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# Distance, skill deepening and development: will peripheral countries ever get rich?

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**Abstract**

This paper models the relationship between countries' distance from global economic activity, endogenous investments in education and economic development. Firms in remote locations pay greater trade costs on both exports and intermediate imports, reducing the amount of value added left to remunerate domestic factors of production. If skill-intensive sectors have higher trade costs, more pervasive input–output linkages or stronger increasing returns to scale, we show theoretically that remoteness depresses the skill premium and therefore incentives for human capital accumulation. Empirically, we exploit structural relationships from the model to demonstrate that countries with lower market access have lower levels of educational attainment. We also show that the world's most peripheral countries are becoming increasingly economically remote over time.


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## 1. Introduction

Why some nations are rich and others are poor is perhaps one of the oldest and most fundamental questions in economics. In 1996, the per capita income of the country at the 90th percentile of the world income distribution was more than 30 times higher than the country at the 10th percentile. The persistence of such differences is surprising in light of the increasing integration of goods and financial markets in the post-war period.

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Economists have pointed to a number of factors which may have prevented these income differences from being arbitraged away, including institutional ineffectiveness, sluggish technology diffusion and endowment disadvantages.[2]

A more recent line of research has highlighted the potential importance of trade costs in reducing per capita income.[3] These trade costs include not only the expense of physically moving products between locations but also all information, communication, monitoring and policy (e.g. tariff) costs associated with transacting at a distance. Because firms in remote locations pay greater trade costs on both their sales to final markets and their purchases of imported intermediate inputs, they have less value added available to remunerate domestic factors of production.

In this paper, we focus on an additional penalty of remoteness. We demonstrate that being located on the economic periphery can reduce the return to skill, thereby reducing incentives for investment in human capital accumulation. This penalty magnifies the effect that economic geography can have on cross-country per capita income. Increasing a country's relative trade costs not only reduces contemporaneous factor rewards, but also lowers gross domestic product by suppressing human capital accumulation and decreasing the supply of high-income skilled workers.[4] This result emerges from an extension of the standard two-sector (agriculture and manufacturing) Fujita et al. (1999) economic geography model to allow unskilled individuals to endogenously choose whether to invest in education. Our framework shows that the distribution of world economic activity has important implications for incentives to acquire skills. We believe this effect of economic geography to be important and largely neglected in the existing literature.[5]

The paper reports three main theoretical results. First, we show that countries located further from global economic activity have a lower skill premium if manufactured goods are relatively skill intensive and face relatively large trade costs. The intuition for this result can be conveyed via the well-known Stolper–Samuelson theorem: increased remoteness has the same effect as a reduction in the relative price of the manufactured good. Because manufacturing is relatively skill intense, the relative wage of skilled workers—and the incentive to educate—falls.

Second, we demonstrate that this result is robust to more general assumptions regarding trade costs. In particular, because of input–output linkages and increasing returns to scale in manufacturing, remoteness reduces incentives to accumulate skill even if relative trade

[2] Engerman and Sokoloff (1997) and Leamer et al. (1999), for example, analyse the effect of institutions and resource endowments on educational attainment in Latin America. Studies examining the links between human capital, development and growth include Benhabib and Spiegel (1994), Bils and Klenow (2000), Eicher and Garcia-Penalosa (2001), Galor and Mountford (2002), Lucas (1988) and Mankiw et al. (1992).

[3] See, in particular, Hanson (1998) and Redding and Venables (2001). For early analyses of trade costs, geography and per capita income, see Gallup et al. (1998, 2000), Hummels (1995), Leamer (1997) and Radelet and Sachs (1998). This paper focuses on economic geography (the location of economic agents relative to one another in space) rather than physical geography (e.g. climate and disease, see Gallup et al., 1998, 2000).

[4] A wide range of empirical studies for developed and developing countries provide evidence that skilled or educated workers receive higher wages (see Psacharopoulos, 1994).

[5] Our analysis focuses on the relationship between the existing location of economic activity and incentives to acquire skills. We do not explain the historical factors leading, for example, to the emergence of Western Europe as a center of world economic activity.

costs in manufacturing are lower.[6] Input–output linkages are important because trade costs must be paid on both imported intermediates and exported output, with the result that even relatively small trade costs can be magnified into a large share of value added. Increasing returns to scale, on the other hand, mean that proximity to large as opposed to small markets becomes especially important. Firms that are remote from large markets have to charge a lower price net of trade costs in order to export sufficient quantity to cover fixed costs. As a result, the equilibrium skill premium depends upon both physical remoteness (i.e. bilateral trade costs) and economic remoteness (i.e. the spatial distribution of economic activity).

Third, we show how our model can be used to formalize the role of a number of other determinants of human capital investment, including agricultural productivity and technology. We demonstrate that higher agricultural productivity (or, more generally, an abundance of natural resources) hinders manufacturing development and reduces incentives to invest in human capital. We also show that a transfer of manufacturing technology from developed to developing countries not only raises output per capita directly but also has a positive indirect effect through induced human capital accumulation. In general, the indirect effect will not be internalized by private sector agents, and the existence of this pecuniary externality provides a potential rationale for policies designed to accelerate technology transfer.

