# Capital Imports Composition, Complementarities, and the Skill Premium in Developing Countries*

## JOB MARKET PAPER

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**Abstract**

We study how the composition of capital imports affects relative demand for skill and the skill premium in a sample of developing economies. Capital imports *per se* do not affect the skill premium; their *composition* does. While imports of R&D-intensive capital equipment raise the skill premium, imports of less innovative equipment lower the skill premium. We estimate that R&D-intensive capital is complementary to skilled workers, whereas less innovative capital equipment is complementary to unskilled labor—which explains the composition effect. This mechanism has substantial explanatory power. We document larger tariff cuts and smaller distance-related import costs for R&D-intensive capital equipment versus less innovative equipment, implying that on average trade liberalization increases inequality through the composition channel.

JEL classifications: F14, F16, J23, J24, J31

Keywords: Capital imports, capital-skill complementarity, skill premium, trade liberalization

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# 1 Introduction

The concurrent rise in trade flows and increase in the skill premium in developing countries is one of the most striking economic phenomena of the 1980s and 1990s (Goldberg and Pavcnik (2007)), and has prompted many economists to ask: Is there a causal relationship between the two? And if so, what is the mechanism? The failure of standard Heckscher-Ohlin theory to explain distributional changes across skill groups in developing countries has shifted focus to either more nuanced forms of competition in the final goods space, or to other channels through which globalization may affect factor prices.[1] [2]

In this paper we empirically study a new channel: Variation in the composition of capital imports.[3] While other papers highlight the role of capital imports under the assumption of capital-skill complementarity (Griliches (1969)) within structural quantitative trade models (e.g., Burstein, Cravino, and Vogel (2013), Parro (2013)), this paper is the first to test the mechanism directly in a sample of developing countries. We find that capital imports *per se* do not affect the skill premium; rather, it is the *composition* of capital imports that matters. While imports of R&D-intensive capital equipment raise the skill premium, imports of less innovative capital equipment actually lower the skill premium. As Figure 1 illustrates, a high ratio of R&D-intensive capital relative to less innovative capital imports (henceforth, the capital import ratio) is associated with larger increases in the skill premium, while the overall level of capital imports does not matter (Panel B). This is the first contribution of this paper. We then investigate why this is the case.

We find that only R&D-intensive capital equipment is complementary to skilled labor; in contrast, we find that less innovative capital equipment is complementary to unskilled labor. To our best knowledge, we are the first to empirically document that some types of capital are more complementary to unskilled workers. Acemoglu (2002) suggests an explanation for why this is the case: An increase in the supply of skilled labor in industrial economies (which occurred during the same period that we study) "directs" more innovation and resources (read: R&D expenditures) towards developing skill-complementary machines, and relatively less towards machines that are

[1] See Feenstra and Hanson (1996), Zhu and Trefler (2005), Yeaple (2005), Zeira (2007), Verhoogen (2008), Bustos (2011), Burstein and Vogel (2012), Harrigan and Reshef (2012), and Bonfatti and Ghatak (2013). Harrison, McLaren, and McMillan (2011) provide a recent survey.

[2] The failure to detect Stolper-Samuelson effects in skill abundant countries, let alone in unskilled abundant countries, together with scant evidence of industry reallocations due to trade liberalization, have prompted many researchers to abandon the trade explanation altogether and focus on technological explanations, for example Berman, Bound, and Griliches (1994). However, see also Bernard and Jensen (1997) for evidence on trade-induced changes in demand for skill and reallocations across plants within industries.

[3] We look into capital equipment specifically. The use of the more general term 'capital' throughout the paper is made for convenience.

complementary to unskilled workers.[4]

In the model of Acemoglu (2003) "technology firms" in less developed countries copy blueprints of machines from developed countries (at some cost), produce them domestically, and sell to final goods producers. If the ability to successfully copy is not available or is not optimal, then importing machines from developed countries is another way to obtain the technology that they embody. Our work focuses on this channel of embodied technology diffusion. Indeed, developing countries import much of their equipment, which originates mostly in developed, skill abundant countries (Eaton and Kortum (2001)). Therefore we can treat capital imports as a good measure of investment in developing countries (Caselli and Wilson (2004)). We expect to see the skill premium rise when the composition of capital imports (investment) becomes more R&D intensive. This happens when the relative price of skill-complementary capital decreases, shifting imports towards R&D-intensive capital and hence increasing the capital import ratio. This, in turn, shifts the composition of the capital stock towards more skill-complementary capital. We find that this mechanism has substantial explanatory power for changes in the skill premium.

Finally, we ask *whether* trade liberalization increase the skill premium. The capital composition mechanism described above only tells us *how* trade liberalization *may* increase the skill premium. In this context, the question is whether trade liberalization shifted the distribution of capital imports towards more skill-complementary equipment. We provide some evidence that suggests this may have been the case. First, we show that tariffs on skill-complementary capital imports have dropped more than tariffs on unskilled-complementary equipment. Second, we show that (transportation) freight costs for skill-complementary capital are lower relative to unskilled-complementary equipment. The latter causes equal tariff reductions to have a larger effect on prices of skill-complementary capital imports. Estimates of gravity models support the findings on freight costs. Since tariffs have generally been falling, and more so for skill-complementary capital, both findings imply a decrease in the relative price of skill-complementary capital versus less innovative equipment, which increases the import ratio. Therefore, *on average,* trade liberalization increases inequality through the composition channel.

Our work contributes to three broad strands of literature: (1) Trade liberalization and changes in relative demand for skill; (2) Capital-skill complementarity; and (3) Computers and relative demand for skill. First, we provide empirical evidence for a new mechanism that links trade liberalization and relative factor demand in developing countries—through the composition of capital imports. In an important contribution, Caselli and Wilson (2004) document broad cross-country variation in the

[4] This is the "market size" effect of Acemoglu (2002). Similar ideas are investigated in Galor and Moav (2000), but the framework in Acemoglu (2002) is more closely related to ours. Both are reminiscent of historical accounts of innovation and demand for skill in Goldin and Katz (2008).

composition of capital imports by R&D intensity. They link this composition to differences in total factor productivity (TFP). Coe and Helpman (1995) and Acharya and Keller (2009) investigate the role of aggregate imports in facilitating R&D spillovers and technology transfers. None of these studies address changes in relative demand for skill. Burstein, Cravino, and Vogel (2013) and Parro (2013) assume that aggregate capital is complementary to skill, but do not test whether this is indeed the case.

More closely related to our work is Koren and Csillag (2012) who show how imports of machines increase the wages of workers whose occupations are particularly complementary to those machines. While their estimates focus on micro, within-worker effects in Hungary alone, we address relative demand shifts for the entire economy, in 20 developing countries. In addition, we show how R&D intensity is an indicator for complementarity with different types of workers, and hence an indicator for which workers gain in terms of wages when investments are made. Zhu and Trefler (2005) offer an elegant general equilibrium model and show how trade liberalization may increase demand for skill in developing countries through shifts in the composition of exports towards skill intensive goods. We exploit similar data in our analysis, but find that empirically their mechanism is orthogonal to ours. We also demonstrate that our mechanism has substantially stronger explanatory power for the skill premium.

We highlight the effects of trade liberalization through the input side of production. For example, Amiti and Konings (2007) study how greater access to inputs increases productivity, and Goldberg, Khandelwal, Pavcnik, and Topalova (2010) show how this may have an effect on product growth. Amiti and Davis (2012) find that trade liberalization increases wages at firms that import more intermediate inputs in Indonesia, and offer a fair-wage mechanism. Our work can help explain results in Amiti and Cameron (2012), who find that imports of intermediate inputs tend to lower skill premia within firms in Indonesia.[5] Amiti and Cameron (2012) do not study complementarities of intermediate inputs with skilled and unskilled labor, and their results are confined to firms that actually import. While our results pertain to the entire economy, we conjecture that similar forces (composition in conjunction with complementarities) drive their results. Saravia and Voigtländer (2012) argue that high quality intermediate inputs substitute for skilled workers, but that the quality gains at the firm output level increase returns to employing skilled workers. In contrast to all these studies, we focus on aggregate, economy-wide relative demand effects that are not confined to importing firms alone.

Second, we contribute to the literature on capital-skill complementarity. Since the seminal work of Griliches (1969) it has become standard to assume capital is complementary to skilled labor;

[5] Indonesia is not one of the countries in our sample.

indeed, several studies adopted this framework in order to address questions on economic growth, trade, and inequality.[6] However, most of this work uses an aggregate measure of capital; we show that complementarities vary at disaggregated levels. Our analysis reveals that it is the most innovative, R&D-intensive capital that is complementary to skilled workers, while other types of capital are in fact complementary to the unskilled. We also show that the magnitude of complementarity between the former two types and that between the two latter ones is approximately the same. These results are robust to different definitions of skill. These findings can help explain the lack of robustness in previous attempts to test the aggregate capital-skill complementarity hypothesis, e.g. Duffy, Papageorgiou, and Perez-Sebastian (2004): Differences in the composition of capital across countries may render the overall characterization of complementarity elusive.

Finally, our work is also related to the literature on computers and demand for skill. We find that the R&D-intensive, skill-complementary capital is, to a first approximation, mostly composed of information and communications technology (ICT) equipment. The work of Autor, Katz, and Krueger (1998), Bresnahan, Brynjolfsson, and Hitt (1999), and Autor, Levy, and Murnane (2003) all indicate that this type of equipment raises relative demand for skilled labor, although their empirical results focus on the U.S. Michaels, Natraj, and Van Reenen (2011) study the effect of ICT capital deepening on polarization of labor demand in developed countries; they find that ICT deepening reduces relative demand for medium-skilled workers, while increasing relative demand for high skill workers.[7] While we take advantage of similar distinctions between types of capital in some of our specifications, we investigate in greater detail the pattern of complementarities across more disaggregated types of capital, relate this pattern to R&D intensity, and find that other types of capital are actually complementary to unskilled labor, a new result. In addition, we apply our results to imports in developing countries.

After introducing the framework that underpins our analysis in Section 2, in Section 3 we document the strong effect of the composition of capital imports on the skill premium. In Section 4 we show that more R&D-intensive capital equipment is complementary to skilled labor, and that less innovative capital equipment is complementary to unskilled labor. Section 5 argues that trade liberalization increases inequality through the composition channel. Section 6 concludes.

[6] For example, Stokey (1996) and Krusell, Ohanian, Rios-Rull, and Violante (2000).

[7] For evidence on polarization and for the "routinization" hypothesis see Goos and Manning (2007) for the U.K., Autor, Katz, and Kearney (2006) for the U.S., and Goos, Manning, and Salomons (2009) for European and other developed countries.

## 2 Analytical framework

In this section we lay out a simple analytical framework to help organize the discussion. Since we are considering developing countries, we ignore the possibility to produce capital goods domestically, but allow them to import capital goods, whose prices are given internationally. We make an Armington assumption and let final goods be differentiated by country of production. We ignore balanced trade considerations, since these are not essential to the analysis here.

There are two types of capital—$C$ and $K$ (think computers and tractors, respectively)—and two types of labor—skilled $H$ and unskilled $L$. The aggregate production function for the economy is

$$Q = \left[\delta X^{\frac{\sigma-1}{\sigma}} + (1-\delta) Y^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} ,$$

where

$$\begin{aligned} X &= H^{\beta} C^{1-\beta} \\ Y &= L^{\beta} K^{1-\beta} , \end{aligned}$$

$\beta \in (0,1)$ and $\sigma > 1$. The critical assumption here is that each type of capital is more complementary to one type of labor than with the other: $C$ with $H$, and $K$ with $L$. Any production function that maintains this property will suffice. We devote Section 4 to justifying this assumption. Adopting a Cobb-Douglas framework in $X$ and $Y$ implies that the degree of complementarity between $C$ and $H$ is the same as that between $K$ and $L$; some of our estimates in Section 4 are consistent with this. Allowing $\beta$ to vary across $X$ and $Y$ unnecessarily complicates the discussion; our estimates in Section 3 are consistent with this assumption.[8] Estimates of the aggregate elasticity of substitution between $H$ and $L$ in the literature are typically above unity; this implies $\sigma > 1$.[9]

Workers supply labor—both $H$ or $L$— inelastically. Denote the wage of skilled labor by $w_H$ and the wage of unskilled labor by $w_L$. Denote the price of capital as $r_j$ for $j \in \{C, K\}$. We ignore depreciation rates, which do not affect our analysis unless they vary systematically over time—which is unlikely. Competitive factor markets imply that factors are paid the value of their marginal product.

[8] In Tables 3 and 4 the coefficients to different types of capital are very similar in absolute value. Acemoglu (2002) also makes this assumption to streamline his model.

[9] The elasticity of substitution between between $H$ and $L$ in the current framework is $\sigma/\left[\sigma - \beta(\sigma-1)\right]$. If this is greater than unity, then so is $\sigma$, given $\beta \in (0,1)$. For the U.S., Katz and Murphy (1992) estimate an aggregate elasticity of substitution between college and high-school graduates at 1.4. More recent estimates are reported by Heckman, Lochner, and Taber (1998) at 1.44, and Krusell, Ohanian, Rios-Rull, and Violante (2000) at 1.67. Despite estimating an elasticity of substitution in services at less than one, Reshef (2013) estimates an aggregate elasticity (that takes into account substitution across sectors, not just within) above one.

Some algebra (see Appendix) yields

$$\omega = \frac{\delta}{1-\delta}\left(\frac{H}{L}\right)^{-\frac{\sigma-\beta(\sigma-1)}{\sigma}}\left(\frac{C}{K}\right)^{\frac{(1-\beta)(\sigma-1)}{\sigma}} , \tag{1}$$

where $\omega \equiv w_H/w_L$. Holding constant $C/K$, greater skill abundance $H/L$ reduces the relative wage of skilled labor $\omega$. Holding constant $H/L$, a greater $C/K$ ratio also increases $\omega$ as long as $\sigma > 1$.[10] Equation (1) also shows that the overall quantity of capital $C+K$ is not important for determining $\omega$: Only the composition matters. A higher $C/K$ ratio is equivalent to a higher share of $C$ in total capital.

Taking logs of (1) we have

$$\ln\omega = \kappa - \alpha\ln\left(\frac{H}{L}\right) + \lambda\ln\left(\frac{C}{K}\right) , \tag{2}$$

where $\kappa = \ln\left(\frac{\delta}{1-\delta}\right)$, $\alpha = \frac{\sigma-\beta(\sigma-1)}{\sigma}$, and $\lambda = \frac{(1-\beta)(\sigma-1)}{\sigma}$. Now take differences of (2) to get

$$\Delta\ln\omega = -\alpha\Delta\ln\left(\frac{H}{L}\right) + \lambda\Delta\ln\left(\frac{C}{K}\right) . \tag{3}$$

Our empirical counterpart to (3) includes country fixed effects (e.g., due to variation in changes in industrial structure $\delta$) and other controls. We also include time effects to deal with common unobserved trends (e.g., disembodied technological change). We use imports of $C$ and $K$ as proxies for changes in stocks.

We use the framework to identify a valid instrument for $C/K$. Similar derivations to those that give (1) yield

$$\frac{C}{K} = \left(\frac{\delta}{1-\delta}\right)^{\frac{\sigma}{\sigma-(1-\beta)(\sigma-1)}}\left(\frac{H}{L}\right)^{\frac{\beta(\sigma-1)}{\sigma-(1-\beta)(\sigma-1)}}\left(\frac{r_C}{r_K}\right)^{-\frac{\sigma}{\sigma-(1-\beta)(\sigma-1)}} . \tag{4}$$

Higher relative prices $r_C/r_K$ lower relative demand $C/K$ (since $\sigma - (1-\beta)(\sigma-1) > 0$ always, as demonstrated in the Appendix). An increase in $H/L$ increases $C/K$ as long as $\sigma > 1$ (holding constant $r_C/r_K$).[11]

Equation (4) implies that relative capital prices $r_C/r_K$ can affect $\omega$ only through their effect on $C/K$. This means that $r_C/r_K$ is a valid instrument for $C/K$ in (3). We exploit this property in the empirical analysis below.

[10] When $\sigma < 1$ strong complementarity between $X$ and $Y$ change the direction of the effect. Take the extreme case of $\sigma = 0$, i.e. fixed proportions in $X$ and $Y$. An increase in $C/K$ increases the relative supply of $X/Y$, but since there is no substitution we do not need as much $X$ and hence demand for skilled labor (in terms of bodies) falls.

[11] The effects depends on $\sigma$ for reasons discussed in footnote above.

