1996), "Trade in Ideas: Patenting and Productivity in the OECD." *Journal of International Economics 40*: 251-278.

Eaton, Jonathan and Samuel Kortum (1999), "International Technology Diffusion: Theory and Measurement." *International Economic Review 40*: 537-570.

Eaton, Jonathan and Samuel Kortum (2000), "Technology, Geography, and Trade." mimeo, Boston University.

Feenstra, Robert C., Robert E. Lipsey, and Henry P. Bowen (1997), "World Trade Flows, 1970-1992, with Production and Tariff Data." *NBER Working Paper No. 5910.*

Frankel, Jeffrey A. and David Romer (1999), "Does Trade Cause Growth?" *American Economic Review 89*: 379-399.

Gilchrist, Simon and John C. Williams (2000), "Transition Dynamics in Vintage Capital Models: Explaining the Postwar Catch-Up of Germany and Japan." mimeo, Boston University.

Gordon, Robert J. (1990), *The Measurement of Durable Goods Prices* (University of Chicago Press).

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

Haveman, Jonathan (2000), "Useful Gravity Model Data." available at
`http://www.eiit.org/Trade.Resources/TradeData.html`.

Heston, Alan, Robert Summers, Bettina Aten, and Daniel A. Nuxoll (1995), "New Kinds of Comparisons of the Prices of Tradables and Nontradables." CICUP Working Paper 95-3.

Holmes, Thomas J. and James A. Schmitz (1995), "Resistance to New Technologies and Trade Between Areas," *Federal Reserve Bank of Minneapolis Quarterly Review 19*: 2-17.

Hulten, Charles R. (1992), "Growth Accounting when Technical Change is Embodied in Capital." *American Economic Review 82*: 964-980.

IMF (1995), *International Financial Statistics* (International Monetary Fund, Washington, DC).

Jones, Charles I. (1994), "Economic Growth and the Relative Price of Capital." *Journal of Monetary Economics 34*: 359-382.

Jovanovic, Boyan and Rafael Rob (1997), "Solow vs. Solow: Machine Prices and Development." *NBER Working Paper # 5871*.

Keller, Wolfgang (1998), "Are International R&D Spillovers Trade Related? Analyzing Spillovers Among Randomly Matched Trade Partners." *European Economic Review 42*: 1469-1481.

Keller, Wolfgang (2000), "How Trade Patterns and Technology Flows Affect Productivity Growth." forthcoming in *World Bank Economic Review*.

Kravis, Irving and Robert Lipsey (1988), "National Price Levels and the Price of Tradables and Nontradables." *American Economic Review: Papers and Proceedings 78*: 474-478.

Kyriacou, G. (1991), "Level and Growth Effects of Human Capital." *C.V. Starr Center Working Paper 91-26*.

Leamer, Edward and James Levinsohn (1995), "International Trade Theory: The Evidence." In *The Handbook of International Economics, Volume III,* edited by Gene M. Grossman and Kenneth Rogoff (North-Holland, Amsterdam).

Mankiw, N. Gregory, David Romer and David N. Weil (1992), "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics 107*: 407-437.

Mayer, Jörg (2000), "Technology Transfer and Economic Growth in Developing Countries." mimeo, UNCTAD.

Navaretti, Giorgio Barba, Isidro Soloaga, and Wendy Takacs (2000), "Vintage Technologies and Skill Constraints: Evidence from U.S. Exports of New and Used Machines." *World Bank Economic Review 14*: 91-109.

OECD (1995a), *Basic Science and Technology Statistics* (OECD, Paris).

OECD (1995b), *STAN Database for Industrial Analysis* (OECD, Paris).

OECD (1996), *Input-Output Database* (OECD, Paris).

Parente, Stephen L. and Edward C. Prescott (1994), "Barriers to Technology Adoption and Development." *Journal of Political Economy 102*: 298-321.

Parente, Stephen L. and Edward C. Prescott (1999), "Monopoly Rights: A Barrier to Riches." *American Economic Review 89*: 1216-1233.

Restuccia, Diego and Carlos Urrutia (2000), "Relative Prices and Investment Rates." forthcoming in *Journal of Monetary Economics.*

Rodríguez-Clare, Andrés (1996), "The Role of Trade in Technology Diffusion." mimeo, University of Chicago.

Romer, Paul (1994), "New Goods, Old Theory, and the Welfare Costs of Trade Restrictions." *Journal of Development Economics 43*: 5-38.

Samuelson, Paul A. (1964), "Theoretical Notes on Trade Problems." *Review of Economics and Statistics 46*: 145-164.

Smith, M.A.M. (1974), "International Trade in Second-Hand Machines." *Journal of Development Economics 1*: 261-278.

Solow, Robert M. (1960), "Investment and Technological Progress." In *Mathematical Methods in the Social Sciences 1959,* edited by Kenneth J. Arrow and Patrick Suppes (Stanford University Press).

Summers, Robert and Alan Heston (1991), "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988." *Quarterly Journal of Economics 106*: 327-368.

UNIDO (1999), *Industrial Statistics Database* (United Nations, New York).

United Nations (1994), *World Comparisons of Real Gross Domestic Product and Purchasing Power, 1985: Phase V of the International Comparison Programme* (United Nations Publications).

Wang, Jianmao and Bin Xu (1999), "Capital Goods Trade and R&D Spillovers in the OECD." *Canadian Journal of Economics 32*: 1258-1274.

World Bank (1993), *Purchasing Power of Currencies, Comparing National Incomes Using ICP Data* (World Bank, Washington, DC).

World Bank (1999), *World Development Indicators* (World Bank, Washington, DC).

Young, Alwyn (1995), "The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience." *Quarterly Journal of Economics 110*: 641-680.

A Data Appendix

The dataset includes production, trade, and prices for a cross-section of 34 countries in 1985.

A.1 Equipment Producing Industries

Trade data are available by type of product, but not according to the way in which the product is used (i.e. as an intermediate good, consumption good, or investment good). Thus, we must approximate trade in capital equipment by trade in goods associated with major equipment-producing industries. We identified the equipment-producing industries after consulting input-output tables and capital flows tables of domestic transactions (OECD, 1996) for each of the three major capital-goods producers (Germany, Japan, and the United States). Based on the discussion below we identify three industries, electrical machinery, nonelectrical machinery, and instruments, as equipment producers.

