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# Trade in capital goods

Jonathan Eaton[a,b], Samuel Kortum[a,b,*]

[a]Department of Economics, Boston University, 270 Bay State Road, Boston, MA 02215, USA
[b]NBER, Cambridge, MA, USA

**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% 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. © 2001 Elsevier Science B.V. All rights reserved.

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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 Fig. 1 shows, the

* Corresponding author. Tel.: + 1-617-353-4822.
*E-mail addresses:* jeaton@bu.edu (J. Eaton), kortum@bu.edu (S. Kortum).


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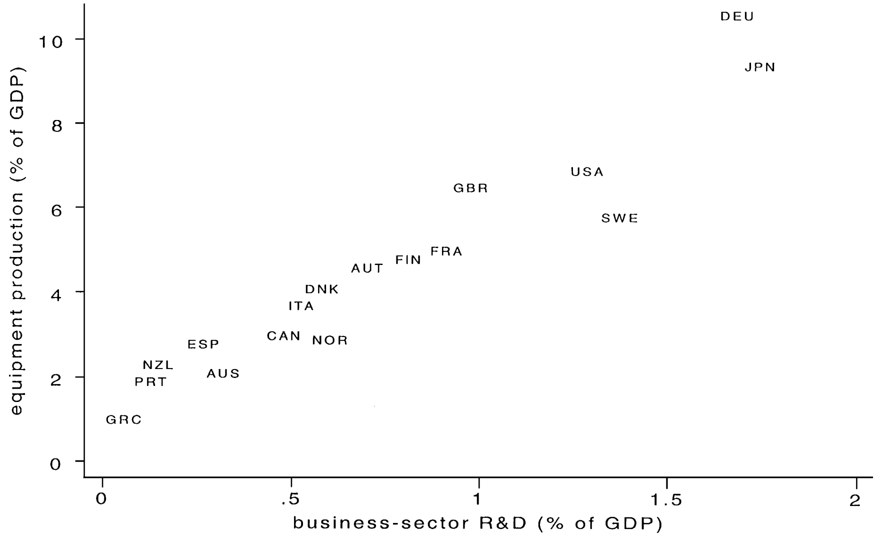


Fig. 1. R&D and specialization in equipment production.

*Note*: See Table 1 for country codes.

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 et al. (1992). As pointed out by De Long and Summers (1991), Jones (1994), and Restuccia and Urrutia (2000), however, cross-country differences in real rates

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

[2] Smith (1974) provides a theoretical model of trade in vintage capital. Hulten (1992), Greenwood et al. (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.

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 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 et al. (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 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.

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

[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.

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% of productivity differences between developing and developed countries. We attribute a bit less than half of this 25% 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 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 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 these trade-based equipment prices, compare them with 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

[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% of total factor productivity growth to new technology embodied in capital equipment, while Hulten (1992) comes up with a more modest 20%, closer to our finding in the cross-country dimension.

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 Appendix A.

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% in Malawi to a high of 10.5% in Germany. Fig. 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 to do with income and relates much more to R&D as a percent of GDP, as shown in Fig. 1.

Turning to international trade in equipment, Fig. 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

[7] As we discuss in Appendix A, 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% 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-1990s, may soon be available.

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

Table 1
Production of manufactures and equipment[a]