Taking logs of (4) we have

$$\ln\left(\frac{C}{K}\right) = \mu + \rho \ln\left(\frac{H}{L}\right) - \varphi \ln\left(\frac{r_C}{r_K}\right) \ , \tag{5}$$

where $\mu = \frac{\sigma}{\sigma-(1-\beta)(\sigma-1)} \ln\left(\frac{\delta}{1-\delta}\right)$, $\rho = \frac{\beta(\sigma-1)}{\sigma-(1-\beta)(\sigma-1)}$ and $\varphi = \frac{\sigma}{\sigma-(1-\beta)(\sigma-1)}$. Now take differences of (5) to get

$$\Delta \ln\left(\frac{C}{K}\right) = \rho \Delta \ln\left(\frac{H}{L}\right) - \varphi \Delta \ln\left(\frac{r_C}{r_K}\right) \ . \tag{6}$$

Equation (6) implies that the distribution of changes of $C/K$ is determined by changes in $H/L$ and $r_C/r_K$. We test this as well in the empirical analysis below.[12]

Before turning to the empirical analysis we make the following observation. An alternative interpretation of $Q$ is utility over a skill intensive good $X$ and a skill un-intensive good $Y$. This would open the door to production and export composition effects that are reminiscent of Zhu and Trefler (2005) (henceforth, ZT)—but for different reasons and through a different mechanism. We shut down this channel in our framework for two reasons. First, using data from the EU-KLEMS dataset (O'Mahony and Timmer (2009)) we find that changes in empirical counterparts of $C$ and $K$ do not induce large changes in relative demand for skill via changes in the industrial composition alone (see details in the Appendix). Second, the changes in export shares towards skill intensive goods in ZT (their $\Delta z$) are virtually uncorrelated with the composition of capital imports (see Table 2). We conclude that the mechanism highlighted in ZT is orthogonal to ours. This may not be surprising, since ZT examine only changes in export shares, while capital imports can affect the entire economy, not only the tradable sectors.

## 3 Capital imports and the skill premium

In this section we demonstrate that the composition of capital imports explains changes in skill premia in developing countries, whereas overall capital imports do not. We focus on the 1980s and 1990s, during which many developing countries—and specifically the ones in our sample—liberalized

[12] By plugging (6) into (3) we can derive an equation for $\Delta \ln \omega$ in terms of $\Delta \ln (H/L)$ and $\Delta \ln(r_C/r_K)$ alone. While this is theoretically aesthetic, empirically it is less successful. The explanatory power of $\Delta \ln(r_K/r_C)$ is much lower than our proxy for $\Delta \ln (C/K)$, which is the log of the import ratio. This happens for two reasons: First, we have only imperfect proxies for $r_C/r_K$, while the data on imports is more accurate. Second, since there is imperfect capital adjustment in the real world, we expect relative prices to have a weaker effect on capital stocks than on investment over short periods of time.

their international trade regimes.[13] [14]

Since we do not have empirical equivalents for $C$ and $K$ for developing countries, we rely on imports of capital to approximate changes in capital stocks, i.e. investment. As discussed in the introduction, this is not a bad assumption for the countries in our sample, since developing countries imported much of their capital during our period of interest (Eaton and Kortum (2001)). Our empirical equivalents of $C$ and $K$ are R&D-intensive and R&D-unintensive capital, respectively. The approximation is likely to be particularly good for investment in $C$, since developing countries are likely to rely much more on imports of R&D-intensive capital, relative to R&D-unintensive capital.

Our data on capital imports are from Feenstra, Lipsey, Deng, Ma, and Mo (2005). We break down total capital imports ($M$) into imports of R&D-intensive capital ($M_H$); imports of relatively R&D-unintensive capital ($M_L$); and imports of capital with intermediary R&D intensity ($M_N$). R&D intensity ranking of capital goods in 1980 is taken from Caselli and Wilson (2004) and are briefly described in Table 1. Their ranking of nine types of equipment is based on estimates of world R&D expenditures divided by world sales for each capital good; it is the same whether R&D flows or stocks (perpetual inventory method) are used. $M_H$ includes the three most R&D-intensive capital equipment, while $M_L$ includes four of the least R&D-intensive capital equipment. The remainder two types of capital are separately aggregated in $M_N$ because—as demonstrated in Section 4 below—their complementarity is not stronger with either skilled or unskilled labor. These two types of equipment have less than half the R&D intensity (however measured) as equipment included in $M_H$. Note that for the average country $M_N$ is a significant portion of aggregate capital imports (Table 2). In addition, we use GDP data from the World Bank's World Development Indicators. All imports and GDP variables are denominated in U.S. 2000 dollars.

We merge these data into the dataset of Zhu and Trefler (2005), which encompasses the most comprehensive sample of developing countries for which there are data on wages for production and non-production workers in manufacturing for our years of interest.[15] This has the advantage of direct comparability to ZT's results, and also relieves us from making judgements on sampling.

[13] For instance, data from the World Bank's World Development Indicators (available at: http://data.worldbank.org/data-catalog/world-development-indicators) reveal that the average increase between 1980-1999 in the share of total trade in GDP for all countries in our sample is approximately 40%, having several countries more than doubling their trade share during this period, including Argentina, India, Mexico, Thailand, and the Philippines. Goldberg and Pavcnik (2007) provide some evidence on policy-oriented trade liberalization acts done during our period of interest in some of the countries in our sample, including Argentina, Mexico, India, and Hong Kong.

[14] Alfaro and Hammel (2007) argue that in the same period stock market liberalizations are associated with increases in imports of capital equipment, due to financial integration. This channel is complementary to liberalization in goods trade—both reduce the cost of purchasing capital equipment abroad.

[15] Based on the availability of wage data from the International Labor Organization's occupational wage database.

The sample includes 58 observations covering 20 developing countries in 1983–1997, and is an unbalanced panel due to data availability.[16]

We use the relative wage of non-production to production workers ($w_H/w_L$) as our measure of skilled relative wages.[17] The ZT data include two additional variables of interest: The first is aggregate relative supply of skilled labor (skill abundance) ($H/L$), where skilled workers have at least secondary education, and the second is the shift in skilled export shares ($\Delta z$), which measures the degree to which export shares shift towards more skill-intensive exports within a given period.[18] ZT argue that $\Delta z$ can help explain changes in wage inequality.

We use these data not only to test whether aggregate capital imports matter or whether only their composition matters—but also examine the relative importance of ZT's mechanism for explaining variation in the skill premium versus capital imports composition.

Table 2 reports descriptive statistics for the main variables of interest. Half of the countries in the sample experience rising inequality while the others experience decreasing inequality; overall, changes in $w_H/w_L$ are roughly split between positive and negative changes. During periods of trade liberalization the skill premium has not uniformly fallen. The log of the import ratio ($M_H/M_L$) is on average low, $-0.74$, which implies that R&D-unintensive capital imports are about twice as large in value relative to R&D-intensive capital imports ($e^{-0.74} \approx 0.5$).[19]

The correlation between $\Delta z$ and $\ln(M_H/M_L)$ is 0.09; to the extent that $M_H$ is complementary to skilled labor and $M_L$ is complementary to unskilled labor, the low correlation implies that changes in capital stock composition in *production* are not tightly related to shifts in skilled *export* shares, as discussed in the end of Section 2. The upshot is that the mechanism that governs variation in $\Delta z$ is different from the one driving variation in the import ratio.

We now turn to testing our main hypotheses. Equation (3) implies a relationship between changes in relative skilled wages and changes in the ratio of skill-complementary to unskilled-complementary capital ($C/K$), but not with overall levels of capital ($C + K$). We approximate

[16] The criterion for being considered a developing country is having real GDP per capita below $14,000 in 1980. The countries in the sample are: Algeria, Argentina, Barbados, Bolivia, Central African Republic, Cyprus, Honduras, Hong Kong, India, South Korea, Sri Lanka, Madagascar, Mauritius, Mexico, Philippines, Singapore, Thailand, Trinidad and Tobago, Uruguay, and Venezuela. See the Appendix for the years in which each country is observed.

[17] Proxying skill by "non-production" is problematic, though it is (by necessity) common practice. Berman, Bound, and Griliches (1994) show that for the United States, the production/non-production worker classification is a good proxy for skilled and unskilled workers. In our estimation of complementarities below we entertain other definitions of skill.

[18] Data to construct $H/L$ is from Barro and Lee (2013). See our appendix for complete documentation on how $\Delta z$ is constructed.

[19] There are only 8 observations in which $M_H > M_L$; 16 countries consistently import more $M_L$ than $M_H$ in all periods; in 17 countries the total $M_L$ imports over the sample are larger than the total of $M_H$ imports.

changes in $C/K$ with the import ratio. We estimate regressions of the type

$$\Delta \ln \omega_{it} = \lambda \ln \left(\frac{M_H}{M_L}\right)_{it} + \theta \ln \left(\frac{M}{GDP}\right)_{it} + \alpha \Delta \ln \left(\frac{H}{L}\right)_{it} + \gamma_i + \delta_t + \varepsilon_{it} \ , \qquad (7)$$

where $\omega = w_H/w_L$, and $\gamma_i$ and $\delta_t$ are country and period fixed effects, respectively. This is the empirical counterpart to Equation (3). Due to data constraints each period $t$ is of different length, so changes are annualized. On average, each country is observed in three periods; see the Appendix for the years in each period across countries. We normalize overall capital imports by GDP. Variables not in changes are averaged within the period to keep consistency with the annualized changes.

The coefficients of interest are $\lambda$ and $\theta$. Our hypothesis is that $\lambda > 0$ and $\theta = 0$.

### 3.1 OLS estimates

Table 3 reports the results. All regressions include country fixed effects and $\Delta \ln(H/L)$ as regressors. In column 1 we see that indeed the import ratio is positively correlated with increases in the relative skilled wage: The partial $R$-squared of the import ratio in this regression is 0.35 (this is the underlying regression for Figure 1-A). In contrast, column 2 shows that overall imports of capital equipment do not affect changes in inequality.

Column 3 delivers the main message of this section: Even in the presence of overall capital imports, only the composition matters for changes in relative skilled wages. In column 4 we see that adding period fixed effects does not change this result. A one standard deviation increase in the import ratio increases the change in the skill premium by roughly one standard deviation. This is a large effect indeed.

The rest of Table 3 is devoted to robustness checks. First, in column 5 we add $\Delta z$: This reduces somewhat the magnitude of the coefficient to the import ratio, but the separate effect remains large. In addition, by multiplying the estimated coefficient to a variable (from Table 3) by the corresponding standard deviation (from Table 2) we find that the explanatory power of the import ratio is 2.7 times that of $\Delta z$.[20] This may not be surprising, because capital imports potentially affect demand for skill in all sectors of the economy, while $\Delta z$ affects demand for skill directly only in the export sector.

In columns 6–8 we separate the numerator from the denominator of the import ratio, normalize each by GDP, and show that each has a sizable and *opposite* effect on the relative skilled wage. This is important because a large import ratio may exist even when import flows are insignificant. We also add $M_N$ and see that it has no effect on changes in the skilled relative wage. The separate

[20] For $\Delta z$ $0.54 \times 0.02 = 0.0108$, and for the log import ratio $0.04 \times 0.73 = 0.0292$; these represent 32% and 86% of the standard deviation of $\Delta \ln \omega$ (0.034).

coefficients are robustly estimated whether or not we include $\Delta z$ or period dummies. The coefficients to $\ln(M_H/GDP)$ and $\ln(M_L/GDP)$ are very similar in absolute value, which is consistent with our assumption of fixed output elasticities ($\beta$) in Section 2 above. Despite this, the explanatory power of $M_H$ is roughly 1.6 times that of $M_L$: The greater variation in R&D-intensive capital renders it the more dominant force.[21]

In the Appendix we show that results are virtually the same both qualitatively and quantitatively in case we normalize capital imports by population rather than by GDP or do not normalize at all.

## 3.2 TSLS estimates

One potential concern is that variation in both capital imports and changes in inequality are driven by third factors.[22] For example, technological shocks that are not Hicks-neutral or are sector-specific may drive up both demand for skilled labor and imports of specific types of equipment. In order to address this concern we construct the following instruments. As implied by (4), prices of different types of capital are valid instruments for capital stocks, as long as these are determined internationally, and not influenced by domestic factors. We take this into account in the construction of our instruments, which are proxies for prices of capital imports.

Our instruments capture supply shocks across capital types, which are importer and period specific. First, we calculate the average real unit value of exports for capital type $j \in \{M_H, M_L\}$ from the three largest exporters that serve each country in each year in our sample, while dropping trade flows to the country at hand

$$uv_{i\tau}^{j} = \frac{\sum_{s \in TOP3_i^j} \sum_{d \neq i} X_{sd\tau}^{j}}{\sum_{s \in TOP3_i^j} \sum_{d \neq i} Q_{sd\tau}^{j}} \quad , \quad j \in \{M_H, M_L\} \ .$$

As before, $i$ is the importing country, but $\tau$ denotes a calendar year, not a period ($t$ above). $TOP3_i^j$ denotes the set of three largest exporters that serve country $i$ capital type $j$ in the first year it is observed; $X$ are exports and $Q$ are physical quantities; $s$ denotes a source country (exporter) and $d$ denotes a destination (importer).[23] As outlined above, we sum over all available destinations besides the country inspected. The unit values are then deflated by 1995 price indices that are specific to $M_H$ or $M_L$, using deflators from the EU-KLEMS database (O'Mahony and Timmer

[21] For $\ln(M_H/GDP)$ $0.046 \times 1.07 = 0.0492$, and for $\ln(M_L/GDP)$ $-0.043 \times 0.73 = -0.0314$.

[22] We are not concerned about endogeneity of $\omega$ and $H/L$ because we are not trying to identify the demand curve in the $(H/L, \omega)$ space; i.e. we are not interested in the structural interpretation of $\alpha$. Moreover, $H/L$ in our data is aggregate skill abundance, whereas $\omega$ is computed only for manufacturing.

[23] Data from Feenstra, Lipsey, Deng, Ma, and Mo (2005).

(2009)). Finally, for each country we calculate the change in these unit values over the given period, i.e. our instruments are $\Delta \ln uv_{it}^{j} = \ln uv_{i2}^{j} - \ln uv_{i1}^{j}$, where 2 denotes the last year in the period and 1 denotes the first.

The $\Delta \ln uv_{it}^{j}$ are valid instruments as long as supply shocks in the set $TOP3_{i\tau}^{j}$ are not correlated with changes in the relative skilled wage. A priori, there is no reason to think so. The exclusion of country $i$'s imports from the calculation of $uv_{i\tau}^{j}$ makes correlation with demand shocks in country $i$ unlikely. Finally, these instruments are excludable on theoretical grounds: Relative demand for skill is not affected directly by prices of capital.

The instruments have independent variation by country, period and capital type. Cross-country variation is given by the heterogeneity of exporters. For example, the top three exporters of $M_H$ in 1990 to Algeria are Sweden, France, and Japan; for Argentina they are the U.S., Japan and Germany. There is not much heterogeneity of exporters across capital groups within countries (a country's three largest international suppliers often supply it with both $M_H$ and $M_L$). For example, in 1990 Hong Kong imported both $M_H$ and $M_L$ mostly from China, Japan, and the U.S. Nevertheless, unit values, and changes thereof, for different types of capital do have independent variation, as demonstrated in Figure A1 in the Appendix.[24]

Table 4 reports our TSLS results, which are not materially different from those in Table 3; the magnitudes of the coefficients, and consequently their explanatory power, remain similar. In columns 1–3 we estimate models with the import ratio as endogenous. As expected, we find that $\Delta \ln uv^{M_H}$ is negatively correlated with the import ratio, and that $\Delta \ln uv^{M_L}$ is positively correlated with the import ratio. The overidentification restriction test fails to reject the null that both instruments are jointly valid at any reasonable level of significance. In columns 4–6 we estimate models with $M_H$ and $M_L$ as separate endogenous variables. Here the unit value instruments are negatively correlated with imports in all specifications; the unit value instrument of the corresponding import type is always statistically significant.[25] We reject the null hypothesis of weak instruments in all specifications at common levels of significance.

To summarize, we find that the composition of capital imports matters, not the overall quantity. These results hold both when using OLS and TSLS estimators. Imports of R&D-intensive equipment is associated with increases in the skill premium; imports of less innovative capital equipment is associated with decreases in the skill premium. In Section 4 we explain why this is the case.

[24] Figure A1 in the Appendix reports the annual rate of change in the average international real unit value of the two types of capital for 1985–1997; we start at 1985 given data availability on quantities traded. The figure exhibits significant and independent variation for both unit values. The correlation between the two variables is only 0.09.

[25] Figure A2 in the Appendix demonstrates this graphically.

### 3.3 Explaining the distribution of the import ratio

In this section we investigate which factors determine the distribution of the import ratio. We add to the specification in the first stage of Table 4 controls for sectoral composition, income per capita, financial development, and protection of intellectual property rights (IPR). These variables are used in Caselli and Wilson (2004) to explain cross-country variation in imports of different types of equipment. While Caselli and Wilson (2004) consider variation within separate equipment groups, we examine the variation in their composition.[26] In a nutshell, changes in skill abundance and in prices of capital are robust and economically important predictors of the import ratio, which is consistent with Equation (6).