While the main focus of the paper is theoretical, we exploit structural relationships from the model to provide empirical evidence that countries located far from centers of world economic activity are characterized by relatively low levels of educational attainment. We also provide evidence that the world's most peripheral countries are becoming relatively more remote from global economic activity over time.

The paper proceeds as follows. Sections 2 and 3 outline the theoretical model and explore the relationship between remoteness and equilibrium investments in skill. Section 4 extends the analysis to allow for a more general specification of trade costs. Section 5 examines the role of other determinants of human capital investments. Sections 6 and 7 use the structure of the model to derive empirical measures of market access and examine the link between market access and educational attainment. Section 8 concludes.

## 2. Theoretical model: geography and skill acquisition

This paper builds upon existing theoretical research on new economic geography as synthesized in Fujita et al. (1999).[7] We extend the standard economic geography model by introducing endogenous human capital accumulation. The analysis emphasizes the importance of the interplay between increasing returns to scale, transport costs, input–

[6] Bernard et al. (2002), for example, show that while U.S. tariffs are higher for skill intensive manufactures (e.g. electronics), freight and insurance costs are higher for bulk commodities (e.g. food).

[7] See also Krugman (1991), Krugman and Venables (1990, 1995) and Venables (1996). In the interests of tractability, much of this literature has assumed a single factor of production, labor. Recent research by Amiti (2001) and Strauss-Kahn (2001) has introduced considerations of Heckscher–Ohlin trade theory into this framework by endowing countries with exogenous quantities of multiple factors of production.

output linkages and human capital investments.[8] We derive predictions for the relationship between remoteness, international trade, human capital investment and levels of per capita income.

### 2.1. Preferences and endowments

The world consists of $i \in \{1,\ldots,R\}$ countries. Each country is endowed with a mass of $\bar{L}_i$ consumers. Consumers have one unit of labour, which is supplied inelastically with zero disutility. This unit of labour begins in an unskilled state, but individuals choose endogenously whether or not to invest in becoming skilled. Consumer preferences are identical and homothetic, and are defined over consumption of a homogenous agricultural good and a variety of differentiated manufacturing goods. For simplicity, the utility function is assumed to take the Cobb–Douglas form,

$$U_j = A_j^{1-\mu} M_j^{\mu}, \qquad 0 < \mu < 1 \tag{1}$$

where $A$ denotes consumption of the homogeneous agricultural good and $M$ corresponds to a consumption index of differentiated manufacturing varieties. Going forward, we use $j$ to denote a country that is demanding or importing a good and $i$ to denote a country that is producing or exporting a good. The consumption index of differentiated varieties takes the form

$$M_j = \left[ \sum_{i=1}^{R} \int_0^{n_i} m_{ij}^C(z)^{(\sigma-1)/\sigma} \mathrm{d}z \right]^{\sigma/(\sigma-1)} = \left[ \sum_{i=1}^{R} n_i (m_{ij}^C)^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}, \tag{2}$$

where $\sigma > 1$ is the elasticity of substitution between manufacturing varieties and the second equation exploits the fact that, in the equilibrium established below, all products produced in a country $i$ are demanded by country $j$ in the same quantity. As a result, we dispense with the index $z$ and rewrite the integral as a product. $n_i$ denotes the number of varieties produced in country $i$ and $m_{ij}^C$ denotes the amount of each variety produced in country $i$ for final consumption in country $j$.

Dual to the consumption index ($M_j$) is a manufacturing goods price index ($G_j$) defined over the prices of individual varieties produced in $i$ and sold in $j$ (i.e. $p_{ij}^M$),

$$G_j = \left[ \sum_{i=1}^{R} \int_0^{n_i} p_{ij}^M(z)^{1-\sigma} \mathrm{d}z \right]^{1/(1-\sigma)} = \left[ \sum_{i=1}^{R} n_i (p_{ij}^M)^{1-\sigma} \right]^{1/(1-\sigma)}, \tag{3}$$

where the second equation makes use of the symmetry in equilibrium prices.

[8] In terms of Marshall's (1920) three forces of agglomeration (a pooled market for specialized skills, input–output linkages and knowledge spillovers), our analysis focuses on input–output linkages. For a model of agglomeration emphasizing search frictions in the labour market, see Amiti and Pissarides (2002), while Mori and Turrini (in press) emphasize complementarities between product variety, product quality and skills.

### 2.2. Production technologies

The homogenous agricultural good is produced under conditions of perfect competition with the following constant returns to scale technology,

$$Y_i = \theta_i^Y (S_i^Y)^{\phi} (L_i^Y)^{1-\phi}, \qquad 0 < \phi < 1 \tag{4}$$

where $Y_i$ denotes output of the agricultural good, $L_i^Y$ denotes the amount of unskilled labour allocated to this sector, $S_i^Y$ denotes the skilled labour allocation and $\theta_i^Y$ indexes agricultural productivity.[9]

To facilitate comparison of our results with the standard economic geography model without endogenous human capital investments, we begin with the conventional assumption that the homogenous agricultural good is traded at no cost. We relax this assumption below to explore further how relative trade costs across sectors influence incentives for human capital accumulation.[10]