The following tables explain this choice. The first table shows that the output of our equipment producing industries is much more likely to be used for investment rather than consumption, while the opposite is true for other manufacturing industries. (Output that is purchased by the government or exported has been ignored in these calculations.) A caveat is that about half of the output of the equipment-producing industries is used as intermediate goods, as discussed in the text.

<div align="center">Uses of Manufacturing Output</div>

Country	Investment goods (%)	Consumption goods (%)	Intermediate goods (%)
	Equipment Producing Industries		
Germany (1986)	39	8	53
Japan (1985)	44	8	48
United States (1985)	36	14	50
	Other Manufacturing Industries		
Germany (1986)	6	30	64
Japan (1985)	3	23	74
United States (1985)	5	33	62

(Shares may not sum to 100 due to rounding.)

The next table shows these three industries generate at least 60 % of the manufacturing

sector's total output of investment goods. Of the industries that we have excluded, the transportation equipment industry also makes a major contribution. Other investment goods are generally produced by either the textile products industry, wood processing, paper products, or metal processing. Our equipment producing industries generate about 80 % of the investment goods used by the manufacturing sector.

Contributors to the Production of Investment Goods

Country	Equipment producers (%)	Transportation equipment (%)	Textiles, wood, paper, and metal processing (%)
	Investment Goods Used Anywhere		
Germany (1986)	60	15	19
Japan (1985)	76	16	6
United States (1985)	60	28	10
	Investment Goods Used by Manufacturers		
Germany (1986)	78	7	11
Japan (1985)	95	4	2
United States (1985)	84	12	4

(Shares may not sum to 100 due to rounding.)

A.2 Factor Shares

The following table provides some evidence about factor intensities in the production of equipment versus other manufactures. To get at labor intensity we report labor compensation as a percentage of value added. To get at skill intensity (following Berman, Bound, and Machin, 1998) we report the percentage of non-production workers in employment (we thank Eli Berman for supplying these data). We focus on the main equipment producing countries (France and Italy do not provide data on employment of production vs. non-production workers). Equipment producing industries appear to be labor intensive and skill intensive relative to other manufacturing industries.

Contributors to the Production of Investment Goods				
Country	Labor Compensation in Value Added (%)		Non-production Workers in Employment (%)	
	Equipment producers	Other manufacturing	Equipment producers	Other manufacturing
Germany	77	63	38	29
Japan (1984)	54	49	48	54
Sweden	72	70	39	28
United Kingdom	80	72	41	29
United States	81	67	39	27

A.3 Trade Data

The bilateral trade data is from Feenstra et. al. (1997). The industry dimension of the trade data is based on a concordance from the 4-digit Standard International Trade Classification to a set of industry codes used by the Bureau of Economic Analysis (BEA). We define equipment trade to be the sum of BEA industry codes 20-27 and 33 (Farm and Garden Machinery; Construction, Mining, etc.; Computer and Office Equipment; Other Nonelectric Machinery; Household Appliances; Household Audio and Video, etc.; Electronic Components; Other Electrical Machinery; and Instruments and Apparatus).

To calculate how much equipment each country provides for itself we need data on production by each country. The United Nations (UNIDO, 1999) assembles data on gross production by 3-digit International Standard Industrial Classification (ISIC) across a wide set of countries. We define production of equipment to be the sum of ISIC 382, 383, and 385 (Machinery, except electrical; Machinery, electric; and Professional and scientific equipment).

A.4 ICP Price Measures

The International Comparisons Programme (ICP) of the United Nations periodically collects information on the prices of a number of types of capital equipment across 30 to 60 countries (United Nations, 1994 and World Bank, 1993). The ICP also assembles a series on equipment investment.

We focus on the year 1985. In that year the ICP global comparisons of prices and out-

put consist of data from 56 countries. We dropped 17 of these countries (Belgium, Benin, Botswana, Cameroon, Congo, Côte d'Ivoire, Ethiopia, Luxembourg, Mali, Poland, Senegal, Sierra Leone, Swaziland, Tanzania, Thailand, Tunisia, and Zambia) because the industry production data was not available for 1985. We dropped Hong Kong, Ireland, Netherlands, and Rwanda because their reported exports of equipment exceeded their reported production. (We also dropped Madagascar.) The final set of 34 countries is shown in Table 1.

For some purposes we needed to translate the ICP measures from local currencies to U.S. Dollars. We use the exchange rate implicit in the UNIDO data (which is available in both the local currency and in U.S. Dollars) for this purpose, with the following exceptions. In general UNIDO uses the rf series from the International Financial Statistics (e.g. IMF, 1995). At the request of Iran, UNIDO uses the yf series for that country, which is much higher [yf = 207.3 Rials/$, rf(reported as wf) = 91.05 Rials/$]. Correspondence with the Trade Branch of the U.N. indicated that they always use the rf series in converting the trade data into U.S. Dollars. Thus, to be consistent with the trade data, we chose to convert Iran's production into U.S. Dollars using the exchange rate of 91.05 Rials/$ in 1985. One other issue is that the ICP data for Kenya is in Kenyan Shillings, while in the UNIDO data it is in Kenyan Pounds, so we adjust the exchange rate appropriately.

A.5 Other Data

In Figure 1 we plot R&D performed and financed by the business sector. Using R&D data for 1981 and 1989 from OECD (1995a), we divided these expenditures by GDP in the corresponding year and then took the simple average.

In estimating the trade equation, we use proxies for geographic barriers. The distance and border dummies were constructed using information from Haveman (2000).