We estimate augmented versions of Equation (6), where we use the instruments $\Delta \ln uv^{M_H}$ and $\Delta \ln uv^{M_L}$ as proxies for the prices of $M_H$ and $M_L$, respectively.[27] Using proxies for prices introduces a measurement issue, where the coefficients to the proxies do not identify the parameter $\varphi$ in (6). However, the exercise is informative due to the strong explanatory power of $\Delta \ln uv^{M_H}$ and $\Delta \ln uv^{M_L}$. We also note that the additional controls are not valid instruments in estimating (7) above, because they are all likely to be correlated with $\Delta \ln \omega$. The current exercise also shows that these omitted variables do not induce bias, because they are not strongly correlated with the import ratio.[28]

Table 5 reports the results. All regressions include country fixed effects; columns 7–12 include in addition period fixed effects. In column 1 we see that although the sign of the coefficient to the ratio of the proxies for prices is correct, it is not precisely estimated. This may be a direct result of using proxies, rather than true prices.[29] In column 2 we separate the numerator from the denominator and estimate large and significant coefficients to $\Delta \ln uv^{M_H}$ and $\Delta \ln uv^{M_L}$. First we add controls for sectoral composition and income per capita, which do not change the sample. These are statistically insignificant and hardly affect the coefficients to $\Delta \ln uv^{M_H}$ and $\Delta \ln uv^{M_L}$.

When we add controls for either financial development, protection of IPR, or both, the sample reduces. The point estimate of the coefficient to $\Delta \ln uv^{M_L}$ drops and eventually becomes imprecise.

[26] Caselli and Wilson (2004) include also inward and outward FDI in their specifications; adding these, however, significantly decreases our sample to a point where it is not testable, which is why we do not include them. See Appendix for complete definitions of variables.

[27] These two variables are likely to satisfy the two conditions for proxy variables in (6): Redundancy in the presence of true prices, and no correlation between the other regressors and the true prices once the proxy is controlled for (Wooldridge (2002), Chapter 4).

[28] We are not concerned about reverse causality from $M_H/M_L$ to $H/L$ because changes in the supply of skills is a slow-moving process with lags, whereas imports respond much more quickly to demand shocks.

[29] If the proxy for $p^{M_j}$ is $uv^{M_j}$, $j \in \{H, L\}$, then we can write $p^{M_j} = \theta_0^j + \theta_1^j uv^{M_j} + \varepsilon^j$. Taking the ratio $p^{M_H}/p^{M_L} = \left(\theta_0^H + \theta_1^H uv^{M_H} + \varepsilon^H\right) / \left(\theta_0^L + \theta_1^L uv^{M_L} + \varepsilon^L\right)$ we see that imprecise estimates may arise from the presence of nonzero $\theta_0^j$ terms, different $\theta_1^j$ terms, and if the variances of $\varepsilon^j$ are large.

The coefficient to protection of IPR is positive and precisely estimated, which is consistent with greater sensitivity of supply of R&D-intensive capital to the threat of reverse engineering. However, once we introduce period fixed effects the point estimate of the coefficient to $\Delta \ln uv^{M_L}$ remains imprecisely estimated. In contrast, the coefficient to protection of IPR is not robustly estimated.

We use column 2 to evaluate the explanatory power of $\Delta \ln uv^{M_H}$ and $\Delta \ln uv^{M_L}$. A one standard deviation decrease in $\Delta \ln uv^{M_H}$ increases the log import ratio by 0.6 standard deviations; a one standard deviation increase in $\Delta \ln uv^{M_L}$ increases the log import ratio by 0.38 standard deviations. These effects are very large, and much larger than the effect of a one standard deviation increase in $\Delta \ln (H/L)$, which is 0.12 standard deviations of the log import ratio.[30]

We conclude that changes in supply of skills and prices are the most important factors determining the import ratio, and together explain 50% of the variation (measured by the $R^2$ of the within estimator).

# 4 Complementarity of capital to skilled and unskilled labor

Since Griliches (1969), capital is considered complementary to skilled labor. With some reservations about robustness, other studies generally confirm the capital-skill complementarity hypothesis.[31] However, these studies (including Griliches') investigate complementarity to aggregate measures of capital; they do not consider the composition of capital. In this section we establish that R&D-intensive capital equipment is complementary to skilled labor, while less innovative capital equipment is complementary to unskilled labor.[32] To be precise, when we say that a type of capital is complementary to a class of workers, this is a relative statement. For example, R&D-intensive capital equipment is more complementary to skilled labor than to unskilled labor.

We follow standard methodology in the capital-skill complementarity literature and estimate a skilled labor share equation, e.g., as in Berman, Bound, and Griliches (1994). Assume a translog cost function where there are three inputs: Skilled and unskilled labor, and capital. If capital is a quasi-fixed factor, skilled and unskilled labor are variable factors, and production exhibits constant returns to scale, then cost minimization yields the following relationship

$$S = \alpha + \beta \ln \left( \frac{w_H}{w_L} \right) + \gamma \ln \left( \frac{K}{Y} \right) , \tag{8}$$

[30] For $\Delta \ln uv^{M_H}$ $0.007 \times -62.76 = -0.44$, for $\Delta \ln uv^{M_L}$ $0.006 \times 46.08 = 0.28$, and for $\Delta \ln (H/L)$ $0.04 \times 2.26 = 0.0904$. The stanard deviation of $\Delta \ln (M_H/M_L)$ is 0.73.

[31] See Fallon and Layard (1975), Bergstrom and Panas (1992), Duffy, Papageorgiou, and Perez-Sebastian (2004).

[32] This in itself can help explain the sensitivity of the results in Duffy, Papageorgiou, and Perez-Sebastian (2004): The composition and, hence, overall degree of complementarity of capital is not the same across countries in their panel.

where $S$ denotes the wage bill share of skilled labor, $w_H$ and $w_L$ are wages of skilled and unskilled labor, $K$ is capital, and $Y$ denotes value added.[33] The coefficient $\gamma$ indicates the type and magnitude of complementarity. $\gamma > 0$ implies stronger complementarity to skilled labor, while $\gamma < 0$ implies stronger complementarity to unskilled labor.

We estimate (8) in a panel of 24 mostly developed countries in 1970–2005 using the EU-KLEMS dataset (O'Mahony and Timmer (2009))

$$S_{it} = \beta \ln \left( \frac{w_H}{w_L} \right)_{it} + \gamma \ln \left( \frac{K}{Y} \right)_{it} + \eta_i + \delta_t + \varepsilon_{it} \ , \tag{9}$$

where $\eta_i$ and $\delta_t$ are country and year fixed effects, respectively. The fixed effects capture *inter alia* unobserved disembodied non-neutral technological change.[34]

The EU-KLEMS disaggregates workers into three groups: High skilled, medium skilled, and low skilled. The definition of high skilled workers is consistent across countries, and implies a university-equivalent bachelors degree. The definitions of the other two groups vary somewhat across countries, but are consistent over time within a country. Medium skilled workers do not attain a university-equivalent bachelors degree, but complete high-school and possibly a non-university vocational degree; low skilled workers do not complete high school. We use two definitions of skill in the implementation of (9): High (narrow definition), and high + medium (broad definition). This facilitates two goals. First and foremost, the broad definition is more relevant for developing countries. Second, it allows checking the robustness of the complementarity results.[35] Wage bill shares for all three groups are given in the data directly. Wages are calculated by dividing wage bills by hours worked.

The EU-KLEMS dataset reports data on capital stocks for five distinct capital groups: computing equipment, communication equipment, software capital, transport equipment, and machinery. First we estimate (9) separately for each capital group. Then we aggregate into two groups: information and communication equipment capital (ICT) and non-ICT; see Table 1. Finally, we also estimate (9) using the total capital stock.

We follow Duffy, Papageorgiou, and Perez-Sebastian (2004) and estimate (9) by TSLS, using lagged values as instruments. We report standard errors using country level clustering.

The results in Table 6 show a clear pattern: On one hand, computing equipment, communication

[33] See Appendix for the complete derivation.

[34] EU-KLEMS sample includes: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxemburg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, United States. See Appendix for further documentation for this dataset.

[35] Duffy, Papageorgiou, and Perez-Sebastian (2004) find the empirical evidence in favor of the capital-skill complementarity hypothesis at the aggregate level most convincing when skilled workers are defined broadly, as high + medium.

equipment, and software capital are complementary to skilled workers; on the other hand, transport equipment, and machinery are complementary to unskilled workers. Due to colinearity we cannot add separately all types of capital, but when ICT and non-ICT capital groups are included, we confirm the results for their subcomponents: ICT capital is complementary to skilled workers; non-ICT capital is complementary to unskilled workers. These results hold whether we use the narrow definition of skill (only high) or the broad definition (high + medium). Since the year fixed effects add little explanatory power, fitting (9) without them yields virtually the same results.[36] Taking changes in (8) and estimating the resulting equation by TSLS with country fixed effects—using lagged variables in changes as instruments—yields remarkably similar results to those reported in Table 6 (see Appendix).

In the last column of Table 6 we also estimate that the aggregate capital stock is complementary to skilled labor. We find it comforting that we can replicate previous findings, where *aggregate* capital equipment in industrial countries is found to be complementary to skilled labor. This should not be confused with the results in Section 3: The composition of the aggregate capital stock and investment in countries in the EU-KLEMS sample—which are mostly developed economies—is likely to be much more R&D intensive, with a higher share of ICT, relative to the sample of developing countries that we examine above.

We wish to estimate (9) using the nine groups by R&D intensity used above in Section 3, in order to bear direct evidence on the mechanism that we highlight. Unfortunately, the EU-KLEMS data on capital stocks are not classified according to ISIC. Based on EU-KLEMS documentation we feel comfortable to classify some ISIC capital types into broad ICT and non-ICT groups (see Table 1), but the mapping at the more disaggregated level is not obvious. Therefore we turn to OECD *StatsExtract* data.[37]

The OECD data report production $Y$, imports $M$, and exports $X$, by ISIC in 1970–2005. This allows estimating gross investment $I$ for each of the nine capital groups

$$I_{g,t} = Y_{g,t} + M_{g,t} - X_{g,t} \ ,$$

where $g = 1, 2, ...9$ denotes R&D intensity rank. We then use the perpetual inventory method to estimate capital stocks

$$K_{g,t+1} = (1 - \delta_g) \, K_{g,t} + I_{g,t} \ .$$

[36] These results are available upon request.
[37] Available at: http://stats.oecd.org/

Since capital stocks in the initial year 1970 are not available by type, we estimate

$$K_{g,1970} = \frac{I_{g,1970}}{\delta_g} \ .$$

Depreciation estimates by capital type $\delta_g$ are from Fraumeni (1997), and are based on U.S. data; these are the same depreciation rates that are used in the EU-KLEMS for construction of capital stocks by group (see O'Mahony and Timmer (2009)). We estimate (9) using these constructed capital stocks by R&D intensity, using the same estimator as above.

Table 7 reports the results, which largely confirm the results in Table 6. Figure 2 summarizes the results in this section, based on Table 7. The most R&D-intensive capital types (aircraft equipment, office, computing and accounting machinery, communication equipment) are complementary to skilled labor. Of the other six relatively less R&D-intensive capital types, four (electrical equipment excluding communication, non-electrical equipment, other transportation equipment, fabricated metal products) are complementary to unskilled labor. Motor vehicles and professional goods are not more complementary to either class of labor. It is for this reason that we do not include the latter two types of capital in $M_L$ in the import composition estimation in Section 3 above. When we aggregate the top three R&D-intensive, skill-complementary capital groups ($K_H$), and the four unskilled-complementary capital groups ($K_L$), we confirm the results for their subcomponents: $K_H$ is complementary to skilled workers; $K_L$ is complementary to unskilled workers. As before, these results hold whether we use the narrow definition of skill (only high) or the broad definition (high + medium).

Overall, using several specifications and data sources, we find strong evidence for capital-skill complementarity for R&D-intensive, innovative capital types; we find that less innovative and relatively R&D-unintensive equipment is complementary to unskilled labor. This is the reason that the composition of capital imports (which stands in for investment), and not the overall quantity, affects the skill premium.

# 5 Trade liberalization and changes in the composition of capital imports

So far, we have investigated a particular mechanism that links the composition of capital imports to changes in the skill premium: A higher share of imports of R&D-intensive, skill-complementary capital $M_H$ in total capital imports $M$ raises the skill premium through its effect on installed capital stocks. And the opposite is true for imports of less innovative unskilled labor-complementary capital $M_L$. To put things in context, the share of $M_H$ in capital imports more than doubles in our sample from 12.6% in 1983 to 30% in 1999, while the the share of $M_L$ in capital imports decreases from 57.5% in 1983 to 48% in 1999.

However, our findings thus far do not necessarily imply that trade liberalization increases the skill premium through this channel. For this, we need evidence on whether the distribution of the import ratio (or the share of $M_H$ in total imports) has shifted to the right, relative to a pre-liberalized era. This is a difficult question to answer, but in this section we provide some evidence that suggests that this may have been the case.

The mechanics of trade liberalization work through relative import prices of $M_H$ versus $M_L$. In the framework of Section 2 this is represented by $r_C/r_K$. We decompose each capital import price $r_j$ into three components: A "free on board" (FOB) price at the source $r_j^*$, ad valorem tariffs $\tau_j$, and specific (transportation) freight costs $\widetilde{f}_j$, so that

$$\frac{r_C}{r_K} = \frac{r_C^*(1+\tau_C)+\widetilde{f}_C}{r_K^*(1+\tau_K)+\widetilde{f}_K} = \frac{1+\tau_C+f_C}{1+\tau_K+f_K}\cdot\frac{r_C^*}{r_K^*}\ ,$$

where $f_j \equiv \widetilde{f}_j/r_j^*$ is the ad valorem equivalent freight cost. Although freight costs are usually denominated in specific (per unit, not per value) terms in the real world, a more meaningful way to analyze their impact on trade flows is to transform them into ad valorem terms (see Hummels and Skiba (2004) and Hummels (2007)).

First, we document that on average $\tau_C$ falls more than $\tau_K$, which reduces $r_C/r_K$, all else equal. We use tariff data from the TRAINS dataset and calculate the average percent (not percent *point*, because we need to compare across different levels) drop in tariffs for each of the nine capital groups from 1988 (the first year available) to 2010 across all countries in that dataset.[38] Figure 3 shows that on average tariffs dropped more for R&D-intensive capital imports. The correlation between the R&D intensity rank and the percent change in tariffs is 0.63. For the group of capital goods that is complementary to skilled labor the drop is 59%, whereas for the group that is complementary to unskilled labor the drop is 41%.

Second, we show that transportation costs are lower for R&D-intensive capital imports ($f_K > f_C$). If this is true, then a blanket drop in tariffs at the same rate will also reduce $r_C/r_K$. To see this, suppose that $\tau_C = \tau_K = \tau$ and that trade liberalization decreases $\tau$. Then

$$\frac{\partial}{\partial\tau}\left(\frac{r_C}{r_K}\right) = \frac{r_C^*}{r_K^*}\cdot\frac{f_K-f_C}{(1+\tau+f_K)^2} > 0 \ \text{ if } \ f_K > f_C\ .$$

[38] TRAINS (Trade Analysis and Information System) data downloaded from http://wits.worldbank.org/wits/. The sample of developing countries is very sparse in the TRAINS data, which precludes computing these changes separately for the sample used above; otherwise, we would have used tariffs as instruments.

We now present evidence that is consistent with $f_K > f_C$. We use data from Hummels (2007) on ad valorem freight costs for shipments into the U.S., and show that these are lower for skill-complementary capital. We estimate regressions of the type in Hummels (2007),

$$\ln (f)_j = \lambda' m_j + \alpha \ln (w/v)_j + \beta \ln (dist)_j + \delta_{t(j)} + \varepsilon_j \ , \quad (10)$$

where $f$ are ad valorem freight costs, $w/v$ is weight per value of shipment, $dist$ is distance between the exporter and the U.S. entry port, $\delta$ are year fixed effects (the notation $t(j)$ means that shipment $j$ is observed in year $t$) and $\varepsilon$ is the projection error. The vector $m$ contains dummies for different types of capital. The coefficients of interest are collected in the vector $\lambda$. Our hypothesis is that they are higher for less R&D-intensive unskilled-complementary capital goods. We estimate (10) separately for air and sea shipments; in the latter case we add the share of value shipped in containers.[39]

Table 8 reports the results. The first column for each mode of transport (air and sea) is a baseline specification, to which we add either R&D intensity indicators in the second column, or indicators for $M_N$ and $M_L$ in the third column; the reference groups are the highest R&D rank capital (aircraft equipment) or $M_H$, respectively. Table 8 reveals a pattern of higher freight costs for R&D-unintensive capital. This is easily seen for air shipments. For sea shipments the coefficients to R&D intensity indicators increase in size, although they are all negative. This is because freight costs of shipments of aircraft equipment by sea are relatively expensive, given their low weight/value ratio (see Panel B). Since these are a minority of shipments of capital type $M_H$, the pattern is clearer for greater freight costs of $M_L$ versus $M_H$. Weighing observations by value of shipment ($v$) hardly affects the results in Table 8.