| No. | Country | Code | Population (1000s) | GDP per capita (intl. $'s) | Manufacturing production (% of GDP) | Equipment production (% of GDP) |
|---|---|---|---|---|---|---|
| 1 | Australia | AUS | 15,758 | 13,583 | 16.8 | 2.0 |
| 2 | Austria | AUT | 7555 | 11,131 | 20.3 | 4.5 |
| 3 | Bangladesh | BGD | 97,100 | 1216 | 4.9 | 0.2 |
| 4 | Canada | CAN | 25,165 | 15,589 | 21.6 | 2.9 |
| 5 | Denmark | DNK | 5114 | 12,969 | 18.1 | 4.0 |
| 6 | Egypt | EGY | 46,511 | 1953 | 10.4 | 1.0 |
| 7 | Finland | FIN | 4902 | 12,051 | 25.1 | 4.7 |
| 8 | France | FRA | 55,170 | 12,206 | 22.5 | 4.9 |
| 9 | Germany | DEU | 61,058 | 12,535 | 35.7 | 10.5 |
| 10 | Greece | GRC | 9934 | 6224 | 14.2 | 0.9 |
| 11 | Hungary | HUN | 10,657 | 5278 | 28.4 | 8.6 |
| 12 | India | IND | 765,147 | 1050 | 7.2 | 1.3 |
| 13 | Iran | IRN | 46,374 | 4043 | 7.0 | 0.9 |
| 14 | Italy | ITA | 57,141 | 10,808 | 15.3 | 3.6 |
| 15 | Japan | JPN | 120,754 | 11,771 | 31.1 | 9.3 |
| 16 | Kenya | KEN | 20,241 | 794 | 11.3 | 0.7 |
| 17 | Korea | KOR | 40,806 | 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 | 22,061 | 1956 | 9.8 | 0.5 |
| 21 | New Zealand | NZL | 3272 | 11,443 | 21.0 | 2.2 |
| 22 | Nigeria | NGA | 83,196 | 1062 | 8.5 | 0.3 |
| 23 | Norway | NOR | 4153 | 14,144 | 13.2 | 2.8 |
| 24 | Pakistan | PAK | 96,180 | 1262 | 10.6 | 0.6 |
| 25 | Philippines | PHL | 54,700 | 1542 | 10.4 | 0.6 |
| 26 | Portugal | PRT | 10,157 | 5070 | 18.9 | 1.8 |
| 27 | Spain | ESP | 38,574 | 7536 | 20.2 | 2.7 |
| 28 | Sri Lanka | LKA | 15,837 | 2045 | 11.0 | 0.3 |
| 29 | Sweden | SWE | 8350 | 13,451 | 24.4 | 5.7 |
| 30 | Turkey | TUR | 50,306 | 3077 | 19.7 | 1.9 |
| 31 | United Kingdom | GBR | 56,618 | 11,237 | 27.4 | 6.4 |
| 32 | United States | USA | 239,279 | 16,570 | 25.2 | 6.8 |
| 33 | Yugoslavia | YUG | 23,124 | 5172 | 36.5 | 6.6 |
| 34 | Zimbabwe | ZWE | 8406 | 1216 | 25.4 | 1.2 |

[a]All data are for 1985. Population and GDP per capita in international $'s (rgdpch) are from Summers and Heston (1991). The share of 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 were 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).

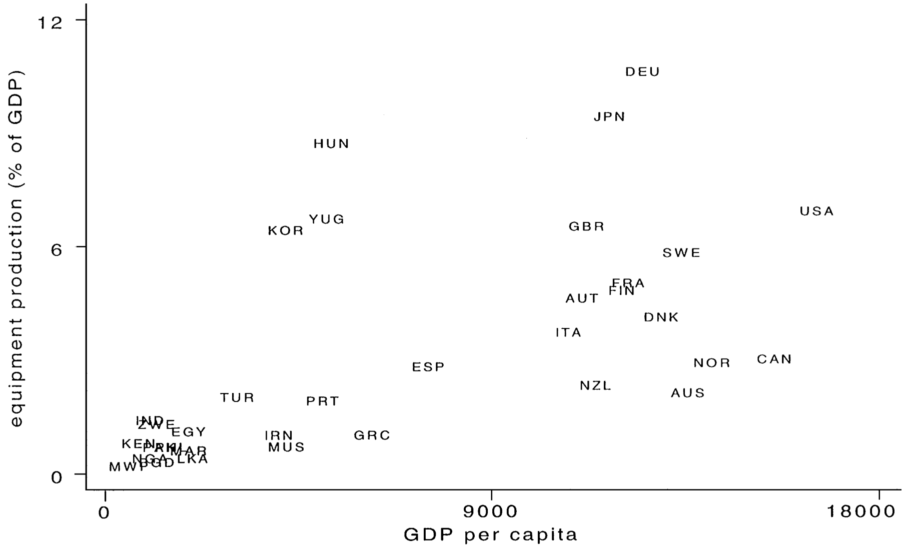


Fig. 2. Development and specialization in equipment production.