Table 1: Production of Manufactures and Equipment

#	Country	Code	Population (thousands)	GDP per capita (intl. $'s)	Manufacturing production (% of GDP)	Equipment production (% of GDP)
1	Australia	AUS	15758	13583	16.8	2.0
2	Austria	AUT	7555	11131	20.3	4.5
3	Bangladesh	BGD	97100	1216	4.9	0.2
4	Canada	CAN	25165	15589	21.6	2.9
5	Denmark	DNK	5114	12969	18.1	4.0
6	Egypt	EGY	46511	1953	10.4	1.0
7	Finland	FIN	4902	12051	25.1	4.7
8	France	FRA	55170	12206	22.5	4.9
9	Germany	DEU	61058	12535	35.7	10.5
10	Greece	GRC	9934	6224	14.2	0.9
11	Hungary	HUN	10657	5278	28.4	8.6
12	India	IND	765147	1050	7.2	1.3
13	Iran	IRN	46374	4043	7.0	0.9
14	Italy	ITA	57141	10808	15.3	3.6
15	Japan	JPN	120754	11771	31.1	9.3
16	Kenya	KEN	20241	794	11.3	0.7
17	Korea	KOR	40806	4217	35.8	6.3
18	Malawi	MWI	7188	518	7.5	0.1
19	Mauritius	MUS	1020	4226	15.9	0.6
20	Morocco	MAR	22061	1956	9.8	0.5
21	New Zealand	NZL	3272	11443	21.0	2.2
22	Nigeria	NGA	83196	1062	8.5	0.3
23	Norway	NOR	4153	14144	13.2	2.8
24	Pakistan	PAK	96180	1262	10.6	0.6
25	Philippines	PHL	54700	1542	10.4	0.6
26	Portugal	PRT	10157	5070	18.9	1.8
27	Spain	ESP	38574	7536	20.2	2.7
28	Sri Lanka	LKA	15837	2045	11.0	0.3
29	Sweden	SWE	8350	13451	24.4	5.7
30	Turkey	TUR	50306	3077	19.7	1.9
31	United Kingdom	GBR	56618	11237	27.4	6.4
32	United States	USA	239279	16570	25.2	6.8
33	Yugoslavia	YUG	23124	5172	36.5	6.6
34	Zimbabwe	ZWE	8406	1216	25.4	1.2

All data are for 1985. Population and GDP per capita in international $'s (rgdpch) are from Summers and Heston (1991). The share manufacturing in GDP is calculated as local currency value added in manufacturing (UNIDO, 1999) as a percentage of local currency GDP (World Bank, 1993). The share of equipment producing industries (nonelectrical machinery, electrical equipment, and instruments) was calculated as the sum of the value added of these industries as a share of GDP. Since only gross production data was available for Sri Lanka, we assumed that the ratio of value added to gross production was the same there as in Bangladesh, (i.e. 0.3455 for total manufacturing and 0.4029 for the equipment industries).

Table 2: Trade in Manufactures and Equipment

#	Country	Imports in absorption		Imports from "Big 7"	
		manufactures (%)	equipment (%)	manufactures (%)	equipment (%)
1	Australia	25.8	58.0	72.1	81.1
2	Austria	41.5	62.3	76.5	80.6
3	Bangladesh	50.8	80.9	36.6	49.0
4	Canada	31.7	62.6	88.8	91.9
5	Denmark	57.2	92.0	67.0	78.7
6	Egypt	33.7	64.6	59.7	79.7
7	Finland	28.0	57.2	69.4	78.1
8	France	25.3	40.3	60.4	75.0
9	Germany	26.1	34.1	49.3	62.5
10	Greece	35.4	67.7	66.4	76.0
11	Hungary	29.1	53.0	33.0	38.1
12	India	12.2	24.3	53.6	73.9
13	Iran	26.6	45.7	55.7	74.3
14	Italy	29.0	54.9	59.7	73.1
15	Japan	5.3	4.7	45.8	73.8
16	Kenya	18.7	60.0	66.1	74.4
17	Korea	23.1	47.9	80.0	90.0
18	Malawi	42.4	99.3	44.1	64.4
19	Mauritius	35.3	87.6	46.3	61.4
20	Morocco	32.8	66.0	67.3	82.0
21	New Zealand	30.3	57.1	66.7	75.1
22	Nigeria	29.1	73.0	66.1	72.7
23	Norway	41.5	49.9	67.0	77.4
24	Pakistan	33.3	66.4	64.6	74.4
25	Philippines	23.5	72.3	57.2	75.8
26	Portugal	31.1	74.1	64.0	76.8
27	Spain	16.4	46.0	74.4	84.1
28	Sri Lanka	48.9	94.0	48.4	72.6
29	Sweden	41.5	80.5	57.4	70.0
30	Turkey	22.4	53.2	64.9	75.1
31	United Kingdom	28.7	46.1	57.2	70.0
32	United States	11.9	16.6	44.4	58.8
33	Yugoslavia	15.6	31.4	55.5	63.8
34	Zimbabwe	18.8	64.7	54.7	72.2

All data are for 1985. Absorption (the denominator of the import share) is calculated as gross production plus imports less exports. Imports from the "Big 7" (France, Germany, Japan, Italy, Sweden, United Kingdom, and United States) are shown as a percentage of total imports. The trade data are from Feenstra et. al. (1997) and the production data are from UNIDO (1999).