Panel B of Table 8 reports averages for variables used in Panel A; for ease of exposition $f$ and $w/v$ are reported in percent points, not in logs, to ease the interpretation. Panel B helps explain the results in Panel A: Heavier, more containerized capital imports, which are relatively less R&D-intensive and are unskilled-complementary, are more costly to ship.[40]

The data on freight costs pertain only to the U.S. In order to complete the picture for other countries, we estimate gravity equations of the type

$$m_{si} = -\beta \cdot dist_{si} + \gamma' x_{si} + \chi_s + \eta_i + \varepsilon_{si} \ , \quad (11)$$

where $m_{si}$ is log imports from source (exporter) $s$ to importer (destination) $i$; $dist_{si}$ is log distance

[39] Year fixed effects absorb global changes in fuel prices. Adding country fixed effects that absorb the distance variation yields virtually identical results (available upon request).

[40] Hummels (2007) discusses why containerization is associated with higher, not lower costs.

between $s$ and $i$, $x_{si}$ is a vector of bilateral trade resistance factors; $\chi_s$ and $\eta_i$ are exporter and importer fixed effects; and $\varepsilon_{si}$ is an error term. The vector $x_{si}$ includes indicators for common language, legal system, common land border, currency union, colonial ties, membership in WTO, islands, landlocked economies, and common regional trade agreements.[41]

The interpretation of $\beta$ in the trade literature (e.g., in Helpman, Melitz, and Rubinstein (2008)) is

$$\beta = (\sigma - 1)\, f\ ,$$

where $f$ is the cost elasticity of distance and $\sigma$ is the elasticity of demand. Given the results in Table 8 on $f$, we expect to find lower estimates of $\beta$ for more R&D-intensive, skill-complementary capital imports.[42]

We estimate (11) separately for each of the nine capital groups by R&D rank, and then separately for $M_H$, $M_N$ and $M_L$. We estimate (11) in 1980 using three estimators: Ordinary least squares (OLS); Heckman correction for sample selection (Heckit); and the Helpman, Melitz, and Rubinstein (2008) correction for extensive margin and sample selection (HMR).[43] In addition, we estimate (11) using port distances from Feyrer (2009), instead of great circle distances between capital cities.[44] We cluster standard errors at the country pair dimension.

Table 9 reports the estimates of $\beta$ across capital groups for all specifications, which all point in same direction: Import resistance to distance is greater for R&D-unintensive, unskilled-complementary capital.[45] In Panel A we see that the Spearman rank correlation is on average 0.83. This is illustrated graphically in Figure 4 for the OLS estimates. When we restrict attention to developing countries in Panel B the rank correlation is on average 0.68.[46] The estimate of $\beta$ for $M_H$ is always significantly smaller than that for $M_L$; test statistics for equality deliver $p$-values well below 1%.

Adding controls for tariffs (which reduces the sample significantly), estimating (11) in 1989, and adding controls for quantities of imports do not change the results. In addition, the estimate

[41] The trade data are from Feenstra, Lipsey, Deng, Ma, and Mo (2005), and the data for all other controls are from Helpman, Melitz, and Rubinstein (2008). See Appendix for complete definitions of variables used in the gravity exercise.

[42] Broda, Greenfield, and Weinstein (2006) estimate elasticities of substitution at the 3-digit HS codes for 73 countries. We are unable to utilize these data. Only one group of capital imports (Office, computing, and accounting machinery, ISIC 3825) matches 1:1 with a 3-digit HS code. All the other capital groups include several 3-digit HS codes. Taking simple or weighted averages of 3-digit HS elasticity estimates that fall within our capital groups ignore substitution across 3-digit HS codes. This makes comparison across these averages uninformative.

[43] We follow the methodology set by Helpman, Melitz, and Rubinstein (2008) for the Heckit and HMR estimations; in both we adopt their religion-based excluding variable.

[44] We thank James Feyrer for sharing his data with us.

[45] All estimates of $\beta$ are statistically significant are any reasonable level. All other coefficients have expected signs. Complete estimation results for all specifications of (11) are available upon request.

[46] Developing countries all have real GDP per capita below \$14,000 in 1980—the same criterion used to define the sample in Section 3. See country list in the Appendix.

of the coefficient to the indicator for common border in (11) (not reported) is positive but smaller for R&D-intensive, skill-complementary capital imports. This is in line with the results for distance: Proximity matters less for R&D-intensive, skill-complementary capital imports relative to less innovative capital.[47]

To summarize this section, we document larger tariff cuts and smaller distance-related import costs for R&D-intensive capital equipment versus less innovative equipment. These both imply that trade liberalization reduces $r_C/r_K$, which in turn increases inequality through the composition channel. We stress that this argument is valid for the average country, whereas on a case-by-case basis the effect of trade liberalization through the composition channel may be different.

# 6 Conclusion

Empirical investigations of episodes of trade liberalization usually do not find large effects on the skill premium. One reason is that these studies focus on traded final goods (e.g., Zhu and Trefler (2005), Verhoogen (2008), Bustos (2011), Burstein and Vogel (2012)) or intermediate inputs (e.g. Feenstra and Hanson (1996), Amiti and Cameron (2012)), and typically focus on mechanisms that directly affect only the traded sector. In this paper we show that the composition of capital imports has strong explanatory power for changes in the skill premium in a sample of developing countries. In addition, we argue that trade liberalization can shift the distribution of capital imports in a way that increases the skill premium. Thus, we provide a plausible and empirically robust novel explanation for the increase in the skill premium in many developing countries that liberalized trade.

We find that when the composition of capital imports is more R&D intensive, the skill premium increases, whereas when it is less R&D intensive the skill premium falls. This is because R&D-intensive capital is complementary to skilled labor, whereas R&D-unintensive capital is complementary to unskilled labor. To our best knowledge, we are the first to argue that some types of capital are more complementary to unskilled workers. The composition of imports has a first order effect on the composition of capital stocks in developing countries, because they import much of their capital and produce little of it domestically. This is why the capital import ratio, a measure of import composition, has such strong explanatory power. We estimate that a one standard deviation increase in the import ratio increases the rate of change in the skill premium by roughly one standard deviation.

We argue that trade liberalization may have shifted the distribution of import composition

[47] All these results are reported in the Appendix.

towards more skill-complementary capital. First, tariff reductions have been larger, on average, for skill-complementary capital. In addition, we show that transport costs are lower for skill-complementary capital. This last finding implies that a blanket reduction in tariffs will lower prices of skill-complementary capital more than unskilled-complementary capital. Overall, this evidence indicates that trade liberalization may have shifted the composition of capital imports towards more R&D-intensive, skill-complementary equipment—and hence caused increases in the skill premium.

Our results highlight the need to pay attention to the composition of imports, not just aggregate quantities. While we focus here on capital imports, we believe that the mechanism that we investigate—composition together with patterns of complementarities—can help explain results in other papers, e.g. Amiti and Cameron (2012). In addition, the importance of composition raises concerns for the validity of estimates of the contribution of capital imports to increases in the skill premium in papers that rely on quantitative trade models with no role for composition. Since the composition of capital imports varies across countries, so does the effective complementarity of aggregate capital imports. Such quantitative analyses—in particular, Burstein, Cravino, and Vogel (2013) and Parro (2013)—can be modified to take into account the capital import composition, together with the pattern of complementarities that we uncover.

# Appendix

## A Detailed descriptions of ISIC capital goods classifications

Capital goods are listed from highest to lowest R&D intensity based on Caselli and Wilson (2004) and ISIC in parentheses:

1. Aircraft equipment (3845): Aircraft and related parts.
2. Office, computing, and accounting machinery (3825): Computers, calculators, typewriters, and other office equipment (excluding photocopiers).
3. Communication equipment (3832): Semiconductors, wire and wireless telephone equipment, radio and TV sets, audio recording equipment, signaling equipment, radar equipment.
4. Professional goods (385): Measuring and controlling equipment, photographic and optical goods, and watches and clocks.
5. Electrical equipment, excluding communication equipment (383 *without* 3832): Electrical industrial machinery, electrical appliances, and other electrical apparatus.
6. Motor vehicles (3843): Automobiles and related parts (excludes industrial trucks and tractors).
7. Non-electrical equipment (382 *without* 3825): Engines and turbines, agricultural machinery (including tractors, excluding metal tools), metal and wood-working machinery, industrial trucks, military ordinance (including tanks).
8. Other transportation equipment (3842, 3844, 3849): Railroad equipment, motorcycles and bicycles, wagons and carts.
9. Fabricated metal products (381): Cutlery, hand tools, general hardware, metal furniture and fixtures, structural metal products.

## B Data

### B.1 Zhu and Trefler (2005) sample

The sample is an unbalanced panel covering 1983–1997 with varying time periods for each country, based on data availability for wage data, and builds on the dataset of Zhu and Trefler (2005). All countries in this sample have real GDP per capita in 1980 below $14,000 in 1980 dollars. The sample is further restricted by data availability.

List of countries and periods: Algeria (1985–1989, 1990–1992), Argentina (1991–1993, 1993–1995), Barbados (1985–1989, 1990–1993, 1993–1995), Bolivia (1991–1994, 1994–1997), Central African Republic (1987–1989, 1991–1993, 1993–1997), Cyprus (1983–1986, 1986–1989, 1990–1993, 1993–1997), Honduras (1983–1987, 1990–1993, 1993–1997), Hong Kong (1983–1985, 1985–1989, 1991–1994, 1994–1997), India (1986–1989, 1990–1994, 1994–1997), South Korea (1983–1986, 1986–1989, 1991–1993, 1993–1997), Sri Lanka (1983–1985, 1985–1988, 1990–1993, 1993–1997), Madagascar (1983–1987, 1994–1995), Mauritius (1983–1985, 1985–1989, 1990–1993, 1993–1997), Mexico (1990–1993, 1993–1997), Philippines (1983–1986, 1986–1989, 1990–1994), Singapore (1985–1989, 1991–1993, 1993–1997), Thailand (1984–1986, 1991–1995), Trinidad and Tobago (1985–1988, 1990–1996), Uruguay (1985–1989, 1990–1993, 1993–1995), Venezuela (1984–1986, 1986–1989, 1990–1997).

### B.2 Variable definitions:

**Data from Zhu and Trefler (2005):**

*Change in the logarithm of skilled relative wage*, $\Delta \ln \omega$: Defined as the wage ratio of manufacturing workers in non-production occupations (managers, professionals, technicians, and clerks) to manufacturing workers in production occupations (craft workers, operators, and laborers). Source: International Labour Organization.

*Change in logarithm of relative supply of skill (skill abundance)*, $\Delta \ln (H/L)$: relative supply of skill is measured by the ratio of skilled to unskilled population. The skilled group is defined as those having at least secondary education. Source: Barro and Lee (2013).

*Shift in export shares*, $\Delta z$: Consider the area under the cumulative distribution function of export shares to OECD countries with 1980 real GDP per capita exceeds $14,000 (in 1980 dollars), where industries are ranked by their skill intensity. $\Delta z$ is the difference in this area between the last and first year in each period. More formally, rank all industries for some country by skill intensity (based on the ratio of non-production workers to production workers) and normalize to 1. Define this rank as $r \in [0,1]$. The export share of each industry in time $t$ is $x_t(r)$, where only exports to OECD countries with real GDP per capita in 1980 above $14,000 in 1980 dollars. $\Delta z_t = \int_0^1 \int_0^r x_t(s)\,dsdr - \int_0^1 \int_0^r x_{t-1}(s)\,dsdr$.

**Data from Feenstra, Lipsey, Deng, Ma, and Mo (2005):**

*Logarithm of imports of R&D-intensive capital:* Imports of R&D-intensive capital are averaged within each time interval. R&D-intensive capital is an aggregated group that includes the following ISICs: computing equipment (3825), communication equipment (3832) and aircraft equipment (3845).

*Logarithm of imports of R&D-unintensive capital:* Imports of R&D-unintensive capital are averaged within each time interval. R&D-unintensive capital is an aggregated group that includes the following ISICs: fabricated metal products (381), non-electrical equipment (382 without 3825), electrical equipment (383 without 3832), and other transportation equipment (3842, 3844, 3849).

*Logarithm of imports of R&D-intermediate-intensive capital:* Imports of R&D-intermediate-intensive capital are averaged within each time interval. R&D-intermediate-intensive capital is an aggregated group that includes the following ISICs: motor vehicles (3843), and professional goods (385).

*Logarithm of aggregate capital imports:* Imports of aggregate capital are averaged within each time interval. Aggregate capital is an aggregated group that includes all nine capital groups.

*The capital import ratio:* The capital import ratio is defined as imports of R&D-intensive capital (averaged within each time interval) divided by R&D-unintensive capital (averaged within each time interval).

*R&D-intensive and R&D-unintensive instruments:* The average change in the real unit price of each type of capital in the three main exporters that serve each country, calculated net of the effect of the country inspected. The unit price is calculated by dividing the average monetary value of exports (in the relevant type of capital) by the average quantity traded; this is then deflated to 1995 prices using specific deflators from the EU-KLEMS database (O'Mahony and Timmer (2009)). The three main exporters of each country are calculated for each country at the beginning of each investigated period. These unit values are then differenced within each period.

**Data from Caselli and Wilson (2004):**

*Industrial/Government/Services share:* Value added share in GDP. Source: World Bank World Development Indicators.

*Income per capita:* GDP per capita. Source: Penn World Tables, Version 6.1 (Heston, Summers, and Aten (2012)).

*Intellectual property rights protection:* The Intellectual Property Rights Protection Index. This index is used to examine what factors or characteristics of economies determine how strongly patent rights will be protected. It is constructed using a coding scheme applied to national patent laws, examining five distinct categories. Source: Ginarte and Park (1997).

*Financial development:* M3 money supply as a fraction of GDP. Source: World Bank, World Development Indicators.

### B.3 Gravity estimation

**Countries in sample:** Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belgium-Lux, Belize, Benin, Bermuda, Bhutan, Bolivia, Brazil, Brunei, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cayman Islds, Central Africa, Chad, Chile, China, Colombia, Comoros Islds., Congo, Costa Rica, Cote D'Ivoire, Cuba, Cyprus, Denmark, Djibouti, Dominican Rep., Ecuador, Egypt, El Salvador, Eq. Guinea, Ethiopia, Fiji, Finland, Fm. Czechoslovakia, Fm. USSR, Fm.Yugoslavia, France, French Guiana, Gabon, Gambia, Germany, Ghana, Greece, Greenland, Guadeloupe, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kiribati, Korea DPR, Korea Rep., Kuwait, Laos, Lebanon, Liberia, Libya, Madagascar, Malawi, Malaysia, Maldives, Malta, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Netherlands, Neth. Antilles, New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Reunion, Romania, Rwanda, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Solomon Islds., Somalia, South Africa, Spain, Sri Lanka, Mali, St. Kitts and Nevis, Sudan, Surinam, Sweden, Switzerland, Syria, Taiwan, Thailand, Togo, Trinidad-Tobago, Tunisia, Turkey, Turks and Caicos, Uganda, United Kingdom, United Arab Em., United Rep.Tanzania, United States, Uruguay, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

**Importing developing countries in restricted sample (exporters are unrestricted):** Albania, Algeria, Argentina, Bahrain, Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Brazil, Bulgaria, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Costa Rica, Cote D'Ivoire, Cuba, Cyprus, Dominican Rep., Ecuador, Egypt, El Salvador, Fiji, Gabon, Gambia, Ghana, Greece, Guatemala, Guinea-Bissau, Guyana, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Ireland, Israel, Jamaica, Jordan, Kenya, Kiribati, Korea Rep., Liberia, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Nepal, New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Portugal, Rwanda, St. Kitts and Nevis, Senegal, Seychelles, Sierra Leone, Singapore, South Africa, Sri Lanka, Sudan, Suriname, Syria, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uruguay, Venezuela, Zambia, Zimbabwe.

**Variables:**

*Disaggregated import flows by R&D intensity* (based on Caselli and Wilson (2004) classification) were retrieved from Feenstra, Lipsey, Deng, Ma, and Mo (2005) trade database. All other data are from Helpman, Melitz, and Rubinstein (2008), except for port distance, which is from Feyrer (2009).

*Distance:* The distance in kilometers between importer and exporter capital cities.

Port Distance: Time in days between importer main port and exporter main port under the assumption that both the Panama and Suez canals are open, and assuming a ship speed of 20 knots and adding (or subtracting) the speed of the average ocean current along the path. In countries with several main ports, the one with lowest average overall distance is used.

*Common Language:* Indicator that equals one if importer and exporter have a common main language, and zero otherwise.

*Common Border:* Indicator that equals one if importer and exporter are neighbors that meet a common physical boundary, and zero otherwise.

Island: Indicator that equals one if both importer and exporter are islands, and zero otherwise.