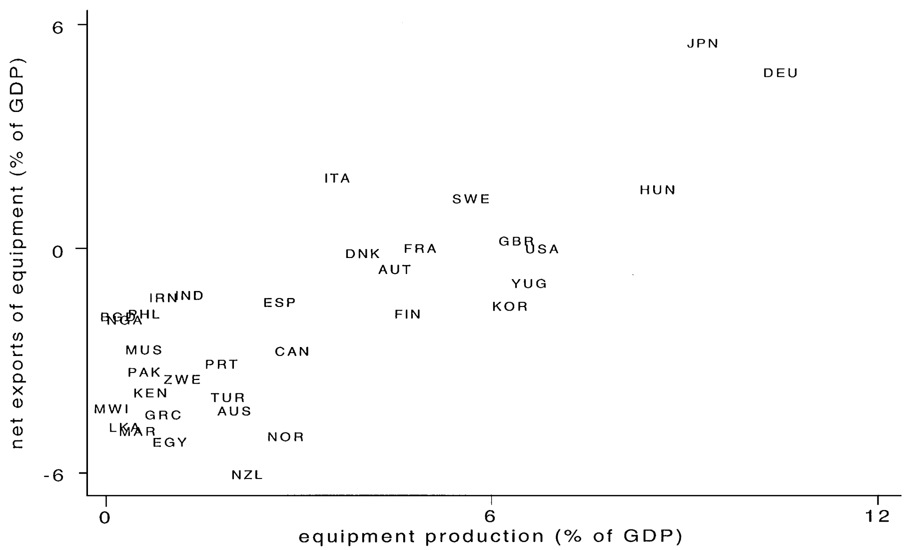


Fig. 3. Specialization in equipment and net exports.

Table 2
Trade in manufactures and equipment[a]

| No. | 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 |

[a]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).

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, 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 Fig. 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 Fig. 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 Fig. 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 the relative price of equipment over time documented by Gordon (1990).

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[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.

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

Table 3
Sources of equipment purchases[a]

| Importing country | Source of equipment purchases (% of absorption) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Home | US | Japan | Germany | UK | 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 |
| UK | 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 |
| US | 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 |

[a] 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[a]

| No. | 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 |

[a]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.

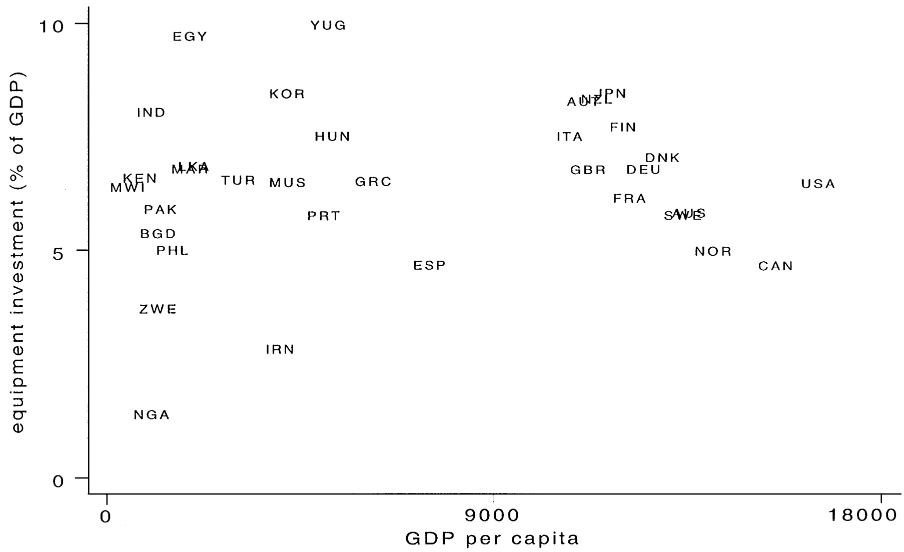


Fig. 4. Development and the savings rate.