Table 3: Sources of Equipment Purchases

Importing country	Source of Equipment Purchases (% of absorption)							
	Home	U.S.	Japan	Germany	U.K.	France	Italy	Sweden
Europe:								
Austria	37.7	3.2	3.6	33.0	2.7	2.4	3.9	1.5
Denmark	8.0	7.9	6.8	28.0	10.3	4.6	4.7	10.2
Finland	42.8	4.7	5.7	13.8	5.1	2.7	2.8	10.0
France	59.7	7.0	3.2	10.7	3.9	—	4.6	0.9
Germany	65.9	5.2	5.1	—	3.6	3.5	3.0	0.9
Greece	32.3	3.8	3.8	18.7	5.3	5.2	13.4	1.3
Hungary	47.0	1.6	2.1	10.9	1.4	1.6	1.6	1.1
Italy	45.1	6.6	3.7	16.6	5.6	6.2	—	1.4
Norway	50.1	6.1	3.7	9.9	6.1	2.0	2.3	8.5
Portugal	25.9	5.0	5.9	18.8	8.5	7.3	9.3	2.1
Spain	54.0	6.5	5.2	10.9	4.2	5.4	5.4	1.2
Sweden	19.5	10.3	8.0	20.7	9.4	4.7	3.3	—
Turkey	46.8	7.1	6.7	14.0	4.5	2.0	4.9	0.8
U.K.	53.9	11.0	5.3	8.5	—	3.4	2.8	1.3
Yugoslavia	68.6	2.9	0.6	8.2	1.6	1.5	4.0	1.2
Pacific:								
Australia	42.0	15.9	16.3	5.5	4.5	1.2	2.1	1.5
Canada	37.4	45.7	5.8	2.1	1.8	0.8	0.7	0.6
Japan	95.3	2.7	—	0.4	0.2	0.1	0.1	0.1
Korea	52.1	12.9	23.9	2.5	1.0	1.5	0.4	0.8
New Zealand	42.9	11.6	15.6	4.8	6.7	1.5	1.7	1.0
Philippines	27.7	26.0	18.1	5.3	2.2	1.7	0.9	0.5
U.S.	83.4	—	6.4	1.3	0.9	0.5	0.4	0.2
South Asia:								
Bangladesh	19.1	5.7	14.9	6.6	6.7	4.0	1.6	0.3
India	75.7	3.7	4.0	4.5	2.9	1.9	0.8	0.3
Iran	54.3	0.9	7.2	13.4	4.9	0.9	5.6	1.1
Pakistan	33.6	11.5	12.2	9.7	8.5	2.5	3.9	1.2
Sri Lanka	6.0	8.9	27.8	10.0	12.9	3.9	2.5	2.2
Africa:								
Egypt	35.4	10.0	8.0	10.7	5.3	6.3	10.2	0.9
Kenya	40.0	4.0	7.4	7.4	17.4	3.3	3.7	1.4
Malawi	0.7	8.0	5.6	7.0	26.9	8.7	6.3	1.3
Mauritius	12.4	1.2	12.0	5.3	8.4	23.3	3.2	0.3
Morocco	34.0	3.2	2.7	7.5	3.7	27.7	7.0	2.4
Nigeria	27.0	8.1	8.0	8.8	16.7	5.5	5.5	0.5
Zimbabwe	35.3	9.1	2.3	7.0	14.7	4.9	6.7	2.1

All data are for 1985. Absorption of equipment is calculated as gross production of equipment producing industries plus imports less exports. The trade data are from Feenstra et. al. (1997) and the production data are from UNIDO (1999).

Table 4: Investment and Prices

#	Country	Investment in equipment (% of GDP)	Price of equip. rel. to consump. (mean = 1)	Price Levels consumption (mean = 1)	equipment (mean = 1)
1	Australia	5.7	0.60	1.73	1.03
2	Austria	8.2	0.61	1.68	1.02
3	Bangladesh	5.3	1.44	0.43	0.62
4	Canada	4.5	0.77	1.82	1.40
5	Denmark	6.9	0.57	1.94	1.11
6	Egypt	9.6	2.28	0.68	1.55
7	Finland	7.6	0.56	2.07	1.17
8	France	6.0	0.69	1.66	1.13
9	Germany	6.7	0.64	1.74	1.11
10	Greece	6.4	0.92	1.14	1.05
11	Hungary	7.4	1.00	0.68	0.68
12	India	7.9	1.85	0.66	1.23
13	Iran	2.7	1.35	1.36	1.83
14	Italy	7.4	0.76	1.37	1.05
15	Japan	8.3	0.78	1.80	1.39
16	Kenya	6.5	1.93	0.51	0.98
17	Korea	8.3	0.95	0.99	0.94
18	Malawi	6.3	1.64	0.47	0.78
19	Mauritius	6.4	2.01	0.29	0.59
20	Morocco	6.7	2.28	0.42	0.96
21	New Zealand	8.2	1.02	1.29	1.32
22	Nigeria	1.3	0.88	1.94	1.70
23	Norway	4.9	0.65	2.15	1.40
24	Pakistan	5.8	1.71	0.47	0.80
25	Philippines	4.9	0.69	0.61	0.42
26	Portugal	5.7	1.29	0.83	1.08
27	Spain	4.6	0.98	1.09	1.07
28	Sri Lanka	6.8	2.14	0.47	1.01
29	Sweden	5.6	0.58	1.91	1.12
30	Turkey	6.4	0.54	0.68	0.37
31	United Kingdom	6.7	0.71	1.47	1.04
32	United States	6.3	0.64	2.01	1.28
33	Yugoslavia	9.9	1.10	0.77	0.85
34	Zimbabwe	3.6	1.39	0.57	0.80

All data are for 1985. Equipment investment is expenditure on producer durables net of producers' expenditures on transportation equipment. Investment expenditures per capita in the local currency are shown as a percentage of local currency GDP per capita (World Bank, 1993). Prices for consumption, producer durables, producers' transportation equipment (each in the local currency) are from World Bank (1993). Each series is divided by the exchange rate and normalized to have a geometric mean of 1. The equipment price excludes transportation equipment. It is constructed from the price series for total equipment and transportation equipment assuming a Cobb Douglas price aggregate.

Table 5: Bilateral Trade Equation, Gravity Parameters

Variable		Manufactures		Equipment	
		est.	s.e.	est.	s.e.
Distance [0,375)	$-\theta d_1$	-4.93	(0.32)	-4.96	(0.34)
Distance [375,750)	$-\theta d_2$	-6.17	(0.23)	-6.06	(0.24)
Distance [750,1500)	$-\theta d_3$	-6.45	(0.15)	-6.22	(0.16)
Distance [1500,3000)	$-\theta d_4$	-6.84	(0.13)	-7.07	(0.14)
Distance [3000,6000)	$-\theta d_5$	-8.24	(0.07)	-8.32	(0.08)
Distance [6000,maximum]	$-\theta d_6$	-8.70	(0.13)	-8.92	(0.14)
Shared border	$-\theta b$	0.20	(0.28)	-0.13	(0.29)
Shared language	$-\theta l$	0.49	(0.19)	0.94	(0.21)

Exporter competitiveness parameters: Table 6
Importer barrier parameters: Table 7

Number of observations	1122	1122	
Uncensored	825	1003	
Left-censored	297	119	

Estimated as a Tobit with import-country specific censoring points. The specification is given in equation (10) of the paper. Standard errors are in parentheses.