*Landlocked:* Indicator that equals one if both exporter and importer have no coastline or direct access to sea, and zero otherwise.

*Colonial Ties:* Indicator that equals one if importer ever colonized exporter or vice versa, and zero otherwise.

*Currency Union:* Indicator that equals one if importer and exporter use the same currency or if within the country pair money was interchangeable at a 1:1 exchange rate for an extended period of time, and zero otherwise.

*Legal System:* Indicator that equals one if the importer and exporter share the same legal origin, and zero otherwise.

*Religion Index:* (% Protestants in country $i$ × % Protestants in country $j$ ) + (% Catholics in country $i$ × % Catholics in country $j$ ) + (% Muslims in country $i$ × % Muslims in country $j$ ).

*FTA:* Indicator that equals one if exporter and importer belong to a common regional trade agreement, and zero otherwise.

*WTO:* Variable equals two if both importer and exporter belong to the GATT/WTO, equals one if only one belongs, and zero if none belong.

# C Capital stocks and changes in relative demand for skill via changes in production patterns

We draw on the EU-KLEMS dataset. For each country and industry in the dataset we collect the following variables for 1983–1997 (the sample in the main analysis):

- The percent contribution to value added growth of two classes of capital—ICT ($c_i$) and non-ICT capital ($n_i$)
- The change in employment share of some industry $i$ within a country ($\Delta l_i$)

In addition, we collect data on two measures of skill intensity in the initial year 1983: wagebill shares of skilled labor ($s$) and employment shares of skilled labor ($e$).

The predicted contributions of each capital type to change in the economy-wide skill intensity in production *through industry growth alone* are

$$
\begin{aligned}
C &= \sum_i c_i \Delta l_i s_i \\
N &= \sum_i n_i \Delta l_i s_i \ ,
\end{aligned}
$$

for ICT and non-ICT capital, respectively. We divide $C$ and $N$ by aggregate skill intensity in the initial year, multiply by 100 and divide by the number of years over which they are computed—this gives us annualized percent point contributions to changes in skill intensity. We compute these both using $s$ and using $e$. We compare $C$ to $N$: This tells you which type of capital contributed to economy skill intensity more, via changes in production patterns.

The assumptions the underpin the validity of these calculations are constant returns to scale industries and that changes in the capital intensities do not alter skill intensity within industries over the period. The first assumption is easy to admit, while the second works only with specific production functions in certain environments (Leontief, or Cobb-Douglas with perfect competition). But what is important is that changes in the capital intensities do not alter the ranking of skill intensity across industries, which is evident in the data during this period.

# D Derivations for analytical framework section

There are two types of capital—$C$ and $K$ (think computers and tractors, respectively)—and two types of labor—skilled $H$ and unskilled $L$. The aggregate production function is given by

$$Q = \left[\delta X^{\frac{\sigma-1}{\sigma}} + (1-\delta) Y^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad ,$$

where

$$\begin{aligned} X &= H^{\beta} C^{1-\beta} \\ Y &= L^{\beta} K^{1-\beta} \ , \end{aligned}$$

$\beta \in (0,1)$ and $\sigma > 1$.

Workers supply labor—either $H$ or $L$— inelastically. Denote the wage of skilled labor by $w_H$ and the wage of unskilled labor by $w_L$. Denote the price of capital as $r_j$ for $j \in \{C, K\}$. Competitive factor markets imply that factors are paid the value of their marginal product:

$$\begin{aligned}
\frac{\partial Q}{\partial H} &= \frac{\sigma}{\sigma-1} [\cdot]^{\frac{\sigma}{\sigma-1}-1} \delta \frac{\sigma-1}{\sigma} X^{\frac{\sigma-1}{\sigma}-1} \beta \frac{X}{H} = \beta\delta Q^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} H^{-1} = w_H \\
\frac{\partial Q}{\partial C} &= \frac{\sigma}{\sigma-1} [\cdot]^{\frac{\sigma}{\sigma-1}-1} \delta \frac{\sigma-1}{\sigma} X^{\frac{\sigma-1}{\sigma}-1} (1-\beta) \frac{X}{C} = (1-\beta)\delta Q^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} C^{-1} = r_C \\
\frac{\partial Q}{\partial L} &= \frac{\sigma}{\sigma-1} [\cdot]^{\frac{\sigma}{\sigma-1}-1} (1-\delta) \frac{\sigma-1}{\sigma} Y^{\frac{\sigma-1}{\sigma}-1} \beta \frac{Y}{L} = \beta (1-\delta) Q^{\frac{1}{\sigma}} Y^{\frac{\sigma-1}{\sigma}} L^{-1} = w_L \\
\frac{\partial Q}{\partial K} &= \frac{\sigma}{\sigma-1} [\cdot]^{\frac{\sigma}{\sigma-1}-1} (1-\delta) \frac{\sigma-1}{\sigma} Y^{\frac{\sigma-1}{\sigma}-1} (1-\beta) \frac{Y}{K} = (1-\beta)(1-\delta) Q^{\frac{1}{\sigma}} Y^{\frac{\sigma-1}{\sigma}} K^{-1} = r_K \ .
\end{aligned}$$

The relative wage of skilled workers is

$$\begin{aligned}
\omega \equiv \frac{w_H}{w_L} &= \frac{\delta X^{\frac{\sigma-1}{\sigma}} H^{-1}}{(1-\delta) Y^{\frac{\sigma-1}{\sigma}} L^{-1}} = \frac{\delta}{1-\delta} \left(\frac{H^{\beta} C^{1-\beta}}{L^{\beta} K^{1-\beta}}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{H}{L}\right)^{-1} \\
&= \frac{\delta}{1-\delta} \left(\frac{H}{L}\right)^{-\frac{\sigma-\beta(\sigma-1)}{\sigma}} \left(\frac{C}{K}\right)^{\frac{(1-\beta)(\sigma-1)}{\sigma}} \ ,
\end{aligned}$$

as in the main text. In order to derive the expression for $C/K$ we start with

$$
\begin{aligned}
\frac{r_C}{r_K} &= \frac{\delta X^{\frac{\sigma-1}{\sigma}} C^{-1}}{(1-\delta) Y^{\frac{\sigma-1}{\sigma}} K^{-1}} = \frac{\delta}{1-\delta} \left( \frac{H^{\beta} C^{1-\beta}}{L^{\beta} K^{1-\beta}} \right)^{\frac{\sigma-1}{\sigma}} \left( \frac{C}{K} \right)^{-1} \\
&= \frac{\delta}{1-\delta} \left( \frac{H}{L} \right)^{\frac{\beta(\sigma-1)}{\sigma}} \left( \frac{C}{K} \right)^{\frac{(1-\beta)(\sigma-1)-\sigma}{\sigma}} ,
\end{aligned}
$$

which gives

$$
\frac{C}{K} = \left( \frac{\delta}{1-\delta} \right)^{\frac{\sigma}{\sigma-(1-\beta)(\sigma-1)}} \left( \frac{H}{L} \right)^{\frac{\beta(\sigma-1)}{\sigma-(1-\beta)(\sigma-1)}} \left( \frac{r_C}{r_K} \right)^{-\frac{\sigma}{\sigma-(1-\beta)(\sigma-1)}} ,
$$

as in the main text.

Here we show that $\sigma - (1-\beta)(\sigma-1) > 0$ for $\beta \in (0,1)$ and $\sigma > 0$, regardless of whether $\sigma$ is greater than unity or not. For $\sigma > 1$ we have a positive fraction, $(1-\beta)$, times a positive number smaller than $\sigma$, $(\sigma-1)$, which together give $(1-\beta)(\sigma-1) < \sigma$. When $\sigma < 1$ the product $(1-\beta)(\sigma-1) < 0$, but then deducting a negative number from a positive one remains positive.

# E Derivation of complementarity equation

Suppose that capital is quasi-fixed and that there are two variable inputs: skilled and unskilled labor, $h$ and $l$, respectively (this naturally extends to $k$ variable inputs). So variable costs are given by $c = w_h \cdot h + w_l \cdot l$. If $h$ and $l$ are the argmin of costs, then $c$ is the cost function. The logarithm of $c$ can be approximated a translog cost function:

$$
\begin{aligned}
\ln(c) &= \alpha_h \ln(w_h) + \alpha_l \ln(w_l) + \alpha_k \ln(k) + \alpha_y \ln(y) + \\
&+ \frac{1}{2} \left[ \beta_{hh} \ln(w_h)^2 + \beta_{hl} \ln(w_h) \ln(w_l) + \beta_{lh} \ln(w_l) \ln(w_h) + \beta_{ll} \ln(w_l)^2 + \beta_{kk} \ln(k)^2 + \beta_{yy} \ln(y)^2 \right] \\
&+ \gamma_{hk} \ln(w_h) \ln(k) + \gamma_{hy} \ln(w_h) \ln(y) + \gamma_{lk} \ln(w_l) \ln(k) + \gamma_{ly} \ln(w_l) \ln(y) + \gamma_{ky} \ln(k) \ln(y) ,
\end{aligned}
$$

where $k$ is capital and $y$ is output. Symmetry implies $\beta_{hl} = \beta_{lh}$.

By Shephard's lemma, $\partial c / \partial w_h = h$, so that the cost share of skilled labor is

$$
S \equiv \frac{w_h h}{c} = \frac{\partial \ln(c)}{\partial \ln(w_h)} = \frac{\partial c}{\partial w_h} \frac{w_h}{c} .
$$

Using this in the translog we get

$$
S = \alpha_h + \beta_{hh} \ln(w_h) + \beta_{hl} \ln(w_l) + \gamma_{hk} \ln(k) + \gamma_{hy} \ln(y) .
$$

By linear homogeneity of cost with respect to prices, cost shares are homogenous of degree zero. Therefore $\beta_{hh} + \beta_{hl} = 0$. By linear homogeneity of the production function we have $\gamma_{hk} + \gamma_{hy} = 0$ (increasing all inputs by same factor increases output by same factor, but this should not affect the cost share). Using these two properties gives

$$
S = \alpha + \beta \ln\left( \frac{w_h}{w_l} \right) + \gamma \ln\left( \frac{k}{y} \right) .
$$

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Table 1: Capital Goods Classifications, R&D Intensity and Complementarity

A. ISIC Classifications

| | R&D intensity rank | Complementarity | EU-KLEMS ICT classification |
|---|---|---|---|
| Aircraft equipment (3845) | 1 | Skilled labor | Non-ICT |
| Office, computing, and accounting machinery (3825) | 2 | Skilled labor | ICT |
| Communication equipment (3832) | 3 | Skilled labor | ICT |
| Professional goods (385) | 4 | - | Non-ICT |
| Electrical equipment, excluding communication (383 *without* 3832) | 5 | Unskilled labor | Non-ICT |
| Motor vehicles (3843) | 6 | - | Non-ICT |
| Non-electrical equipment (382 *without* 3825) | 7 | Unskilled labor | Non-ICT |
| Other transportation equipment (3842, 3844, 3849) | 8 | Unskilled labor | Non-ICT |
| Fabricated metal products (381) | 9 | Unskilled labor | Non-ICT |

B. EU-KLEMS Classifications

| | Complementarity | EU-KLEMS ICT classification |
|---|---|---|
| Computing equipment | Skilled labor | ICT |
| Communication equipment | Skilled labor | ICT |
| Software | Skilled labor | ICT |
| Transportation equipment | Unskilled labor | Non-ICT |
| Machinery | Unskilled labor | Non-ICT |

Notes: R&D intensity rank by ISIC (numbers in parentheses) in 1980 is from Caselli and Wilson (2004). This ranking is based on their estimates of world R&D expenditures divided by world sales for each capital good; it is the same whether R&D flows or stocks (perpetual inventory method) are used. See Appendix for more detailed descriptions of ISIC capital classifications. We allocate EU-KLEMS ICT classifications to the ISIC classification based on the EU-KLEMS documentation. See O'Mahony and Timmer (2009) for documentation of the EU-KLEMS database. The degree of complementarity with skilled or unskilled labor is from authors' estimation; for details see Tables 6-7.

Table 2: Descriptive Statistics and Correlations, Import composition and Relative Wages

A. Descriptive Statistics

| | Mean | Median | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Δln(wH/wL) | -0.002 | -0.0025 | 0.034 | -0.093 | 0.071 |
| Δln(H/L) | 0.04 | 0.03 | 0.04 | -0.03 | 0.21 |
| Δz | 0.0003 | 0 | 0.02 | -0.07 | 0.05 |
| ln(import ratio) | -0.74 | -0.76 | 0.73 | -2.36 | 0.68 |
| ln(R&D intensive capital imports/GDP) | -5.08 | -5.18 | 1.07 | -6.92 | -2.27 |
| ln(R&D un-intensive capital imports/GDP) | -4.34 | -4.26 | 0.73 | -6.45 | -2.55 |
| ln(R&D intermediate-intensive capital imports/GDP) | -4.21 | -4.4 | 0.85 | -5.68 | -2.08 |
| ln(aggregate capital imports/GDP) | -3.28 | -3.28 | 0.73 | -4.49 | -1.54 |
| ln(R&D intensive capital imports) | 6.74 | 6.55 | 2.07 | 2.59 | 10.31 |
| ln(R&D un-intensive capital imports) | 7.48 | 7.27 | 1.79 | 3.98 | 10.56 |
| ln(R&D intermediate-intensive capital imports) | 7.61 | 7.42 | 1.77 | 4.38 | 11.24 |
| ln(aggregate capital imports) | 7.93 | 7.58 | 1.86 | 4.26 | 10.99 |
| Δln(uvH) | -0.00004 | -0.0001 | 0.007 | -0.012 | 0.014 |
| Δln(uvL) | 0.025 | 0.024 | 0.006 | 0.015 | 0.035 |

B. Correlations

| | Δln(wH/wL) | Δln(H/L) | Δz | ln(MH/ML) | ln(MH/GDP) | ln(ML/GDP) | ln(MN/GDP) | ln(M/GDP) | Δln(uvH) | Δln(uvL) |
|---|---|---|---|---|---|---|---|---|---|---|
| Δln(wH/wL) | 1 | | | | | | | | | |
| Δln(H/L) | 0.11 | 1 | | | | | | | | |
| Δz | 0.35 | -0.04 | 1 | | | | | | | |
| ln(import ratio) | 0.5 | 0.07 | 0.09 | 1 | | | | | | |
| ln(R&D intensive capital imports/GDP) | 0.3 | 0.22 | 0.2 | 0.73 | 1 | | | | | |
| ln(R&D un-intensive capital imports/GDP) | -0.06 | 0.25 | 0.21 | 0.07 | 0.74 | 1 | | | | |
| ln(R&D intermediate-intensive capital imports/GDP) | 0.22 | 0.09 | 0.32 | 0.59 | 0.66 | 0.38 | 1 | | | |
| ln(aggregate capital imports/GDP) | 0.16 | 0.2 | 0.3 | 0.53 | 0.89 | 0.78 | 0.85 | 1 | | |
| Δln(uvH) | -0.3 | -0.24 | -0.27 | -0.63 | -0.9 | -0.69 | -0.59 | -0.82 | 1 | |
| Δln(uvL) | -0.01 | -0.13 | -0.32 | -0.19 | -0.69 | -0.82 | -0.49 | -0.81 | 0.72 | 1 |

Notes: The sample includes 58 observations, covering 20 developing countries over the period of 1983-1997. Δln(wH/wL) is change in the logarithm of skilled relative wage in manufacturing; Δln(H/L) is change in logarithm of aggregate relative supply of skill; Δz is shift in export shares to rich OECD countries; ln(import ratio) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; ln(capital imports/GDP) is the logarithm of capital imports (for the R&D intensive, unintensive, and intermediate-intensive groups, as well as the overall aggregated group) normalized by GDP; Δln(uvH) and Δln(uvL) are the R&D-intensive and R&D-unintensive instruments, respectively. See Appendix for further details on the sample and variables.

Table 3: Capital Import Composition and the Skill Premium, 1983-1997, OLS

| | Dependent variable: Δln(wH/wL) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Δln(H/L) | 0.15*** | 0.32*** | 0.15** | 0.22*** | 0.20*** | 0.19*** | 0.16*** | 0.21*** |
| | (0.06) | (0.06) | (0.06) | (0.05) | (0.04) | (0.04) | (0.06) | (0.07) |
| ln(MH/ML) | 0.05*** | | 0.05*** | 0.05*** | 0.04*** | | | |
| | (0.01) | | (0.01) | (0.01) | (0.01) | | | |
| ln(M/GDP) | | 0.01 | 0.01 | 0.008 | 0.00 | | | |
| | | (0.01) | (0.01) | (0.01) | (0.01) | | | |
| Δz | | | | | 0.54*** | 0.54*** | | |
| | | | | | (0.14) | (0.17) | | |
| ln(MH/GDP) | | | | | | 0.038*** | 0.046*** | 0.057*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(ML/GDP) | | | | | | -0.034*** | -0.043*** | -0.051*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(MN/GDP) | | | | | | 0.003 | 0.01* | 0.004 |
| | | | | | | (0.01) | (0.01) | (0.01) |
| R-squared, within | 0.47 | 0.21 | 0.49 | 0.64 | 0.64 | 0.65 | 0.52 | 0.64 |
| Observations | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period FE | No | No | No | Yes | No | No | No | Yes |

Notes: OLS estimates. 20 countries in all specifications. Robust standard errors, clustered by country, in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Δln(wH/wL) is change in the logarithm of skilled relative wage; Δln(H/L) is change in logarithm of relative supply of skill; Δz is shift in export shares; ln(MH/ML) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; ln(M/GDP) is the logarithm of aggregate capital imports normalized by GDP, whereas similarly MH, ML. and MN refer to the R&D intensive, unintensive, and intermediate-intensive capital imports groups, respectively. For further details on sample and variables see Appendix.