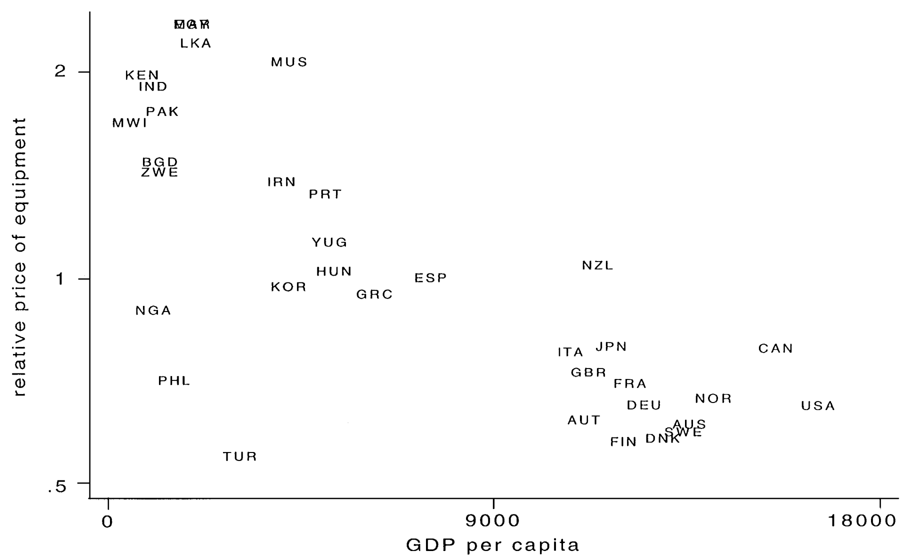


Fig. 5. Development and the relative price of equipment.

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

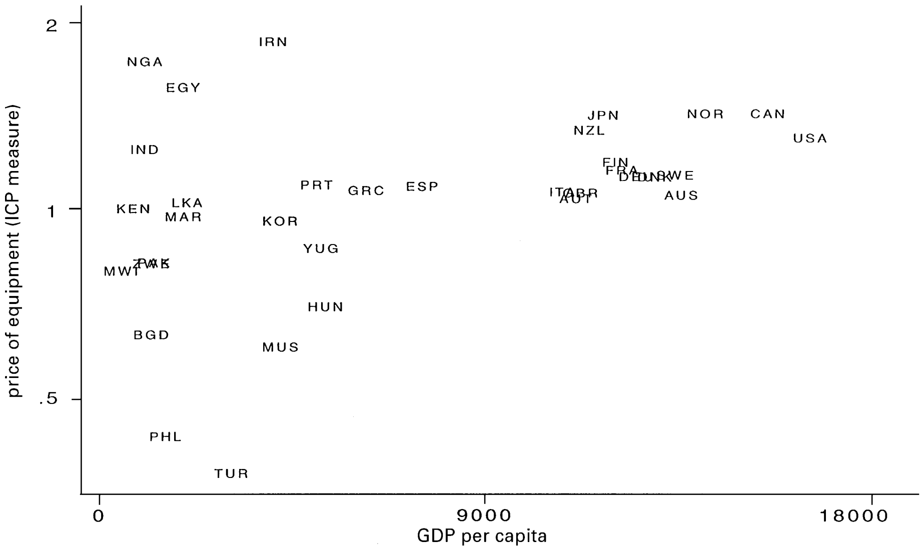


Fig. 6. Development and the price of equipment.

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 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 (Fig. 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.

[14] The *variability* across countries in the price of equipment is certainly consistent with the existence of large trade costs. Heston et al. (1995) examine this variability in ICP prices in more detail. In particular, 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.

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.
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 $i = \mathrm{N, S}$ (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 $A_\mathrm{N} > A_\mathrm{S}$. (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 $i = \mathrm{N, S}$. (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 no strong evidence to the contrary, we make the simplifying assumption that $F$ is common across sectors and countries. Appendix A 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, $P_{\mathrm{S}}^{C} = 1$. Since the North imports $C$ from the South, its price on arrival is $P_{\mathrm{N}}^{C} = d^{C}$. Since the North is incompletely specialized and the capital good is produced in quantity $A_{\mathrm{N}}$ using the same bundle of inputs that would produce a unit of $C$, it follows that $P_{\mathrm{N}}^{K} = P_{\mathrm{N}}^{C}/A_{\mathrm{N}} = d^{C}/A_{\mathrm{N}}$. Since the South imports the capital good, $P_{\mathrm{S}}^{K} = d^{K}P_{\mathrm{N}}^{K} = d^{K}d^{C}/A_{\mathrm{N}}$. Hence in combination the two trade frictions leave the South facing a higher relative price of equipment.[16]