Table 6: Bilateral Trade Equation, Exporter Competitiveness

Country		Manufactures		Equipment	
		est.	s.e.	est.	s.e.
Australia	S_1	1.49	(0.26)	1.80	(0.27)
Austria	S_2	1.40	(0.24)	2.98	(0.25)
Bangladesh	S_3	-1.65	(0.24)	-4.64	(0.33)
Canada	S_4	2.35	(0.25)	3.32	(0.26)
Denmark	S_5	1.51	(0.24)	3.00	(0.25)
Egypt	S_6	-2.94	(0.25)	-6.53	(0.43)
Finland	S_7	1.10	(0.24)	1.86	(0.25)
France	S_8	3.29	(0.24)	4.79	(0.25)
Germany	S_9	4.15	(0.24)	5.79	(0.25)
Greece	S_{10}	-0.71	(0.24)	-2.22	(0.26)
Hungary	S_{11}	-0.52	(0.24)	0.47	(0.25)
India	S_{12}	0.87	(0.24)	0.48	(0.25)
Iran	S_{13}	-3.79	(0.26)	-4.64	(0.33)
Italy	S_{14}	3.21	(0.24)	4.77	(0.25)
Japan	S_{15}	4.87	(0.24)	6.70	(0.25)
Kenya	S_{16}	-3.14	(0.25)	-5.30	(0.38)
Korea	S_{17}	2.38	(0.24)	2.96	(0.25)
Malawi	S_{18}	-6.25	(0.30)	-5.83	(0.39)
Mauritius	S_{19}	-4.61	(0.27)	-3.63	(0.30)
Morocco	S_{20}	-2.27	(0.25)	-5.54	(0.38)
New Zealand	S_{21}	0.70	(0.26)	-0.27	(0.28)
Nigeria	S_{22}	-6.75	(0.33)	-6.80	(0.51)
Norway	S_{23}	0.83	(0.24)	1.40	(0.25)
Pakistan	S_{24}	0.03	(0.24)	-1.16	(0.25)
Philippines	S_{25}	-0.90	(0.25)	-1.79	(0.27)
Portugal	S_{26}	-0.05	(0.24)	-0.15	(0.25)
Spain	S_{27}	1.66	(0.24)	2.53	(0.25)
Sri Lanka	S_{28}	-2.55	(0.24)	-2.88	(0.28)
Sweden	S_{29}	2.20	(0.24)	3.86	(0.25)
Turkey	S_{30}	-1.44	(0.24)	-2.36	(0.27)
United Kingdom	S_{31}	3.55	(0.24)	5.02	(0.25)
United States	S_{32}	4.78	(0.25)	6.50	(0.26)
Yugoslavia	S_{33}	-0.24	(0.24)	0.17	(0.25)
Zimbabwe	S_{34}	-2.54	(0.25)	-4.66	(0.34)

This table is a continuation of Table 5, showing only the parameters related to exporter competitiveness. The parameters are normalized so that $\sum_{i=1}^{34} S_i = 0$. Standard errors are in parentheses.

Table 7: Bilateral Trade Equation, Importer Barriers

Variable		Manufactures		Equipment	
		est.	s.e.	est.	s.e.
Australia	$-\theta m_1$	2.23	(0.40)	2.48	(0.42)
Austria	$-\theta m_2$	1.43	(0.36)	2.57	(0.38)
Bangladesh	$-\theta m_3$	-0.15	(0.35)	-2.99	(0.44)
Canada	$-\theta m_4$	2.35	(0.37)	3.23	(0.39)
Denmark	$-\theta m_5$	2.63	(0.36)	4.52	(0.39)
Egypt	$-\theta m_6$	-3.37	(0.36)	-6.65	(0.52)
Finland	$-\theta m_7$	0.52	(0.35)	1.15	(0.38)
France	$-\theta m_8$	3.40	(0.35)	3.73	(0.37)
Germany	$-\theta m_9$	4.66	(0.36)	5.20	(0.37)
Greece	$-\theta m_{10}$	-0.63	(0.36)	-2.29	(0.41)
Hungary	$-\theta m_{11}$	-1.61	(0.36)	-1.54	(0.40)
India	$-\theta m_{12}$	0.17	(0.36)	-1.34	(0.38)
Iran	$-\theta m_{13}$	-3.42	(0.39)	-4.96	(0.46)
Italy	$-\theta m_{14}$	3.80	(0.36)	4.68	(0.38)
Japan	$-\theta m_{15}$	4.01	(0.35)	3.40	(0.37)
Kenya	$-\theta m_{16}$	-3.18	(0.36)	-4.11	(0.47)
Korea	$-\theta m_{17}$	1.49	(0.35)	1.73	(0.37)
Malawi	$-\theta m_{18}$	-5.35	(0.41)	-0.47	(0.50)
Mauritius	$-\theta m_{19}$	-3.63	(0.39)	-1.95	(0.45)
Morocco	$-\theta m_{20}$	-3.17	(0.36)	-5.73	(0.48)
New Zealand	$-\theta m_{21}$	1.15	(0.42)	-0.08	(0.45)
Nigeria	$-\theta m_{22}$	-7.43	(0.43)	-6.08	(0.59)
Norway	$-\theta m_{23}$	1.09	(0.35)	-0.04	(0.38)
Pakistan	$-\theta m_{24}$	0.61	(0.35)	-0.34	(0.38)
Philippines	$-\theta m_{25}$	-1.66	(0.38)	-1.38	(0.42)
Portugal	$-\theta m_{26}$	-0.35	(0.35)	0.09	(0.38)
Spain	$-\theta m_{27}$	1.03	(0.35)	1.36	(0.37)
Sri Lanka	$-\theta m_{28}$	-1.46	(0.36)	0.35	(0.41)
Sweden	$-\theta m_{29}$	2.62	(0.35)	4.98	(0.38)
Turkey	$-\theta m_{30}$	-1.83	(0.36)	-3.32	(0.40)
United Kingdom	$-\theta m_{31}$	4.26	(0.36)	5.10	(0.37)
United States	$-\theta m_{32}$	4.70	(0.37)	5.15	(0.39)
Yugoslavia	$-\theta m_{33}$	-1.86	(0.36)	-2.41	(0.40)
Zimbabwe	$-\theta m_{34}$	-3.04	(0.37)	-4.04	(0.46)

This table is a continuation of Table 5 (and Table 6), showing only the parameters related to importer barriers. The parameters are normalized so that $\sum_{n=1}^{34} m_n = 0$. Standard errors are in parentheses.