Varieties of manufacturing goods are produced with an increasing returns to scale technology using a composite of primary factors of production (skilled and unskilled labour) and the output of all manufacturing goods (intermediate inputs). The representative country $i$ firm thus faces the following cost function,

$$\Gamma_i = (w_i^S)^{\alpha} (w_i^U)^{\beta} G_i^{(1-\alpha-\beta)} c_i [F + x_i] \tag{5}$$

where $c_i$ denotes a constant marginal input requirement, $c_i F$ is a fixed input requirement and $x_i = \sum_{j=1}^{R} x_{ij}$ is the total output of the firm produced for all markets. We assume that the composite of primary factors of production and intermediate inputs takes the Cobb–Douglas form, where $w_i^S$ is the wage of skilled workers (with input share $\alpha$), $w_i^U$ is the wage of unskilled workers (with input share and $\beta$), $G_i$ is the price index for manufacturing goods from Eq. (3) (with input share $(1-\alpha-\beta)$). The parameter $c_i$ corresponds to an inverse index of technological efficiency that may potentially vary across countries.

We assume trade costs take the iceberg form.[11] In order for one unit of a traded good to arrive in location $j$ from location $i$, $T_{ij}^M > 1$ units must be shipped. Thus, when $T_{ij}^M = 1$ trade is costless and $T_{ij}^M - 1$ measures the proportion of output lost in shipping from $i$ to $j$. We assume the parameter $T_{ij}^M$ captures all trade costs between locations $i$ and $j$, including

[9] While not explicitly modelled here, $\theta_i^Y$ may be thought of as also capturing the effects of endowments of land, other factors of production and the nature of land holdings on agricultural productivity. Introducing these other factors of production more explicitly merely complicates the analysis without adding any insight.

[10] Our focus is on endogenous human capital investments. Davis (1999) examines how agricultural trade costs affect the 'home market effect', while Venables and Limao (2002) consider the relationship between relative trade costs across sectors and industrial structure.

[11] We use iceberg trade costs for tractability. All we require is that remote locations face greater trade costs.

physical transportation costs, information, communication and monitoring costs, tariff barriers and non-tariff barriers.[12]

## 2.3. Human capital investment

An individual $z$ in country $i$ is endowed with one unit of unskilled labour, which can be converted into a unit of skilled labour by incurring a fixed education cost of $\Omega_i(z)$ units of unskilled labour. Denominating the education cost in terms of unskilled labour captures the idea that real resources are used in the process of becoming skilled. As a result, the cost of education is proportional to the unskilled wage, reflecting the higher opportunity cost of the real resources used in countries with a higher unskilled wage (see also Eicher and Garcia-Penalosa, 2001).[13]

The amount of unskilled labour used in becoming skilled depends on two components: $\Omega_i(z)=h_i/a(z)$. First, the parameter $h_i$ captures the effect of all aspects of the institutional environment and of government policies that influence the cost of education, where higher values of $h_i$ correspond to a higher cost of education.

Second, an individual's education cost depends on their ability $a(z)$ and we assume that high-ability individuals face lower education costs. This captures the idea that, for example, high-ability individuals have to work less hard and require fewer educational resources in order to attain a given level of education. Although we have chosen here to make the costs of education a function of ability, one could equivalently assume that the cost of education is the same for all individuals but that the rate of return varies with ability.[14]

We assume that there are upper and lower bounds to ability determined by human biology and that an individual's ability is drawn from a distribution over the interval $[\underline{a}, \bar{a}]$. The probability density function of ability is denoted by $\lambda(a)$, so that the mass of individuals in country $i$ with a particular level of ability $a'$ is $\lambda(a')\bar{L}_i$. We assume the probability density function of ability is determined by human biology and is therefore the same in all countries.

An individual $z$ in country $i$ will choose to become educated if the wage differential between skilled and unskilled workers exceeds education costs,

$$w_i^S - w_i^U \geq \frac{h_i}{a(z)} w_i^U . \tag{6}$$

We assume that the cumulative distribution function of ability $\Lambda(a) = \int_{\underline{a}}^{a} \lambda(a)\mathrm{d}a$ is continuous and monotonically increasing in ability. That is, as we consider successively

[12] Hummels (1999) and Limao and Venables (2001) provide evidence on the importance of transport costs and the role of geography in determining their magnitude. See Leamer and Storper (2001) and Venables (in press) for a discussion of the continuing and sometimes increasing importance of location following the introduction of new information and communication technologies such as e-mail and the internet.

[13] To keep the theoretical analysis as tractable as possible, we consider a static model where human capital accumulation requires real resources but does not take time. Introducing a more explicit dynamic model of skill acquisition would merely complicate the analysis without changing the key insights of the model.

[14] In this alternative specification, the wage $w_i^S$ in firms' cost function is the wage per ability-adjusted (quality-adjusted) unit of skilled labour. An individual $z$ of ability $a(z)$ receives an actual wage of $a(z)w_i^S$. In the alternative formulation, the ability-adjusted skilled wage is the same for all individuals, but actual wages vary with individual ability. All of the paper's results are robust to considering the alternative specification. It is only necessary to slightly modify the condition for an individual to become skilled in Eq. (6) to: $a(z)w_i^S - w_i^U \geq h_i w_i^U$.

higher and higher levels of ability, there will be fewer individuals more able than this level. The analysis is compatible with a wide range of probability density functions for ability. A particularly tractable case is where ability is uniformly distributed over the interval $[\underline{a}, \bar{a}]$, in which case $\lambda(a)=1/[\bar{a}-\underline{a}]$.