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

$$Y_{\mathrm{S}} = F(K_{\mathrm{S}}, L_{\mathrm{S}}) = L_{\mathrm{S}} f(k_{\mathrm{S}}),$$

---

[15] As we show in Appendix A 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 explanation (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 $A_{\mathrm{S}}/A_{\mathrm{N}}$. 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.

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 GDPs 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 measure plotted in Fig. 6 is 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 country (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).

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 $\delta$ 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

[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 as to why, in the context of a model like ours, the proper deflator is simply the price of the consumption good.

$P^K_{it}/P^C_i$ 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 $\alpha$ is capital's share), $g_y = \alpha(g_y + g)$ or $g_y = [\alpha/(1-\alpha)]g$.

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

$$\dot{k}_{it} = s_i \frac{P^C_i}{P^K_{it}} k^\alpha_{it} - \delta k_{it}.$$

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

$$y_{it} = \left(\frac{s_i}{(\delta + g/(1-\alpha))(P^K_{it}/P^C_i)}\right)^{\alpha/(1-\alpha)}. \tag{1}$$

Since the relative price of capital $P^K_{it}/P^C_i$ is higher in the South by a factor of $d^C d^K$, its income is lower by a factor of $(d^C d^K)^{\alpha/(1-\alpha)}$ given equal savings rates $s$. In both the North and the South the relative price of capital $P^K_{it}/P^C_i$ 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 $\rho_i$ 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:

$$s_i = \frac{P^K_{it} I_{it}}{Y_{it}} = \frac{\alpha(\delta + (g/(1-\alpha)))}{\rho_i + \delta + (g/(1-\alpha))}.$$

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

[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, $P^K_S = d^C d^K/A_N$. 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 $d^K s_S Y_S/P^K_S$ (including export costs) and to supply the North is $s_N Y_N/P^K_N$. If the North devoted all its resources to capital goods production it would make $A_N L_N k^\alpha_N$ 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.

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]

Eq. (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]

## 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 $K_t(j)$,

[19] Mankiw et al. (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, 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).

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:

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

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 $i \in \{1, \ldots, N\}$ provides capital of type $j$ with quality $z_{it}(j)$ at a production 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, $z_{it}(j)$, we need to keep track only of the moments of the distribution from which they are drawn.

[21] In Bernard et al. (2000), we show how the approach generalizes quite simply to allow for imperfect competition.

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

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

The minimum cost across all possible sources $i$ is consequently drawn from

$$\Pr[p^K_{nt} \le p] = 1 - \exp(-\Phi_{nt}p^{\theta}),$$

where

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

As we show next, the parameter $\Phi_{nt}$ 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

$$P^K_{nt} = \gamma\Phi_{nt}^{-1/\theta}, \qquad (2)$$

where $\gamma$ 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 $\Phi_{nt}$. (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 $P^K_{nt}$ 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 goods, so that in the end the costs of their goods have the same distributions as any others.) This result allows us to equate

[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 $\gamma$, the elasticity of substitution $\sigma$ can be ignored in what follows.

$\pi_{ni}$ 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 consumption good as given, we can still apply Eq. (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:

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

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 Eqs. (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 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 $\Phi_i/\Phi_N$. 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 $\theta$.

[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 et al. (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.

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 Eq. (4). Next we show how the parameter estimates, when substituted into Eq. (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 Eq. (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 Eq. (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 $k$th interval, $b$ is the effect of $n$ and $i$ sharing a border, $l$ is the effect of $n$ and $i$ sharing a language, and $m_n$ ($n = 1, \ldots, 34$) is an overall destination effect. The error term $\delta_{ni}$ 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 $\delta_{ni}$ is orthogonal to the other regressors (source country dummies and the proxies for geographic barriers listed above).[24]

Imposing this specification of geographic barriers, Eq. (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 Eq. (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 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 $\lambda_n$. Since we do not observe $\lambda_n$ directly, we use the maximum likelihood estimator, $\hat{\lambda}_n = \min_i\{x_{ni}^{K}\}$, where for each importer $n$ the minimum is taken over all sources $i$ appearing in the data.