Table 8: Equipment Prices

#	Country	The Price of Equipment		
		ICP Price measure (U.S. = 1)	Trade-based price measure (U.S. = 1)	Counterfactual under no trade in equipment
1	Australia	0.81	1.63	1.81
2	Austria	0.80	1.36	1.52
3	Bangladesh	0.48	3.32	4.06
4	Canada	1.10	1.24	1.40
5	Denmark	0.86	1.15	1.56
6	Egypt	1.21	4.46	5.06
7	Finland	0.91	1.61	1.78
8	France	0.89	1.13	1.20
9	Germany	0.87	0.99	1.04
10	Greece	0.82	2.55	2.93
11	Hungary	0.53	2.03	2.23
12	India	0.96	2.07	2.14
13	Iran	1.43	3.64	3.92
14	Italy	0.82	1.11	1.22
15	Japan	1.09	0.99	1.00
16	Kenya	0.77	3.69	4.12
17	Korea	0.73	1.47	1.59
18	Malawi	0.61	2.49	4.54
19	Mauritius	0.46	2.91	3.74
20	Morocco	0.75	3.88	4.41
21	New Zealand	1.03	2.14	2.38
22	Nigeria	1.33	4.42	5.17
23	Norway	1.09	1.78	1.93
24	Pakistan	0.63	2.33	2.65
25	Philippines	0.33	2.45	2.86
26	Portugal	0.84	1.95	2.30
27	Spain	0.83	1.55	1.67
28	Sri Lanka	0.79	2.29	3.22
29	Sweden	0.87	1.09	1.33
30	Turkey	0.29	2.78	3.05
31	United Kingdom	0.81	0.99	1.06
32	United States	1.00	1.00	1.02
33	Yugoslavia	0.66	2.14	2.24
34	Zimbabwe	0.63	3.55	4.03

All prices refer to 1985. The ICP equipment price excludes transportation equipment. The price level under no trade in equipment is normalized relative to the U.S. price level in the second column.

Table 9: Productivity and the Relative Price of Equipment

Eqn. #	$\ln s/(P^K/P^C)$	$\ln s/(\hat{P}^K/P^C)$	$\ln s$	$\ln P^K$	$\ln \hat{P}^K$	$\ln P^C$	$\ln \hat{P}^K/P^C$	$\ln P^s/P^C$	R^2
	Variable associated with the estimated coefficient								
1	0.95								0.46
	(0.18)								
2		0.63							0.67
		(0.08)							
3			0.63	-0.36		1.24			0.68
			(0.23)	(0.31)		(0.18)			
4			0.31		-0.62	0.75			0.71
			(0.27)		(0.28)	(0.21)			
5							-0.69	-0.06	0.69
							(0.11)	(0.22)	

The dependent variable is the log of real GDP per capita in 1985, adjusted for years of schooling as described in the text. Each regression has 34 observation. A constant term is included in each regression, but its value is not shown. Standard errors are shown in parentheses. The ICP measure of equipment prices is denoted P^K and our trade-based measure $\hat{P}^K$.
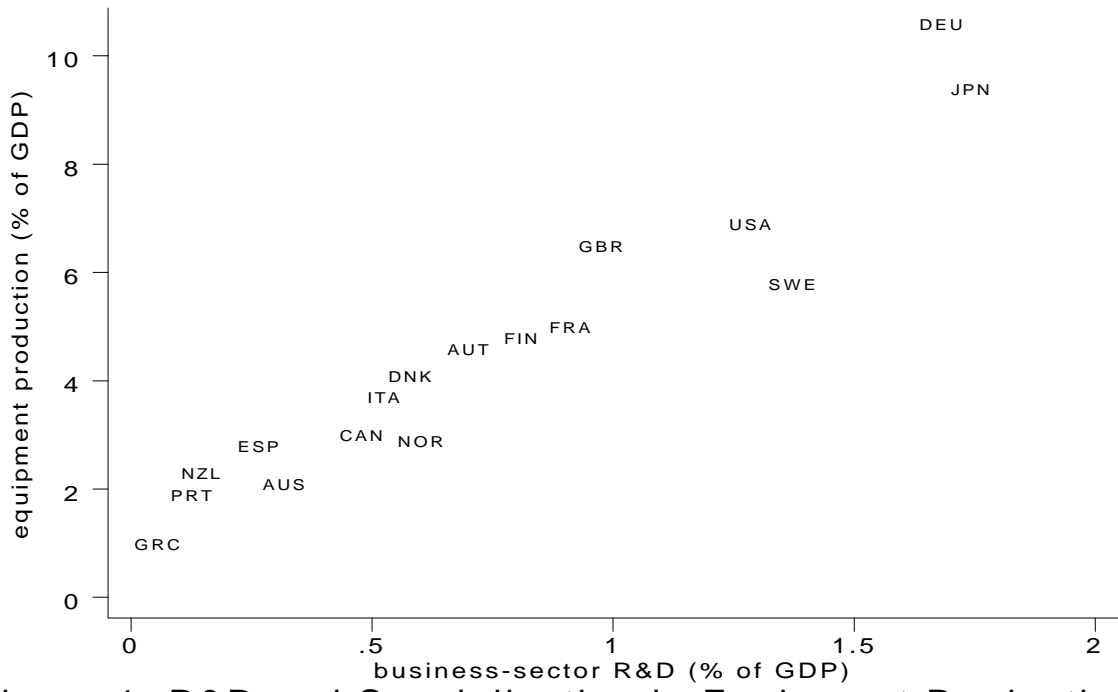
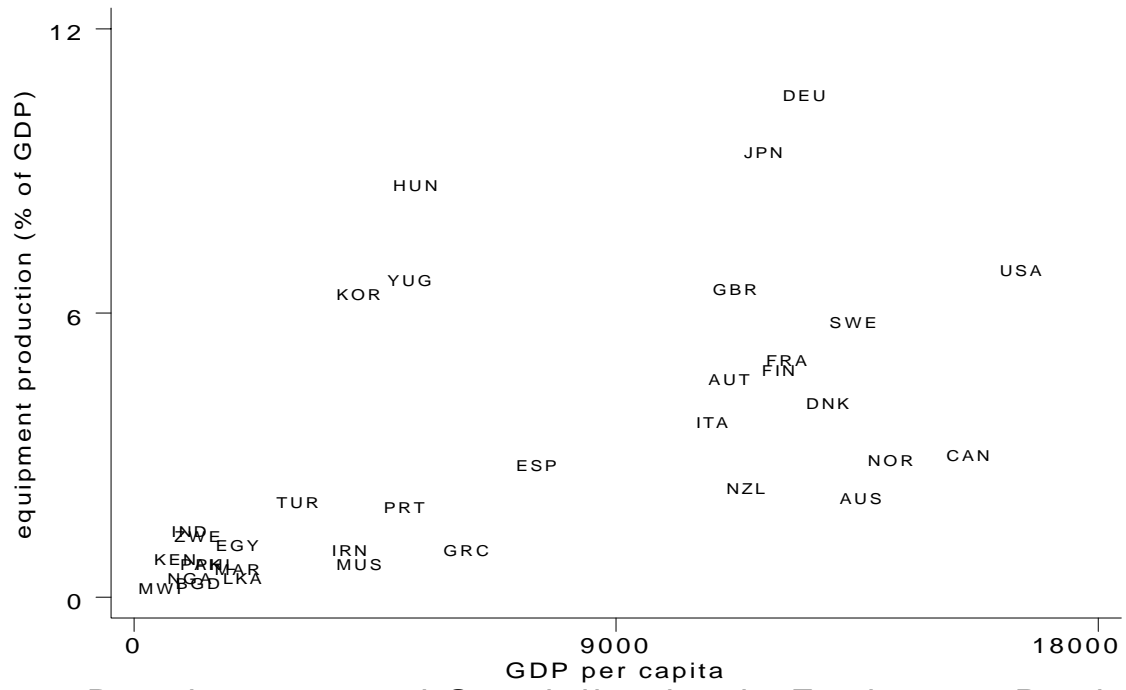Figure 1: R&D and Specialization in Equipment Production