## 2.4. General equilibrium

### 2.4.1. Consumer equilibrium

Consumers maximize period-by-period utility subject to their budget constraint, which specifies that expenditure on manufacturing varieties and the agricultural good must equal income minus any education cost incurred. The first-order conditions imply the following demand-side relationship between the relative price and relative consumption of the two goods,

$$\frac{p_j^Y}{G_j} = \frac{1-\mu}{\mu}\frac{M_j}{A_j}, \tag{7}$$

where $p_j^Y$ is the price of the agricultural good and $G_j$ is the manufacturing goods price index from above. Eq. (7) determines country $j$'s consumption of all manufacturing goods (of the consumption index $M_j$). Final consumption demand for individual varieties produced in $i$ may be derived by applying Shepherd's lemma to the manufacturing price index ($G_j$),

$$m_{ij}^C = (p_{ij}^M)^{-\sigma} E_j^C G_j^{\sigma-1}, \tag{8}$$

where $E_j^C$ denotes total consumer expenditure on manufacturing goods in country $j$.

### 2.4.2. Equilibrium supply of skills

The individual's education decision compares the wage differential between skilled and unskilled workers with the costs of education. Eq. (6) implicitly defines a critical value for ability $a_i^*$ such that all individuals with levels of ability $a(z)\geq a_i^*(z^*)$ choose to become skilled. From above, this critical value for ability is,

$$(\mathbf{S}) \quad a_i^* = \frac{h_i}{(w_i^S/w_i^U - 1)}. \tag{9}$$

The marginal individual with the critical level of ability $a_i^*$ is indifferent between becoming skilled and remaining unskilled, and Eq. (9) is therefore termed the *skill indifference condition* (**S**).

**Proposition 1.** *The equilibrium critical level of ability $a_i^*$ above which individuals become skilled is monotonically decreasing in the relative skilled wage ($w_i^S/w_i^U$) and monotonically increasing in the cost of education parameter ($h_i$).*

**Proof.** Proposition 1 follows immediately from the skill indifference condition (**S**). □

Intuitively, as the relative wage of skilled workers ($w_i^S/w_i^U$) increases, it becomes profitable for individuals of lower ability to invest in education. As the critical level of ability $a_i^*$ falls, the equilibrium number of skilled workers increases and the equilibrium number of unskilled workers decreases. The equilibrium masses of skilled and unskilled workers are,

$$S_i = \int_{a_i^*}^{\bar{a}} \lambda(a)\bar{L}_i \mathrm{d}a \tag{10}$$

$$L_i = \int_{\underline{a}}^{a_i^*} \lambda(a)\bar{L}_i \mathrm{d}a - \int_{a_i^*}^{\bar{a}} \frac{h}{a}\lambda(a)\bar{L}_i \mathrm{d}a \tag{11}$$

$$S_i + L_i + \int_{a_i^*}^{\bar{a}} \frac{h}{a}\lambda(a)\bar{L}_i \mathrm{d}a = \bar{L}_i \tag{12}$$

where the second term on the right-hand side of Eq. (11) captures the real resources used in human capital acquisition.

To provide some intuition for the forces at work in the model, Fig. 1 graphs the supply-side relationship between the relative wage and the critical level of ability above which individuals become skilled (the right-hand side of Eq. (9)).

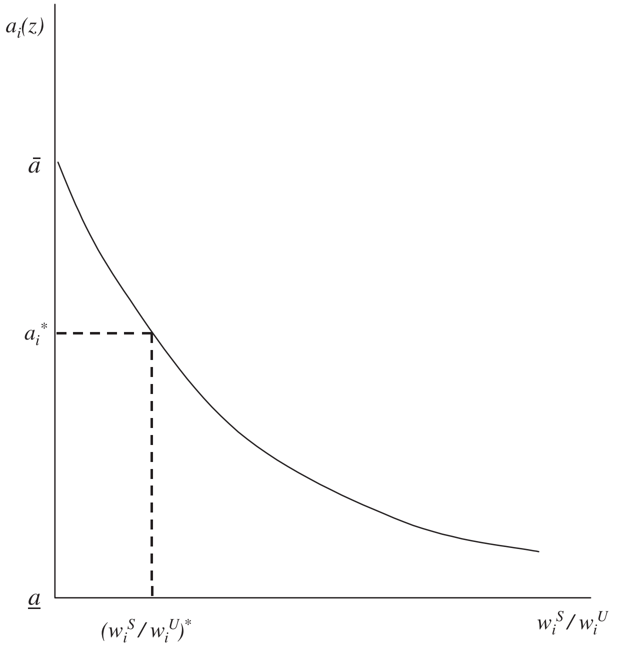


Fig. 1. The supply-side relationship between the critical value of ability $a_i^*$ and the relative wage $w_i^S/w_i^U$. Only individuals with ability greater than $a_i^*$ become educated given the relative wage $(w_i^S/w_i^U)^*$.