Tables 5–7 show the results of the Tobit estimation of Eq. (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, 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 larger 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 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.

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

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

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

Table 5
Bilateral trade equation, gravity parameters[a]

| 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 | |

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

The World Bank (1999) provides a measure $\tau_n$ of the average ad valorem duty across all tariff lines for manufactured products (World Bank, 1999).[27] A tariff $\tau_n$ on equipment imports should raise $\theta m_n$ 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 $\theta$ of 9.2 with a standard error of 3.1 (the $R^2$ of the regression is 0.25). This estimate of $\theta$ 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%.[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.

[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 1980s and early 1990s (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).

Table 6
Bilateral trade equation, exporter competitiveness[a]

| 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) |

[a]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.

### 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 $\hat{S}_i$ and of geographic barriers $\widehat{\theta m_n} + \widehat{\theta d_k} + \widehat{\theta b} + \widehat{\theta l}$

Table 7
Bilateral trade equation, importer barriers[a]

| 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) |

[a]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.

into the right-hand side of Eq. (11) yields the log of our trade-based measure of equipment prices, up to the unknown parameter $\theta$:

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

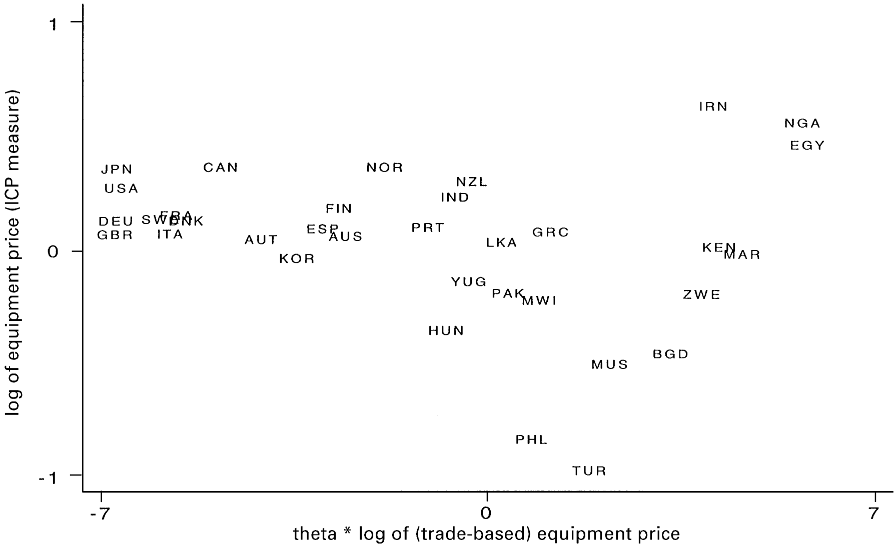


Fig. 7. Equipment prices as predicted and from the ICP.

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

Fig. 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 Eq. (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.

[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.

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 the finding of Navaretti et al. (2000) 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 be substantial.[32]

To extract a properly scaled trade-based price measure from (11) we need to take a stand on $\theta$. We set $\theta = 8.3$ as estimated in Eaton and Kortum (2000). Using this value of $\theta$, 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 US 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 Fig. 7 is about 8 times the range of variation along the vertical axis). More significantly, however, our measure, unlike the ICPs, 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 $\pi_{ni}$ is never more than 28% (the share of France in Morocco's absorption of equipment). Using this large value for $\pi_{ni}$ we find that the price of capital would rise by only 4% 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

[31] This explanation parallels developments in measures of US 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% annually since 1950.

[32] See Navaretti et al. (2000) and Mayer (2000).