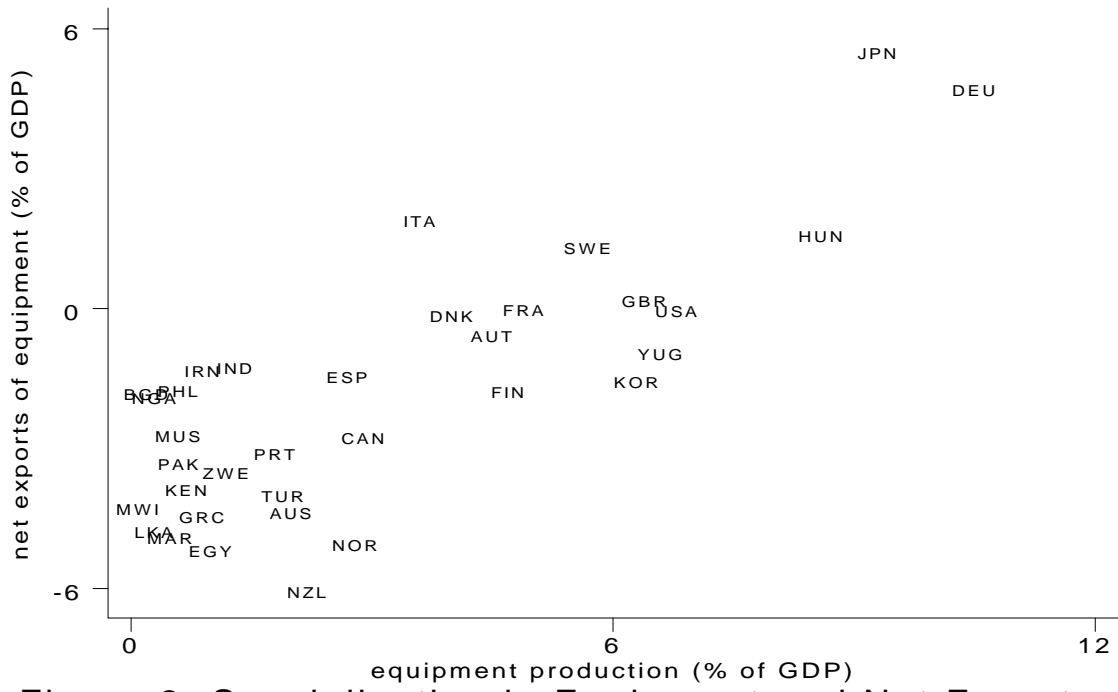Figure 2: Development and Specialization in Equipment Production

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net exports of equipment (% of GDP)

6

JPN
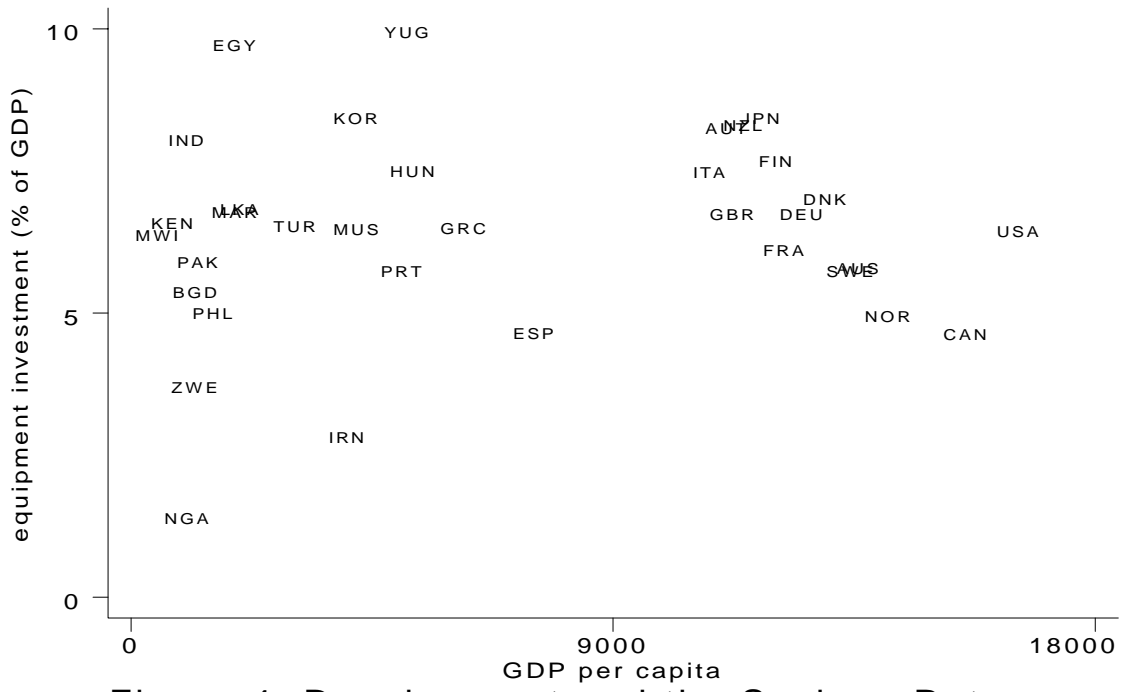DEU

ITA
HUN
SWE
GBR
0   DNK   FRA   USA
AUT
YUG
IRN ND
ESP   KOR
BGP HL
NGA FIN
MUS
CAN
PAK ZWE PRT
KEN
MWI GRC TUR
LKA AUS
MAR
EGY   NOR
-6
NZL