*2.4.3. Producer equilibrium*

In the agricultural sector, profit maximization and constant returns to scale imply that price equals unit costs of production if the agricultural good is produced,

$$p_i^Y = 1 = \frac{1}{\theta_i^Y}(w_i^S)^{\phi}(w_i^U)^{1-\phi}, \tag{13}$$

where we choose the agricultural good for the numeraire and hence $p_i^Y=1$ for all $i$. In the manufacturing sector, the representative country $i$ firm maximizes the following profit function,

$$\pi_i = \sum_{j=1}^{R} \frac{p_{ij}^M x_{ij}}{T_{ij}^M} - (w_i^S)^{\alpha}(w_i^U)^{\beta} G_i^{(1-\alpha-\beta)} c_i[F + x_i]. \tag{14}$$

The first-order conditions for profit-maximization yield the standard result that equilibrium prices are a constant mark-up over marginal cost,

$$p_i^M = \left(\frac{\sigma}{\sigma - 1}\right)(w_i^S)^{\alpha}(w_i^U)^{\beta} G_i^{(1-\alpha-\beta)} c_i, \tag{15}$$

where $p_i^M = p_{ij}^M / T_{ij}^M$ is the 'free on board' or 'customs' price charged by the firm prior to trade costs. Substituting this pricing rule into Eq. (14), we obtain the following expression for the equilibrium profit function,

$$\pi_i = \left(\frac{p_i^M}{\sigma}\right)[x_i - (\sigma - 1)F]. \tag{16}$$

In order to break even in a monopolistically competitive equilibrium, the firm's output must equal a constant: $\bar{x}=(\sigma-1)F$. The price needed to sell this many units is determined by the firm's demand function, where demand consists of the sum of final consumption and intermediate demand across all markets. A firm in country $i$ will therefore sell the quantity $\bar{x}$ when it charges a price,[15]

$$(p_i^M)^{\sigma} = \left(\frac{1}{\bar{x}}\right) \sum_{j=1}^{R} E_j G_j^{\sigma-1} (T_{ij}^M)^{1-\sigma}, \tag{17}$$

where $E_j = E_j^C + E_j^I$ denotes total country $j$ expenditure (final consumption and intermediate) on manufacturing goods.

Combining the expression in Eq. (17) with the fact that, in equilibrium, prices are a constant mark-up over marginal cost, we obtain the following zero-profit condition,

$$(\mathbf{W}) \quad \left(\frac{\sigma}{\sigma - 1}(w_i^S)^{\alpha}(w_i^U)^{\beta} G_i^{(1-\alpha-\beta)} c_i\right)^{\sigma} = \left(\frac{1}{\bar{x}}\right) \sum_{j=1}^{R} E_j G_j^{\sigma-1} (T_{ij}^M)^{1-\sigma}. \tag{18}$$

This relationship is termed the *wage equation* (**W**). It pins down the maximum wages of skilled and unskilled workers that a firm in country $i$ can afford to pay, given demand for its products (as captured in the summation on the right-hand side of the equation) and

[15] The transport cost term ($T_{ij}$) enters with exponent $1-\sigma$ and not $\sigma$ because total shipments to market $j$ are $T_{ij}$ times quantities consumed.

given the cost of intermediate inputs (as captured in the manufacturing price index on the left-hand side of the equation).

*2.4.4. Market clearing conditions*

Factors are relatively immobile internationally, and we therefore make the standard trade theory assumption of factor mobility across sectors within a country and immobility across countries. General equilibrium requires that each country's labour market clears,

$$S_i^Y + S_i^M = S_i \tag{19}$$

$$L_i^Y + L_i^M = L_i \tag{20}$$

where $\{S_i^M, L_i^M\}$ and $\{S_i^Y, L_i^Y\}$ denote skilled and unskilled employment in the manufacturing and agricultural sectors respectively. The total supplies of skilled and unskilled labour $\{S_i, L_i\}$ are determined according to Eqs. (10) and (11) above.

In equilibrium, we also require goods markets to clear at the world level, for manufacturing varieties and the homogeneous agricultural good.

## 3. Geography and skill deepening

The general equilibrium of the model combines consumer optimization, education optimization and producer optimization with the market clearing conditions to solve for equilibrium prices, equilibrium expenditures and the equilibrium location of production.

In this section, we use structural equations of the model to characterize the nature of the relationship between location and incentives to invest in skills that must hold in general equilibrium. We follow Redding and Venables (2001) in using the model to derive theory-consistent measures of a country's location relative to its markets and sources of supply. We then go on to demonstrate how market access and supplier access influence incentives to invest in human capital acquisition.

We begin by combining final consumption demand (from Eq. (8)) and intermediate demand to obtain an expression for bilateral trade flows between countries $i$ and $j$. Expressing this relationship in aggregate value terms, yields,

$$(\mathbf{T}) \quad n_i p_i x_{ij} = n_i p_i^{1-\sigma} (T_{ij}^M)^{1-\sigma} E_j G_j^{\sigma-1}. \tag{21}$$

In this gravity equation (the *trade equation*, **T**), bilateral exports depend on three sets of considerations. First, on a measure of demand in the importing country $j$ termed *market capacity* ($m_j \equiv E_j G_j^{\sigma-1}$) and comprised of total expenditure on manufacturing goods in market $j$ ($E_j$) as well as the number of competing firms and the prices they charge as summarized in the manufacturing price index ($G_j$). Second, on a measure of supply potential in the exporting country $i$ termed *supply capacity* ($s_i \equiv n_i p_i^{1-\sigma}$) and comprised of the number of manufacturing firms ($n_i$) together with the prices they charge ($p_i$). Third, on bilateral trade costs $(T_{ij}^M)^{1-\sigma}$.