Table 8
Equipment prices[a]

| No. | Country | The price of equipment | | |
|---|---|---|---|---|
| | | ICP price measure (US = 1) | Trade-based price measure (US = 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 |

[a] 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 US price level in the second column.

equipment price levels. For most countries the rise is modest, although it can go as high as 80%.[33]

*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. Eq. (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 the 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 $\varepsilon_n$. In terms of (schooling-adjusted) output per capita $y_n^*$, Eq. (12) becomes

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

[33] In Malawi, which is particularly dependent on imports, we find that autarky would force prices to rise over 80%. 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 US level) suffers only an 8% 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% rise in prices if imports were cut off, but even so, its prices would be only 30% higher than those in the United States.

[34] Following Bils and Klenow (1998), we divide GDP per capita by $e^{0.09H_i}$ 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 are from Barro and Lee (1993) with missing values filled in for Egypt, Morocco, and Nigeria using data from Kyriacou (1991).

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 $s_n$ 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 Eq. (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 $\alpha_e$ and $\alpha_s$ 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 $\eta$ is a complicated constant.[36] (Implicit in the derivation are the assumptions that the savings rate is constant across countries and that the price of structures,

[35] The similarity of these coefficients also lends some support to our choice of $\theta = 8.3$. Had we used a value of $\theta$ 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.

[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 $\kappa^s = \alpha_s/[\rho + \delta^s + \alpha_s g/(1-\alpha)]$.

Table 9
Productivity and the relative price of equipment[a]

| Eq. no. | Variable associated with the estimated coefficient | | | | | | | | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| | $\ln s/(P^K/P^C)$ | $\ln s/(\hat{P}^K/P^C)$ | $\ln s$ | $\ln P^K$ | $\ln \hat{P}^K$ | $\ln P^C$ | $\ln \hat{P}^K/P^C$ | $\ln P^s/P^C$ | |
| (1) | 0.95 (0.18) | | | | | | | | 0.46 |
| (2) | | 0.63 (0.08) | | | | | | | 0.67 |
| (3) | | | 0.63 (0.23) | − 0.36 (0.31) | | 1.24 (0.18) | | | 0.68 |
| (4) | | | 0.31 (0.27) | | − 0.62 (0.28) | 0.75 (0.21) | | | 0.71 |
| (5) | | | | | | | − 0.69 (0.11) | − 0.06 (0.22) | 0.69 |

[a]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 $\hat{P}^K$.

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 Eq. (14) using ICP data on the relative price of capital structures and our trade-based 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 trade-based 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 $\varepsilon$ and the relative price of equipment. It is quite likely that countries where equipment is cheap are also more productive for other reasons. 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 Eq. (14). We then use the equation to account for differences in productivity levels. (Based on the results above, we ignore variation 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 $\Omega_S$ (Malawi, Kenya, India, Philippines, Nigeria, Zimbabwe, Bangladesh, Pakistan, Egypt, and Sri Lanka). Similarly, we denote the set of 10 high-productivity countries by $\Omega_N$ (Australia, Japan, Norway, United States, Sweden, Germany, Austria, Canada, Italy, and France). Our accounting is then based on

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

where $\varepsilon$ 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% 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 $-3\%$ of the productivity differences. With our trade-based measure we can explain 12%, 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% of the difference in productivity.

How big is 26%? A basis for comparison is the contribution of the declining relative price of equipment over time to US productivity growth. While, as discussed above, Greenwood et al., attribute almost 60% of US productivity growth to falling equipment prices, Hulten (1992) puts the number at 20%. 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.

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## Appendix A

The data set 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.

Uses of manufacturing output

| 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 vs. other manufactures. To get at labor intensity we report labor compensation as a percentage of value added. To get at skill intensity (following Berman et al., 1998) we report the percentage of nonproduction workers in employment. We focus on the main equipment-producing countries (France and Italy do not provide data on employment of production vs. nonproduction workers). Equipment-producing industries appear to be labor- and skill intensive relative to other manufacturing industries.

Contributors to the production of investment goods

| Country | Labor compensation in value added (%) | | Nonproduction 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 30–60 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 output 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 US Dollars. We use the exchange rate implicit in the UNIDO data (which is available in both the local currency and in US 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 UN indicated that they always use the rf series in converting the trade data into US Dollars. Thus, to be consistent with the trade data, we chose to convert Iran's production into US 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 Fig. 1, we plot R&D performed and financed by the business sector. Using R&D data for 1981 and 1989 from OECD (1995), 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).

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