Table 4: Capital Import Composition and the Skill Premium, 1983-1997, TSLS

A. Second stage results

| | Dependent variable: Δln(wH/wL) | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Δln(H/L) | 0.11* | 0.21*** | 0.15** | 0.17*** | 0.13* | 0.23*** |
| | (0.07) | (0.06) | (0.06) | (0.07) | (0.07) | (0.06) |
| Δz | | | 0.51*** | 0.55*** | | |
| | | | (0.16) | (0.15) | | |
| ln(MH/ML) | 0.06*** | 0.06*** | 0.05*** | | | |
| | (0.01) | (0.01) | (0.01) | | | |
| ln(M/GDP) | 0.01 | 0.01 | 0.01 | | | |
| | (0.01) | (0.01) | (0.01) | | | |
| ln(MH/GDP) | | | | 0.04*** | 0.05*** | 0.06*** |
| | | | | (0.01) | (0.01) | (0.01) |
| ln(ML/GDP) | | | | -0.04*** | -0.05*** | -0.05*** |
| | | | | (0.01) | (0.02) | (0.02) |
| R-squared, within | 0.47 | 0.64 | 0.62 | 0.63 | 0.47 | 0.64 |
| Observations | 58 | 58 | 58 | 58 | 58 | 58 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Period FE | No | Yes | No | No | No | Yes |

B. First stage results

| | (1) | (2) | (3) | (4H) | (4L) | (5H) | (5L) | (6H) | (6L) |
|---|---|---|---|---|---|---|---|---|---|
| Dep. Var.: | | ln(MH/ML) | | ln(MH/GDP) | ln(ML/GDP) | ln(MH/GDP) | ln(ML/GDP) | ln(MH/GDP) | ln(ML/GDP) |
| Δln(uv_MH) | -62.39*** | -63.27*** | -60.41*** | -84.88*** | -25.07 | -84.49*** | -21.74 | -82.9*** | -17.73 |
| | (15.93) | (14.71) | (15.84) | (18.4) | (15.91) | (17.67) | (17.91) | (18.24) | (15.99) |
| Δln(uv_ML) | 71.24*** | 66.72*** | 68.19*** | -55.85*** | -102.75*** | -55.74*** | -101.82*** | -53.09*** | -100.17*** |
| | (15.24) | (18.61) | (15.23) | (15.45) | (11.19) | (15.25) | (11.89) | (14.64) | (10.99) |
| Hansen J-stat (p-value) | 0.535 (0.47) | 0.6 (0.94) | 0.468 (0.49) | - | | - | | - | |
| F-stat for weak instruments | 16.936 | 19.235 | 15.367 | 11.403 | | 11.903 | | 14.054 | |

Notes: TSLS estimates. 20 countries in all specifications. Robust standard errors, clustered by country, in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Δln(wH/wL) is change in the logarithm of skilled relative wage; Δln(H/L) is change in logarithm of relative supply of skill; Δz is shift in export shares; ln(MH/ML) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; ln(M/GDP) is the logarithm of aggregate capital imports normalized by GDP, whereas similarly MH, ML. and MN refer to the R&D intensive, unintensive, and intermediate-intensive capital imports groups, respectively; Δln(uvH) and Δln(uvL) are the R&D-intensive and R&D-unintensive instruments, respectively. For further details on sample and variables see Appendix.

Table 5: Determinants of the Import Ratio, 1983-1997

| | Dependent variable: ln(MH/ML) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Δln(H/L) | 3.26*** | 2.26** | 2.64** | 3.80** | 2.77** | 4.33*** | 3.61*** | 2.49** | 2.89** | 3.30** | 2.78** | 3.74** |
| | (0.778) | (0.902) | (1.144) | (1.696) | (1.069) | (1.448) | (1.086) | (1.046) | (1.080) | (1.407) | (1.046) | (1.366) |
| Δln(uv_MH/uv_ML) | -0.78 | | | | | | -0.77 | | | | | |
| | (0.559) | | | | | | (0.520) | | | | | |
| Δln(uv_MH) | | -62.76*** | -61.80** | -52.16** | -66.68*** | -56.26*** | | -65.17*** | -61.83*** | -57.67*** | -64.30*** | -58.88*** |
| | | (21.887) | (21.934) | (19.858) | (21.449) | (18.689) | | (17.856) | (17.037) | (17.991) | (17.615) | (18.260) |
| Δln(uv_ML) | | 46.08*** | 43.44*** | 35.45** | 38.90*** | 25.43 | | 47.08*** | 46.40*** | 42.93*** | 44.10*** | 31.70** |
| | | (14.649) | (13.740) | (15.420) | (12.807) | (16.588) | | (11.395) | (10.529) | (12.628) | (10.518) | (14.538) |
| Industrial share | | | 0.27 | 1.93 | 0.14 | 2.74* | | | 0.05 | 1.07 | 0.09 | 2.48 |
| | | | (0.456) | (1.176) | (0.539) | (1.481) | | | (0.339) | (1.228) | (0.369) | (1.430) |
| Government share | | | 0.08 | 0.18 | 0.05 | 0.26 | | | 0.15 | 0.29* | 0.10 | 0.29* |
| | | | (0.138) | (0.165) | (0.186) | (0.203) | | | (0.177) | (0.156) | (0.182) | (0.165) |
| Services share | | | -0.21 | 1.37 | -0.52 | 1.99 | | | -0.97 | 0.03 | -0.81 | 1.69 |
| | | | (0.924) | (1.508) | (1.053) | (1.865) | | | (1.036) | (1.685) | (1.036) | (1.736) |
| Income per capita | | | 0.15 | 0.04 | 0.03 | -0.11 | | | 0.03 | 0.07 | 0.03 | -0.02 |
| | | | (0.173) | (0.185) | (0.180) | (0.183) | | | (0.156) | (0.171) | (0.145) | (0.184) |
| Financial development | | | | -0.15 | | -0.40 | | | | -0.30 | | -0.48 |
| | | | | (0.422) | | (0.383) | | | | (0.314) | | (0.333) |
| IPR protection | | | | | 0.29** | 0.35*** | | | | | 0.08 | 0.26* |
| | | | | | (0.129) | (0.083) | | | | | (0.127) | (0.129) |
| R-squared, within | 0.249 | 0.508 | 0.516 | 0.575 | 0.575 | 0.671 | 0.387 | 0.654 | 0.665 | 0.683 | 0.669 | 0.721 |
| Observations | 58 | 58 | 57 | 54 | 54 | 51 | 58 | 58 | 57 | 54 | 54 | 51 |
| No. of countries | 20 | 20 | 20 | 20 | 19 | 19 | 20 | 20 | 20 | 20 | 19 | 19 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Period FE | No | No | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: OLS estimates. Robust standard errors, clustered by country, *** p<0.01, ** p<0.05, * p<0.1. ln(MH/ML) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; Δln(H/L) is change in logarithm of relative supply of skill; Δln(uvH) and Δln(uvL) are the R&D-intensive and R&D-unintensive instruments, respectively; Industrial/Govnerment/Services share are the sectoral value added share in GDP; Income per capita is GDP per capita; Financial development is the M3 money supply as a fraction of GDP; IPR protection is the Intellectual Property Rights Protection Index. For further details on sample and variables see Appendix.

Table 6: Capital Complementarity to Skilled and Unskilled Labor, EU-KLEMS data, 1970-2005

Dependent variable: Wage bill share of skilled workers

A. Narrow definition of skilled labor: University-equivalent tertiary education

| Capital type: | Computing equipment | Communication equipment | Software | Transport equipment | Machinery | - | Total |
|---|---|---|---|---|---|---|---|
| | 0.21*** | 0.15* | 0.22*** | -0.54*** | -0.62*** | | 0.23*** |
| | (0.03) | (0.08) | (0.05) | (0.09) | (0.11) | | (0.03) |
| ICT (groups 1,2,3) | | | | | | 0.21*** | |
| | | | | | | (0.06) | |
| Non-ICT (groups 4,5) | | | | | | -0.54*** | |
| | | | | | | (0.12) | |
| Observations | 345 | 345 | 345 | 345 | 345 | 345 | 345 |
| No. of countries | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| R-squared, within | 0.820 | 0.37 | 0.43 | 0.7 | 0.74 | 0.83 | 0.36 |

B. Broad definition of skilled labor: At least high-school

| Capital type: | Computing equipment | Communication equipment | Software | Transport equipment | Machinery | - | Total |
|---|---|---|---|---|---|---|---|
| | 0.08*** | 0.17*** | 0.06*** | -0.20*** | -0.23*** | | 0.09*** |
| | (0.01) | (0.012) | (0.016) | (0.046) | (0.054) | | (0.010) |
| ICT (groups 1,2,3) | | | | | | 0.10*** | |
| | | | | | | (0.024) | |
| Non-ICT (groups 4,5) | | | | | | -0.18*** | |
| | | | | | | (0.044) | |
| Observations | 345 | 345 | 345 | 345 | 345 | 345 | 345 |
| No. of countries | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| R-squared, within | 0.754 | 0.673 | 0.331 | 0.714 | 0.682 | 0.837 | 0.350 |

Notes: This table reports TSLS estimates of γ in the regression $S = \beta*\ln(wH/wL) + \gamma*\log(capital/output) + \varepsilon$, for different capital types. S is the wage bill share of skilled workers and wH/wL is the relative wage of skilled to unskilled workers. Positive coefficients indicate complementarity to skilled workers; negative coefficients indicate complementarity to unskilled workers. Instruments are lagged values; all first stage results report F-statistics higher than 1000. All regressions include time and country fixed effects. Data: EU KLEMS. Standard errors in parentheses are clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Capital Complementarity to Skilled and Unskilled Labor, Imputed Capital Stocks

| | Dependent variable: Wage bill share of skilled workers | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **A. Narrow definition of skilled labor: University-equivalent tertiary education** | | | | | | | | | | | |
| R&D intensity rank: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | - |
| Capital type: | Aircraft equipment | Office, computing, and accounting machinery | Communication equipment | Professional goods | Electrical equipment, excluding communication | Motor vehicles | Non-electrical equipment | Other transportation equipment | Fabricated metal products | - | Total |
| | 0.19** | 0.19*** | 0.04* | -0.01 | -0.14*** | -0.12 | -0.17* | -0.40*** | -0.43*** | | 0.40*** |
| | (0.07) | (0.05) | (0.02) | (0.08) | (0.03) | (0.07) | (0.09) | (0.07) | (0.09) | | (0.07) |
| KH (R&D ranks 1,2,3) | | | | | | | | | | 0.89*** | |
| | | | | | | | | | | (0.08) | |
| KL (R&D ranks 5,7,8,9) | | | | | | | | | | -0.90*** | |
| | | | | | | | | | | (0.12) | |
| Observations | 459 | 411 | 435 | 435 | 435 | 346 | 368 | 448 | 464 | 286 | 286 |
| No. of countries | 24 | 23 | 24 | 24 | 24 | 18 | 20 | 24 | 24 | 16 | 16 |
| R-squared, within | 0.672 | 0.583 | 0.609 | 0.774 | 0.643 | 0.474 | 0.620 | 0.640 | 0.658 | 0.702 | 0.666 |
| **B. Broad definition of skilled labor: At least high-school** | | | | | | | | | | | |
| R&D intensity rank: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | - |
| Capital type: | Aircraft equipment | Office, computing, and accounting machinery | Communication equipment | Professional goods | Electrical equipment, excluding communication | Motor vehicles | Non-electrical equipment | Other transportation equipment | Fabricated metal products | - | Total |
| | 0.15 | 0.03 | 0.06* | -0.02 | -0.11*** | 0.13* | 0.01 | -0.16*** | -0.13 | | 0.24*** |
| | (0.12) | (0.02) | (0.03) | (0.05) | (0.02) | (0.07) | (0.05) | (0.05) | (0.08) | | (0.07) |
| KH (R&D ranks 1,2,3) | | | | | | | | | | 0.51*** | |
| | | | | | | | | | | (0.16) | |
| KL (R&D ranks 5,7,8,9) | | | | | | | | | | -0.43*** | |
| | | | | | | | | | | (0.13) | |
| Observations | 459 | 411 | 435 | 435 | 435 | 346 | 368 | 448 | 464 | 286 | 286 |
| No. of countries | 24 | 23 | 24 | 24 | 24 | 18 | 20 | 24 | 24 | 16 | 16 |
| R-squared, within | 0.491 | 0.524 | 0.552 | 0.546 | 0.534 | 0.398 | 0.434 | 0.560 | 0.470 | 0.657 | 0.582 |

Notes: This table reports TSLS estimates of γ in the regression $S = \beta^*\ln(wH/wL) + \gamma^*\log(\text{capital/output}) + \varepsilon$, for different capital types. S is the wage bill share of skilled workers and wH/wL is the relative wage of skilled to unskilled workers. Positive coefficients indicate complementarity to skilled workers; negative coefficients indicate complementarity to unskilled workers. Instruments are lagged values; all first stage results report F-statistics higher than 1000. All regressions include time and country fixed effects. All data except capital stocks are from the EU KLEMS. Capital stocks are imputed perpetual inventory method; see text for details. Standard errors in parentheses are clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: R&D Intensity and Trade Costs, U.S. 1974-2004

A. Regressions

| | Dependent variable: Log ad valorem freight cost | | | | | |
|---|---|---|---|---|---|---|
| | Air shipments | | | Sea shipments | | |
| Log(weight/value) | 0.57 | 0.55 | 0.56 | 0.47 | 0.46 | 0.47 |
| Log(distance) | 0.25 | 0.25 | 0.25 | 0.14 | 0.14 | 0.13 |
| Log(containerized share) | | | | 0.04 | 0.03 | 0.04 |
| R&D intensity rank = 1 | | - | | | - | |
| R&D intensity rank = 2 | | 0.18 | | | -0.55 | |
| R&D intensity rank = 3 | | 0.19 | | | -0.53 | |
| R&D intensity rank = 4 | | 0.23 | | | -0.33 | |
| R&D intensity rank = 5 | | 0.22 | | | -0.46 | |
| R&D intensity rank = 6 | | 0.47 | | | -0.25 | |
| R&D intensity rank = 7 | | 0.26 | | | -0.47 | |
| R&D intensity rank = 8 | | 0.44 | | | -0.28 | |
| R&D intensity rank = 9 | | 0.46 | | | -0.35 | |
| MH indicator | | | - | | | - |
| MN indicator | | | 0.08 | | | 0.17 |
| ML indicator | | | 0.13 | | | 0.07 |
| Observations | 237,470 | 237,470 | 237,470 | 186,647 | 186,647 | 186,647 |
| R-squared, within | 0.465 | 0.472 | 0.467 | 0.331 | 0.338 | 0.333 |
| Number of year | 31 | 31 | 31 | 31 | 31 | 31 |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

B. Averages

| | Air shipments | | | | Sea shipments | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Capital type | Freight cost (%) | Log wgt./val. | Log dist. | Obs. | Freight cost (%) | Log wgt./val. | Log dist. | Container share (%) | Obs. |
| R&D intensity rank = 1 | 5.16 | -0.48 | 8.63 | 3220 | 6.36 | 0.67 | 8.77 | 8.64 | 1630 |
| R&D intensity rank = 2 | 5.61 | -0.19 | 8.66 | 15338 | 3.59 | 1.37 | 8.81 | 8.71 | 7420 |
| R&D intensity rank = 3 | 7.18 | 0.12 | 8.68 | 16317 | 4.02 | 1.51 | 8.86 | 9.07 | 9646 |
| R&D intensity rank = 4 | 6.53 | -0.03 | 8.70 | 43724 | 4.77 | 1.47 | 8.87 | 8.17 | 23982 |
| R&D intensity rank = 5 | 8.86 | 0.38 | 8.67 | 47378 | 5.21 | 2.06 | 8.80 | 8.78 | 32548 |
| R&D intensity rank = 6 | 23.19 | 1.85 | 8.62 | 2928 | 9.04 | 2.71 | 8.70 | 9.72 | 3889 |
| R&D intensity rank = 7 | 10.98 | 0.87 | 8.65 | 58660 | 5.87 | 2.33 | 8.79 | 8.82 | 57163 |
| R&D intensity rank = 8 | 21.30 | 1.71 | 8.65 | 3038 | 7.80 | 2.54 | 8.83 | 7.97 | 3149 |
| R&D intensity rank = 9 | 16.64 | 1.30 | 8.69 | 46867 | 7.80 | 2.81 | 8.80 | 9.20 | 47220 |
| MH | 6.30 | -0.07 | 8.66 | 34875 | 4.05 | 1.38 | 8.83 | 8.89 | 18696 |
| MN | 7.57 | 0.09 | 8.70 | 46652 | 5.37 | 1.64 | 8.85 | 8.39 | 27871 |
| ML | 12.24 | 0.87 | 8.67 | 155943 | 6.41 | 2.43 | 8.80 | 8.92 | 140080 |

Notes: For both transport modes (air and sea) in Panel A regressions the reference group is the highest R&D rank capital (aircraft equipment) or MH. All coefficients are highly statistically significant, at significance levels well below 1%. Panel B reports averages by capital type for all variables used in Panel A. Note that % denotes percent points for variables not in logs, even if in Panel A the variable is used in logs; this is done to ease interpretation. Data: Hummels (2007).