For each exporter $i$, we may sum market capacities in the importers it serves, weighting by bilateral trade costs. This yields a measure of the country's overall access to markets—*market access* ($\mathrm{MA}_i$),

$$\mathrm{MA}_i \equiv \sum_{j=1}^{R} (T_{ij}^{M})^{1-\sigma} E_j G_j^{\sigma-1} = \sum_{j=1}^{R} (T_{ij}^{M})^{1-\sigma} m_j. \tag{22}$$

Similarly, for each importer $j$, we may sum supply capacities in the exporters that it receives goods from, weighting by bilateral trade costs. This yields a measure of the country's overall access to sources of supply—*supplier access* ($\mathrm{SA}_j$),

$$\mathrm{SA}_j \equiv \sum_{i=1}^{R} (T_{ij}^{M})^{1-\sigma} n_i p_i^{1-\sigma} = \sum_{i=1}^{R} (T_{ij}^{M})^{1-\sigma} s_i. \tag{23}$$

From the trade equation (**T**), market and supplier access may be constructed from information on bilateral trade flows. We now show how the wage equation (**W**), which pins down the maximum wages of skilled and unskilled workers that firms in each location can afford to pay, may be written as a function of market and supplier access. Taking the manufacturing price index over to the right-hand side of (**W**) and using the definition in Eq. (22), we have,

$$(w_i^S)^{\alpha} (w_i^U)^{\beta} = \xi \frac{1}{c_i} (\mathrm{MA}_i)^{\frac{1}{\sigma}} G_i^{(\alpha+\beta-1)}, \tag{24}$$

where $\xi$ absorbs earlier constants. Now note from Eqs. (3) and (23) that the manufacturing price index ($G_i$) may be written as a function of a country's supplier access alone,

$$(\mathbf{P}) \quad G_i = [\mathrm{SA}_i]^{\frac{1}{1-\sigma}}. \tag{25}$$

Combining the expression for the price index (**P**) with Eq. (24), the maximum skilled and unskilled wages that a firm in location $i$ can afford to pay can be written as,

$$(\mathbf{W}') \quad (w_i^S)^{\alpha} (w_i^U)^{\beta} = \xi \frac{1}{c_i} (\mathrm{MA}_i)^{\frac{1}{\sigma}} (\mathrm{SA}_i)^{\frac{(1-\alpha-\beta)}{(\sigma-1)}}. \tag{26}$$

Intuitively, countries whose locations provide easy access to supplies of manufacturing goods (a high value of $\mathrm{SA}_i$) are characterized by low values of the manufacturing price index. This itself reduces unit costs of production and increases the maximum wages that manufacturing firms in those locations can afford to pay. If a country's location also provides easy access to markets for manufacturing goods (a high value of $\mathrm{MA}_i$), this increases the 'free on board' price that manufacturing firms can charge for their products while still selling enough output to cover the fixed costs of production, thereby again increasing the maximum wages that the firms can afford to pay.

Consider a country that is incompletely specialized in agriculture and manufacturing. We establish below the conditions under which this occurs.[16] The zero profit conditions in agriculture (Eq. (13)) and manufacturing (Eq. (26)) together implicitly define the equilibrium wages of skilled and unskilled workers. Manipulating these zero profit conditions and combining them with the skill indifference condition (**S**), we are able to completely characterize the equilibrium relationship between geographical location and endogenous human capital investments.[17] Taking logarithms and totally differentiating each zero profit condition, we have,

$$0 = \phi \frac{\mathrm{d}w_i^S}{w_i^S} + (1-\phi)\frac{\mathrm{d}w_i^U}{w_i^U} \tag{27}$$

$$\alpha \frac{\mathrm{d}w_i^S}{w_i^S} + \beta \frac{\mathrm{d}w_i^U}{w_i^U} = \frac{1}{\sigma}\frac{\mathrm{dMA}_i}{\mathrm{MA}_i} + \frac{(1-\alpha-\beta)}{(\sigma-1)}\frac{\mathrm{dSA}_i}{\mathrm{SA}_i} \tag{28}$$

**Proposition 2.** *Suppose a country becomes more remote in the sense that equilibrium market and supplier access fall ($dMA_i/MA_i = dSA_i/SA_i = -\gamma < 0$). If manufacturing is skill intensive relative to agriculture and the country remains incompletely specialized, the new equilibrium must be characterized by a lower relative wage of skilled workers.*

**Proof.** See Appendix A. □

Intuitively, a fall in market and supplier access in the manufacturing zero profit condition acts exactly like a fall in the price of the skill-intensive good in the Stolper–Samuelson theorem of Heckscher–Ohlin trade theory. A fall in market and supplier access leads to a violation of the manufacturing zero profit condition at initial equilibrium factor prices and results in a decline in the size of the manufacturing sector. The decline in manufacturing releases relatively more skilled labour than is demanded in agriculture at initial equilibrium relative factor prices. Hence, at the new equilibrium, the nominal skilled wage is lower, the nominal unskilled wage is higher (so that the agricultural zero profit condition continues to be satisfied), and these together imply that the relative wage of skilled workers is lower.