0   6   12

equipment production (% of GDP)

Figure 3: Specialization in Equipment and Net Exports

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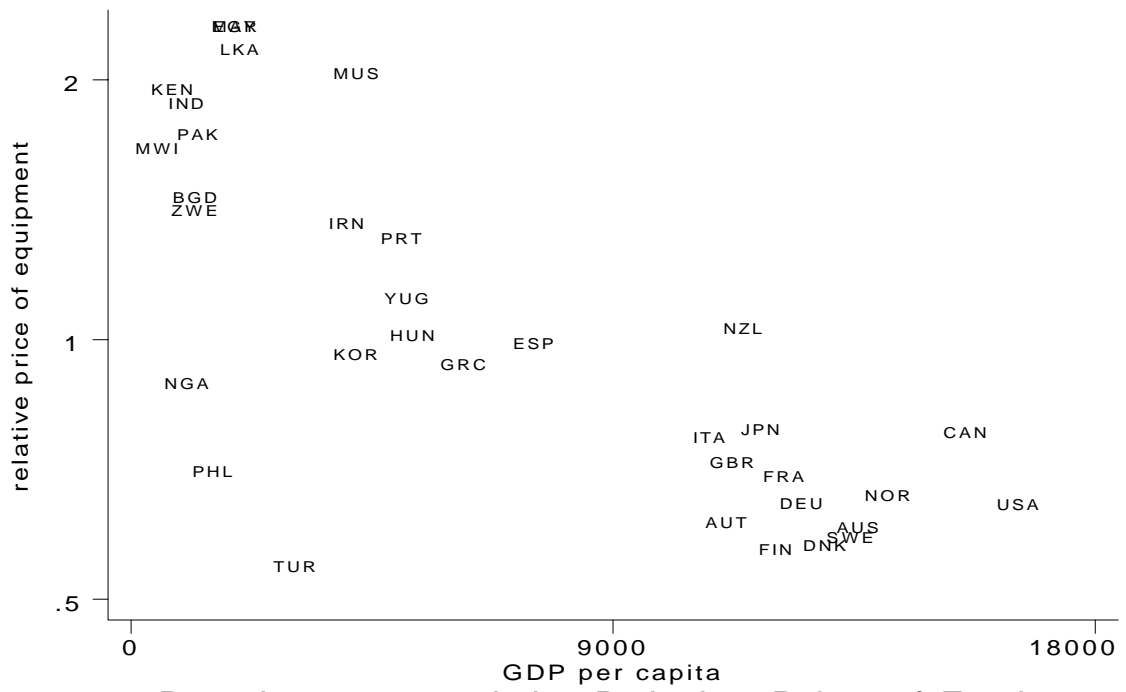
Figure 4: Development and the Savings Rate
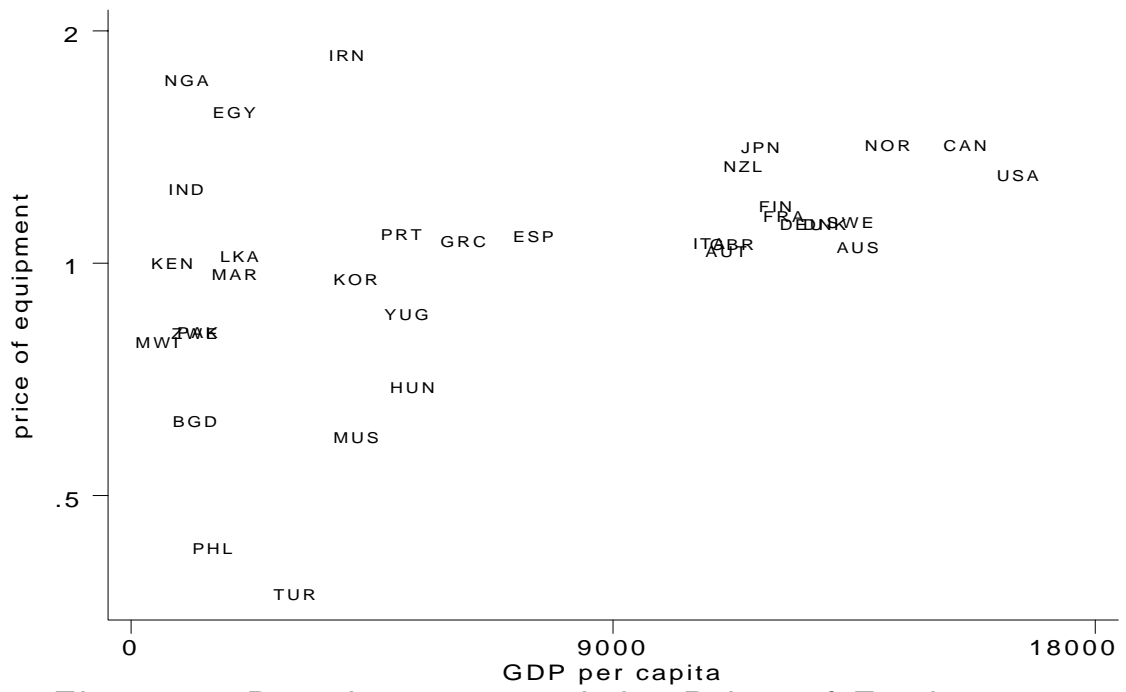
Figure 5: Development and the Relative Price of Equipment

Figure 6: Development and the Price of Equipment

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Figure 7: Equipment Prices as Predicted and from the ICP