Table 9: R&D Intensity and Import Elasticity with respect to Distance, 1980

A. All countries

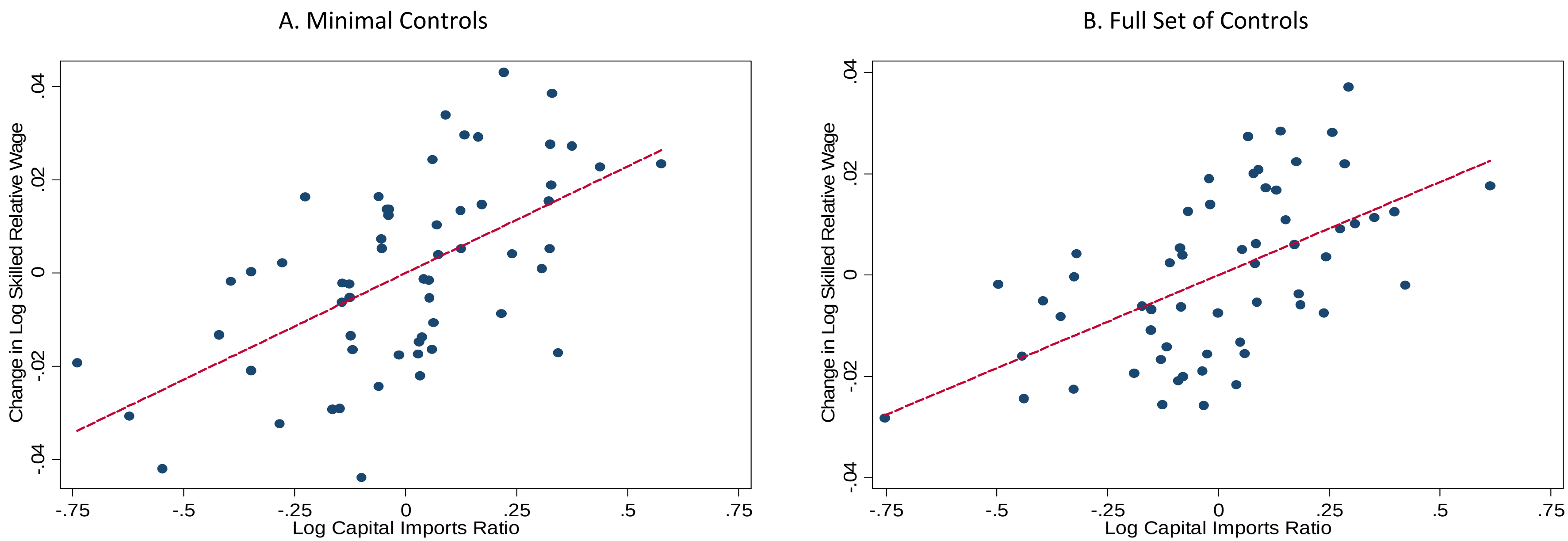
| R&D intensity rank: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | 1+2+3 | 4+6 | 5+7+8+9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital type: | Aircraft equipment | Office, computing, and accounting machinery | Communication equipment | Professional goods | Electrical equipment, excluding communication | Motor vehicles | Non-electrical equipment | Other transportation equipment | Fabricated metal products | Spearman rank correlation with R&D intensity | MH | MN | ML |
| OLS | -0.62 | -0.95 | -1 | -1.04 | -1.29 | -1.29 | -1.24 | -1.1 | -1.41 | -0.85 | -1.01 | -1.2 | -1.32 |
| Heckit | -0.51 | -0.79 | -0.75 | -0.83 | -1 | -0.87 | -1.06 | -0.93 | -1.03 | -0.87 | -0.85 | -0.92 | -1.11 |
| HMR | -0.15 | -0.43 | -0.48 | -0.59 | -0.77 | -0.79 | -0.76 | -0.51 | -0.87 | -0.78 | -0.55 | -0.76 | -0.85 |
| OLS, using port distance | -0.46 | -0.86 | -0.8 | -0.86 | -1.12 | -1.12 | -1.11 | -1.01 | -1.26 | -0.82 | -0.86 | -1.04 | -1.18 |

B. Developing countries

| R&D intensity rank: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | 1+2+3 | 4+6 | 5+7+8+9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital type: | Aircraft equipment | Office, computing, and accounting machinery | Communication equipment | Professional goods | Electrical equipment, excluding communication | Motor vehicles | Non-electrical equipment | Other transportation equipment | Fabricated metal products | Spearman rank correlation with R&D intensity | MH | MN | ML |
| OLS | -0.64 | -0.94 | -0.91 | -1.07 | -1.33 | -1.19 | -1.28 | -0.89 | -1.35 | -0.58 | -0.92 | -1.21 | -1.38 |
| Heckit | -0.55 | -0.87 | -0.83 | -0.91 | -1.17 | -0.89 | -1.15 | -0.84 | -1.06 | -0.53 | -0.84 | -1.04 | -1.18 |
| HMR | -0.34 | -0.51 | -0.49 | -0.69 | -0.87 | -0.77 | -0.84 | -0.54 | -0.92 | -0.77 | -0.57 | -0.81 | -0.95 |
| OLS, using port distance | -0.59 | -0.84 | -0.76 | -0.90 | -1.21 | -1.11 | -1.17 | -0.95 | -1.29 | -0.82 | -0.79 | -1.09 | -1.26 |

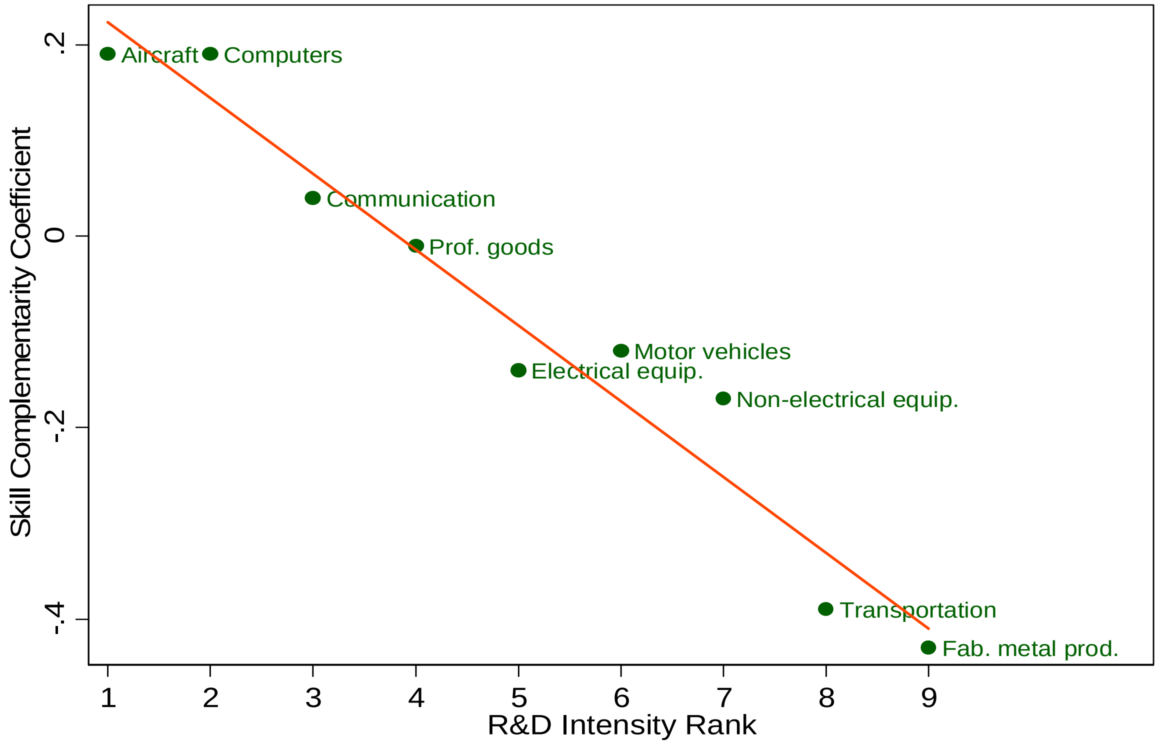
Notes: The table reports estimates of the coefficient to log distance in a gravity equation, in 1980. Other variables included in the regression are language, legal system, border, currency union, colonial ties, membership in WTO, islands, landlocked economies, common regional trade agreement, importer/exporter fixed effects, and an intercept. All coefficients to log distance are statistically significant at the 1% level. Estimation methods are OLS, Heckit correction for sample selection (Heckit) and Helpman, Melitz and Rubinstein (2008) correction for sample selection and extensive margin (HMR). Port distances are from Feyrer (2009). For description, and sources of variables, as well as list of economies included in each regression, see Appendix.

Figure 1: Wage Inequality and the Composition of Capital Imports, 1983-1997



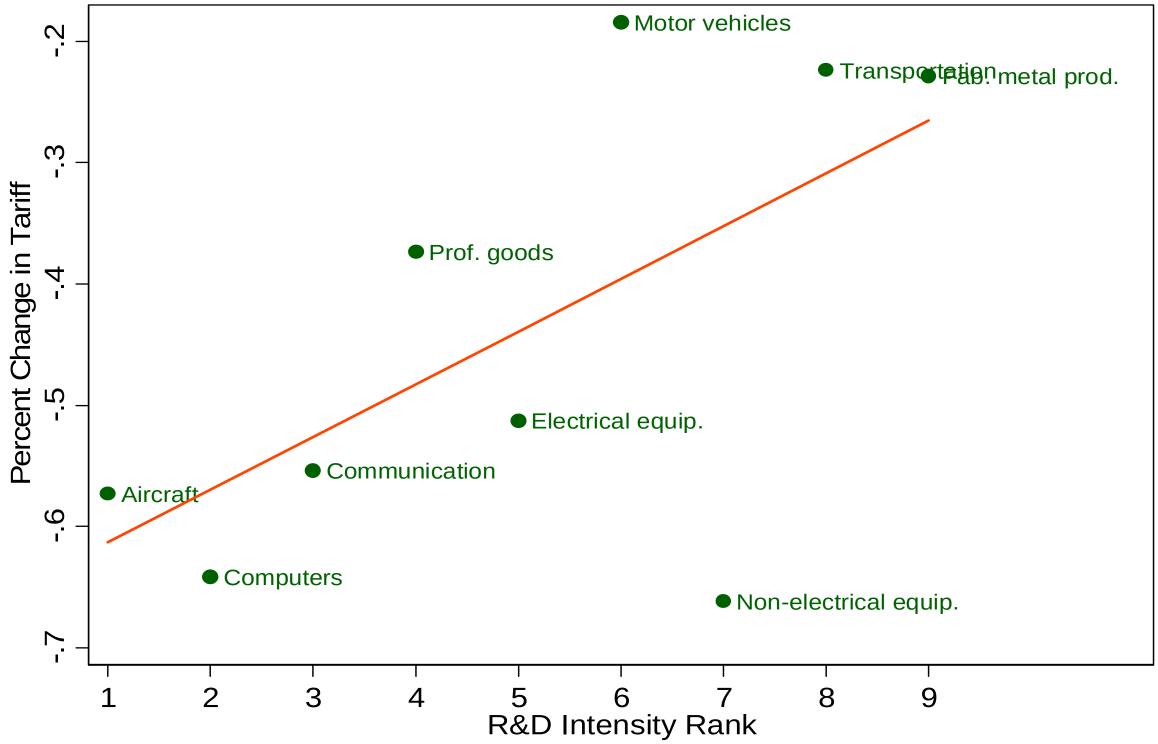

Notes: Both figures present conditional correlations between changes in log skilled relative wage, defined as the wage of nonproduction workers to production workers, and the capital import ratio. The latter is defined as the ratio of R&D-intensive capital equipment imports relative to less innovative capital equipment imports. In Panel A we control for the change in skill abundance and country fixed effects; the slope is 0.046 with partial R-squared of 0.35. In Panel B we control in addition for overall capital imports/GDP and shifts in export shares, the latter defined as the degree to which export shares from countries in the sample shift towards more skill intensive goods (Zhu and Trefler, 2005); the slope is 0.037 with partial R-squared of 0.32.

Figure 2: Technology and Complementarity to Skill



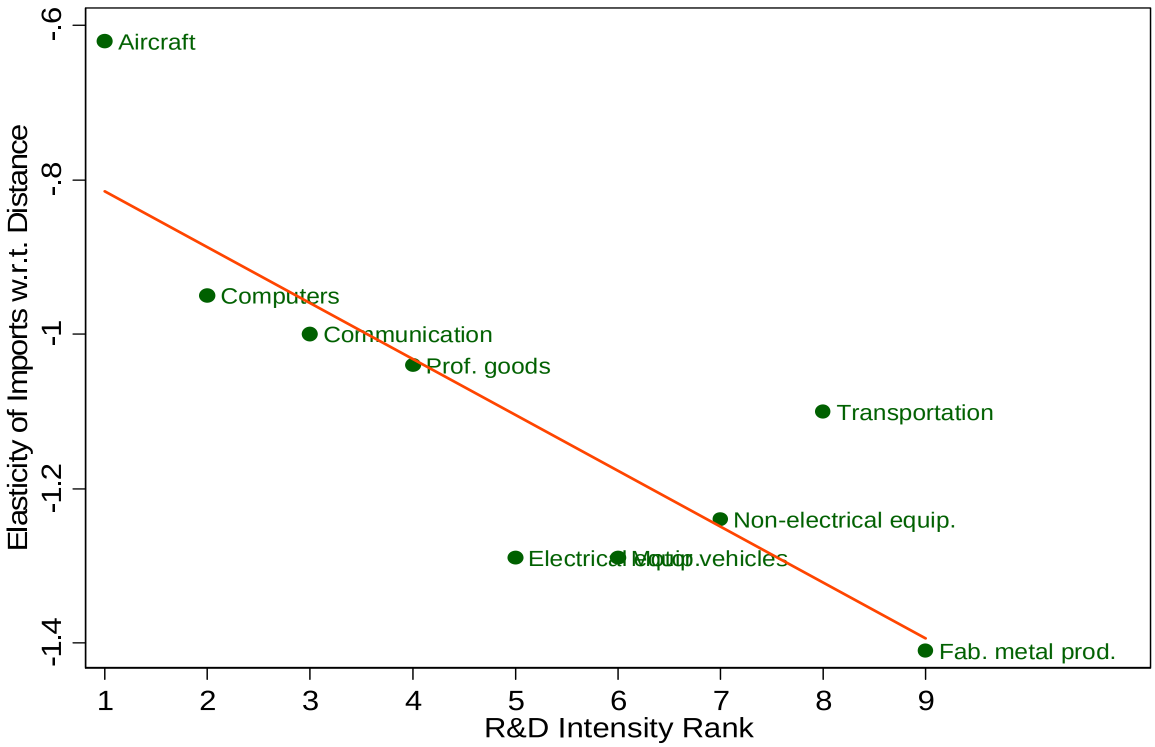

Notes: R&D intensity rank of capital goods group is from Caselli and Wilson (2004); lower numbers mean higher R&D intensity. The skill complementarity coefficient for each capital goods group is estimated in Table 7; higher numbers mean stronger complementarity with skilled labor, and negative numbers mean stronger complementarity with unskilled labor. The correlation between R&D intensity rank and complementarity coefficient is 0.98.

Figure 3: Technology and Change in Tariffs in 1988-2010




Notes: R&D intensity rank of capital goods group is from Caselli and Wilson (2004); lower numbers mean higher R&D intensity. The percent change in tariffs in 1988-2010 is the average change across all countries in the TRAINS dataset. The correlation between R&D intensity rank and the change in tariffs is 0.63.