A lower relative wage of skilled workers unambiguously reduces the incentive to invest in skills. Hence, as a country's equilibrium values of market and supplier access fall, the number of skilled workers falls and the number of unskilled workers rises.

**Proposition 3.** *Suppose a country becomes more remote in the sense that equilibrium market and supplier access fall ($dMA_i/MA_i = dSA_i/SA_i = -\gamma < 0$). If manufacturing is skill*

[16] Empirically, countries produce both agriculture and manufacturing. It is straightforward to also examine the complete specialization case. With complete specialization in manufacturing, the relative wage will be determined by combining the relative supply of skilled workers from Proposition 1 with a relative demand relationship derived from the manufacturing wage equation that depends on market and supplier access.

[17] It is relatively straightforward to introduce a non-traded goods sector into the model. If a country is incompletely specialized in agriculture and manufacturing, the zero profit conditions for the two traded sectors must hold, pinning down the equilibrium wages of skilled and unskilled workers. The equilibrium price of the non-traded good would be determined from its unit cost function at these equilibrium wages.

*intensive relative to agriculture and the country remains incompletely specialized, the new equilibrium must be characterized by: (a) a higher critical level of ability $a_i$* above which individuals become skilled and (b) a reduced supply of skilled workers and an increased supply of unskilled workers.*

**Proof.** See Appendix A. □

Equilibrium relative wages and employment in the two sectors for given levels of market and supplier access are shown graphically in Fig. 2. This is the direct analogue of the isoprice line representation of equilibrium in the Heckscher–Ohlin trade model (the dual of the Lerner diagram). The more steeply sloped curve is the unit cost function in agriculture, which must equal price in an equilibrium where agriculture is produced. The more shallow-sloped curve is the marginal cost function in manufacturing ($b_i$=$(w_i^S)(w_i^U)$ $G_i^{(1-\alpha-\beta)}c_i$), which is drawn in skilled wage-unskilled wage space for a given level of market and supplier access. The level of supplier access pins down the value of the manufacturing price index ($G_i$=$[\mathrm{SA}_i]^{1/1-\sigma}$). The manufacturing wage equation (**W′**) implies that, in an equilibrium where manufacturing goods are produced, marginal costs are proportional to market access ($b_i$=$\xi(\mathrm{MA}_i)^{1/\sigma}$).

A reduction in market and supplier access corresponds to an inward shift in the manufacturing isoprice line (less value added is available to remunerate the factors of production). From Fig. 2, the new equilibrium must be characterized by a lower skilled wage and higher unskilled wage.

The manufacturing production technology implies that marginal and average relative unit factor input requirements are the same. Hence, the slope of each isoprice line corresponds to relative employment of skilled and unskilled labour by a representative

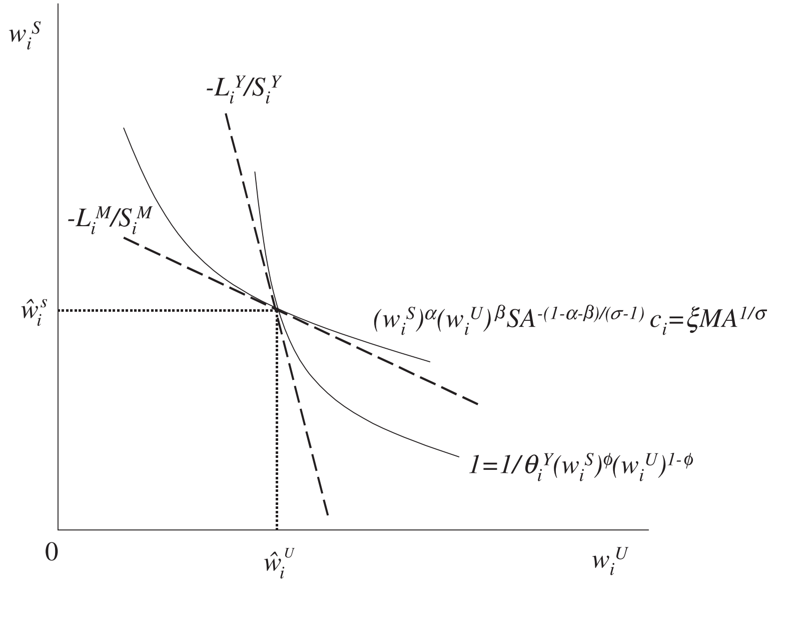


Fig. 2. Equilibrium skilled wage, unskilled wage, and relative unit factor input requirements in each sector.

firm in that sector. In order for both manufacturing and agriculture to be produced in equilibrium, we require that, at the equilibrium relative factor prices ($\hat{w}_i^S$, $\hat{w}_i^U$), the slope of a line indicating the endogenous relative supply of skilled and unskilled workers ($S_i$, $L_i$) lies in between the tangents to the two isoprice lines.