Figure 4: Technology and Distance Trade Resistance




Notes: R&D intensity rank of capital goods group is from Caselli and Wilson (2004); lower numbers mean higher R&D intensity. The coefficient on log distance is the elasticity of imports with respect to estimated from the gravity equations, reported in Table 9; higher numbers in absolute value mean stronger trade resistance. The correlation between R&D intensity rank and the distance elasticity is 0.83.

Table A1: Contribution of ICT and non-ICT Capital to Changes in Demand for Skill

A. Annualized percent contribution to aggregate skill intensity

| | Employment share | | Wagebill share | |
|---|---|---|---|---|
| | ICT | Non-ICT | ICT | Non-ICT |
| EU15 | 0.170 | 0.396 | 0.156 | 0.360 |
| Japan | 0.118 | 0.405 | 0.119 | 0.419 |
| South Korea | 0.034 | 0.223 | 0.035 | 0.226 |
| U.S. | 0.049 | 0.131 | 0.046 | 0.129 |
| Czech Republic | 0.029 | 0.064 | 0.029 | 0.052 |
| Hungary | 0.077 | 1.363 | 0.048 | 1.395 |

B. Annualized percent contribution to skill intensity in manufacturing

| | Employment share | | Wagebill share | |
|---|---|---|---|---|
| | ICT | Non-ICT | ICT | Non-ICT |
| EU15 | 0.047 | 0.042 | 0.050 | 0.042 |
| Japan | 0.017 | 0.034 | 0.017 | 0.044 |
| South Korea | 0.016 | 0.999 | 0.017 | 1.047 |
| U.S. | 0.006 | 0.017 | 0.009 | 0.018 |
| Czech Republic | 0.037 | 0.230 | 0.044 | 0.250 |
| Hungary | 0.235 | 1.566 | 0.313 | 1.906 |

Notes: Sample for EU15, Japan, South Korea, U.S. is 1983-1997. Sample for Czech Republic, Hungary is 1995-1999. See Appendix for details on the exact calculations made.

Table A2: Capital Import Composition and the Skill Premium, 1983-1997, OLS

| | Dependent variable: Δln(wH/wL) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Δln(H/L) | 0.15*** | 0.32*** | 0.17** | 0.23*** | 0.19*** | 0.20*** | 0.18*** | 0.23*** |
| | (0.06) | (0.06) | (0.07) | (0.05) | (0.04) | (0.04) | (0.06) | (0.06) |
| ln(MH/ML) | 0.05*** | | 0.04*** | 0.05*** | 0.04*** | | | |
| | (0.01) | | (0.01) | (0.01) | (0.01) | | | |
| ln(M) | | 0.02* | 0.01 | 0.002 | -0.004 | | | |
| | | (0.01) | (0.01) | (0.01) | (0.01) | | | |
| Δz | | | | | 0.6*** | 0.58*** | | |
| | | | | | (0.15) | (0.16) | | |
| ln(MH) | | | | | | 0.036*** | 0.043*** | 0.055*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(ML) | | | | | | -0.037*** | -0.041*** | -0.048*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(MN) | | | | | | 0.00 | 0.008 | 0.001 |
| | | | | | | (0.01) | (0.01) | (0.01) |
| R-squared, within | 0.47 | 0.25 | 0.48 | 0.62 | 0.64 | 0.64 | 0.49 | 0.63 |
| Obs. | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | No | No | No | Yes | No | No | No | Yes |

Notes: OLS estimates. 20 countries in all specifications. Robust standard errors, clustered by country, in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Δln(wH/wL) is change in the logarithm of skilled relative wage; Δln(H/L) is change in logarithm of relative supply of skill; Δz is shift in export shares; ln(MH/ML) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; ln(M) is the logarithm of aggregate capital imports, whereas similarly MH, ML. and MN refer to the R&D intensive, unintensive, and intermediate-intensive capital imports groups, respectively. For further details on sample and variables see Appendix.

Table A3: Capital Import Composition and the Skill Premium, 1983-1997, OLS

| | Dependent variable: Δln(wH/wL) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Δln(H/L) | 0.15*** | 0.32*** | 0.16** | 0.23*** | 0.19*** | 0.2*** | 0.17*** | 0.23*** |
| | (0.06) | (0.06) | (0.06) | (0.05) | (0.04) | (0.04) | (0.06) | (0.06) |
| ln(MH/ML) | 0.05*** | | 0.04*** | 0.05*** | 0.037*** | | | |
| | (0.01) | | (0.01) | (0.01) | (0.004) | | | |
| ln(M/POP) | | 0.02* | 0.01 | 0.005 | -0.005 | | | |
| | | (0.01) | (0.01) | (0.01) | (0.01) | | | |
| Δz | | | | | 0.6*** | 0.58*** | | |
| | | | | | (0.14) | (0.16) | | |
| ln(MH/POP) | | | | | | 0.036*** | 0.043*** | 0.055*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(ML/POP) | | | | | | -0.037*** | -0.041*** | -0.047*** |
| | | | | | | (0.01) | (0.01) | (0.01) |
| ln(MN/POP) | | | | | | 0.00 | 0.01 | 0.003 |
| | | | | | | (0.007) | (0.01) | (0.01) |
| R-squared, within | 0.47 | 0.24 | 0.47 | 0.63 | 0.64 | 0.64 | 0.49 | 0.63 |
| Obs. | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| Country FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | No | No | No | Yes | No | No | No | Yes |

Notes: OLS estimates. 20 countries in all specifications. Robust standard errors, clustered by country, in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Δln(wH/wL) is change in the logarithm of skilled relative wage; Δln(H/L) is change in logarithm of relative supply of skill; Δz is shift in export shares; ln(MH/ML) is the logarithm of the ratio of R&D-intensive capital imports to R&D-unintensive capital imports; ln(M/GDP) is the logarithm of aggregate capital imports normalized by population, whereas similarly MH, ML. and MN refer to the R&D intensive, unintensive, and intermediate-intensive capital imports groups, respectively. For further details on sample and variables see Appendix.

Table A4: Capital Complementarity to Skilled and Unskilled Labor, EU-KLEMS data, 1970-2005

| | Dependent variable: Wage bill share of skilled workers | | | | | | |
|---|---|---|---|---|---|---|---|
| **A. Narrow definition of skilled labor: University-equivalent tertiary education** | | | | | | | |
| Capital type: | Computing equipment | Communication equipment | Software | Transport equipment | Machinery | - | Total |
| | 0.47*** | 0.79*** | 0.31*** | -1.24*** | -2.06*** | | 0.48*** |
| | (0.015) | (0.029) | (0.004) | (0.053) | (0.059) | | (0.006) |
| ICT (groups 1,2,3) | | | | | | 0.71*** | |
| | | | | | | (0.014) | |
| Non-ICT (groups 4,5) | | | | | | -1.02*** | |
| | | | | | | (0.039) | |
| Observations | 327 | 327 | 327 | 327 | 327 | 327 | 327 |
| No. of countries | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| R-squared, within | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| **B. Broad definition of skilled labor: At least high-school** | | | | | | | |
| Capital type: | Computing equipment | Communication equipment | Software | Transport equipment | Machinery | - | Total |
| | 0.26*** | 0.45*** | 0.11*** | -0.51*** | -0.82*** | | 0.16*** |
| | (0.004) | (0.008) | (0.001) | (0.016) | (0.021) | | (0.001) |
| ICT (groups 1,2,3) | | | | | | 0.32*** | |
| | | | | | | (0.003) | |
| Non-ICT (groups 4,5) | | | | | | -0.34*** | |
| | | | | | | (0.012) | |
| Observations | 327 | 327 | 327 | 327 | 327 | 327 | 327 |
| No. of countries | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| R-squared, within | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

Notes: This table reports TSLS estimates of $\gamma$ in the regression $\Delta S = \beta^*\Delta \ln(wH/wL) + \gamma^*\Delta \log(capital/output) + \varepsilon$, for different capital types. S is the wage bill share of skilled workers and wH/wL is the relative wage of skilled to unskilled workers. Δ is the first difference operator. Positive coefficients indicate complementarity to skilled workers; negative coefficients indicate complementarity to unskilled workers. Instruments are lagged values; all first stage results report F-statistics higher than 1000. All regressions include country fixed effects. Data: EU KLEMS. Standard errors in parentheses are clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

Table A5: R&D Intensity and Import Elasticity with respect to Distance, Robustness Checks

All countries

| R&D intensity rank: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | - | 1+2+3 | 4+6 | 5+7+8+9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital type: | Aircraft equipment | Office, computing, and accounting machinery | Communication equipment | Professional goods | Electrical equipment, excluding communication | Motor vehicles | Non-electrical equipment | Other transportation equipment | Fabricated metal products | Spearman rank correlation with R&D intensity | MH | MN | ML |
| OLS, controlling for tariffs, 1980 | -0.65 | -0.91 | -0.83 | -1.05 | -1.27 | -1.19 | -1.18 | -1.04 | -1.43 | -0.75 | -0.91 | -1.13 | -1.09 |
| OLS, border coefficient, 1980 | 0.56 | 0.31 | 0.5 | 0.41 | 0.68 | 0.62 | 0.51 | 1.01 | 0.53 | 0.45 | 0.48 | 0.63 | 0.83 |
| OLS, 1989 | -0.44 | -0.98 | -0.67 | -0.82 | -1.03 | -0.93 | -0.99 | -1.09 | -1.12 | -0.83 | -0.9 | -0.89 | -1.15 |
| OLS, controlling for quantity, 1989 | -0.44 | -0.98 | -0.66 | -0.81 | -1.02 | -0.92 | -0.99 | -1.09 | -1.12 | -0.83 | -0.89 | -0.88 | -1.14 |

Notes: The table reports estimates of the coefficient to log distance in a gravity equation. Other variables included in the regression are language, legal system, border, currency union, colonial ties, membership in WTO, islands, landlocked economies, common regional trade agreement, importer/exporter fixed effects, and an intercept. All coefficients to log distance are statistically significant at the 1% level. Estimation methods are OLS, Heckit correction for sample selection (Heckit) and Helpman, Melitz and Rubinstein (2008) correction for sample selection and extensive margin (HMR). Port distances are from Feyrer (2009). For description, and sources of variables, as well as list of economies included in each regression, see Appendix.

Figure A1: Independent Variation in Unit Value Instruments, 1985-1997

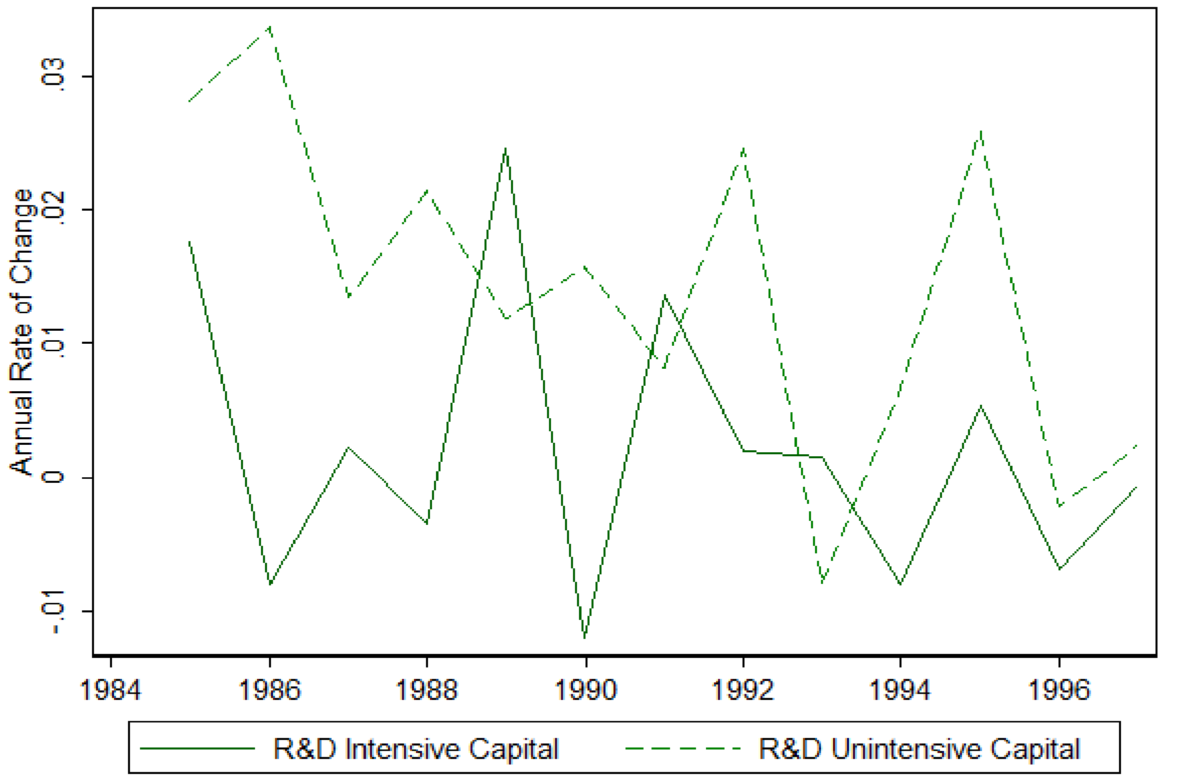
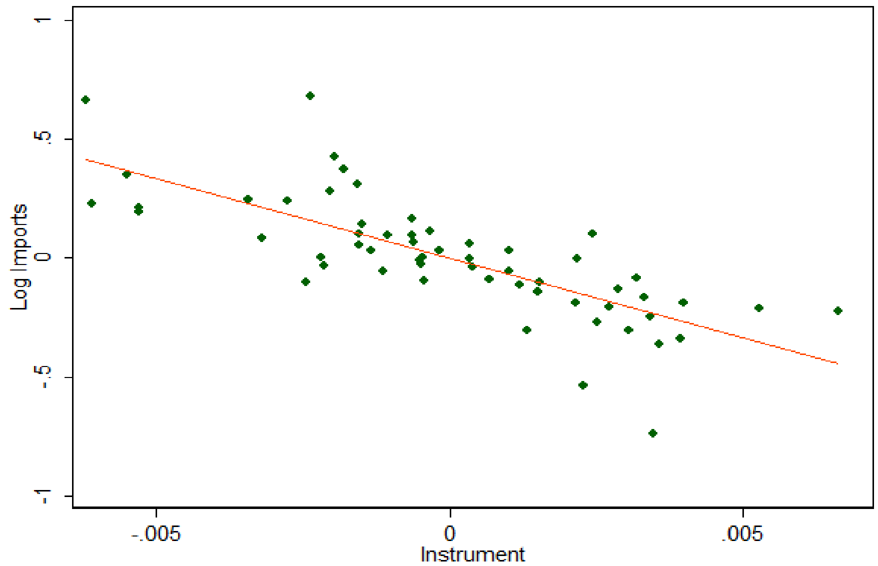


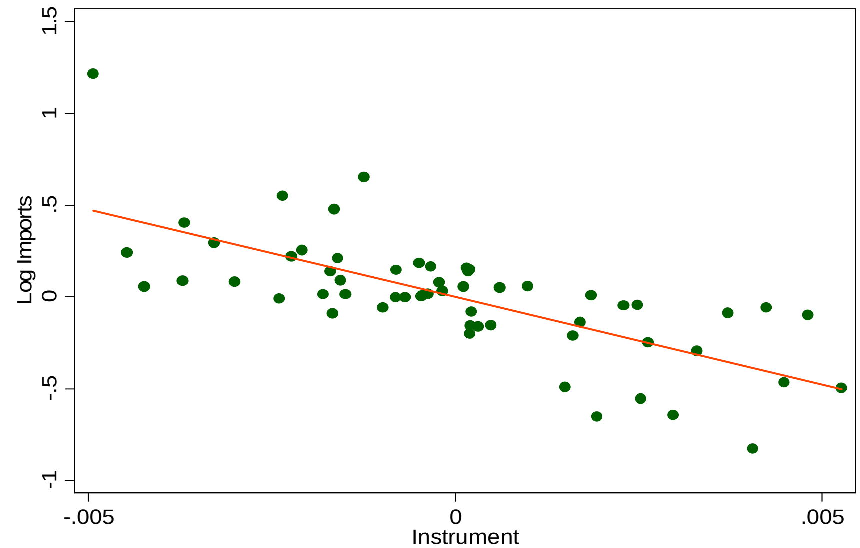

Figure presents the annual rate of change in the average international real unit price of R&D intensive and unintensive capital for the period of 1985-1997. The measure is calculated as a simple average, over all countries, starting at 1985 given data availability on quantity traded.

Figure A2: First Stage Partial Correlations (from Table 4)

A. R&D Unintensive Capital Equipment




B. R&D Intensive Capital Equipment




Figures present conditional correlations from the benchmark first stage regressions, controlling for change in skill intensity, the shift in export shares (Zhu and Trefler 2005), and country fixed effects. In Panel A the slope is -67.22 with partial R-squared of 0.57; in Panel B the slope is -95.49 with partal R-squared of 0.51.