Skill accumulation may be directly linked to economic development within the model. National income net of resources used in education is equal to $w_i^S S_i + w_i^U L_i$ where, in equilibrium, $w_i^S > w_i^U$. The relationship is particularly clear in the case where agriculture uses only unskilled labour ($\phi=0$, which together with our choice of numeraire implies $w_i^U=1$). Increases in the skilled wage and, since $w_i^S > w_i^U = 1$, increases in $S_i$ relative to $L_i$ will unambiguously raise national income.

In the full general equilibrium of the model, market and supplier access are endogenously determined by the distribution of production and expenditure across locations. Propositions 2 and 3 characterize relationships that hold in the full general equilibrium. They exploit the equilibrium structure of production and the supply of skills to characterize the relationship between market access, supplier access and human capital investments when countries are incompletely specialized.[18] In our empirical work, we use the trade equation (**T**) to measure market and supplier access from bilateral trade data. We take as given the location of production and expenditure, as revealed by bilateral trade, and examine to what extent cross-country investments in human capital are consistent with the equilibrium relationship predicted by the model.

To keep the analysis as clean as possible and to facilitate comparison with the standard economic geography model, we have so far assumed that the agricultural good is freely traded. In Section 4, we relax this assumption.

## 4. Equilibrium with trade costs in manufacturing and agriculture

To introduce agricultural trade costs in as tractable way as possible, we modify consumers' utility function slightly. Specifically, we assume that each country produces a single differentiated agricultural good.[19] These differentiated goods enter a consumption index $A_j$ in Eq. (1) that takes the Dixit–Stiglitz form,

$$A_j = \left[ \sum_{i=1}^{R} A_{ij}^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}, \qquad \sigma > 1. \tag{29}$$

The differentiation of goods across countries may be interpreted in two ways, which for our purposes are equivalent. First, there are a number of different agricultural goods

[18] Again, note the analogy with the Stolper–Samuelson theorem. In general, relative goods prices are endogenously determined. The Stolper–Samuelson theorem exploits the equilibrium structure of production to derive a relationship between relative goods and relative factor prices when countries are incompletely specialized.

[19] It is possible to analyze the role of agricultural trade costs while retaining the assumption that agricultural goods are homogenous. This complicates the analysis because, with an homogenous product and trade costs, exporters of agriculture will not generally export to all locations and importers will not generally import from all locations (see, for example, Venables and Limao, 2002). As discussed further below, one interpretation of the specification here is that countries are specialized in different agricultural goods which are imperfect substitutes for one another.

(e.g. wheat, corn, barley, maize), which are imperfect substitutes for one another, and each country completely specializes in a different agricultural good due to Ricardian differences in technology or unmodelled variation in land endowments (as in Davis, 1997; see also Deardorff, 1998; Krugman and Venables, 2001). Second, there is Armington differentiation by country of origin. The first is the more plausible interpretation and the one taken here.

In order for one unit of an agricultural good to arrive in location $j$ from location $i$, we assume that $T_{ij}^A>1$ units must be shipped, so that $T_{ij}^A-1$ is a measure of agricultural trade costs. With perfect competition and constant returns to scale, the free on board (fob) price of agricultural goods in each location $i$ will equal the average cost of production, while the cost inclusive of freight price (cif) charged in an importing location $j$ will be a mark-up over average production cost with the size of the mark-up determined by bilateral trade costs,

$$\frac{p_{ij}^Y}{T_{ij}^A} = p_i^Y = \frac{1}{\theta_i^Y}(w_i^S)^{\phi}(w_i^U)^{1-\phi}, \tag{30}$$

and we choose the cif price of country $i$'s agricultural good in one location (for example, $j$=1) as the numeraire (so that $p_{i1}^Y=1$ and $p_i^Y=1/T_{i1}^A$).

The manufacturing zero profit condition (Eq. (26)) continues to depend on market and supplier access, while agricultural trade costs ($T_{ij}^A$) now enter directly into the agricultural zero profit condition (Eq. (30)). To examine the effects of increased remoteness, we again totally differentiate the two zero profit conditions, assuming that a country remains incompletely specialized in agriculture and manufacturing,

$$-\frac{\mathrm{d}T_{i1}^A}{T_{i1}^A} = \phi\frac{\mathrm{d}w_i^S}{w_i^S} + (1-\phi)\frac{\mathrm{d}w_i^U}{w_i^U}, \tag{31}$$

$$\alpha\frac{\mathrm{d}w_i^S}{w_i^S} + \beta\frac{\mathrm{d}w_i^U}{w_i^U} = \frac{1}{\sigma}\frac{\mathrm{dMA}_i}{\mathrm{MA}_i} + \frac{(1-\alpha-\beta)}{(\sigma-1)}\frac{\mathrm{dSA}_i}{\mathrm{SA}_i}, \tag{32}$$

where we have used our choice of numeraire ($p_i^Y=1/T_{i1}^A$) and manufacturing is assumed to be skill intensive relative to agriculture ($\alpha/\beta>\phi/(1-\phi)$).

Suppose that the country experiences an equiproportionate increase in the value of agricultural and manufacturing trade costs to all locations: $\mathrm{d}T_{ij}^M/T_{ij}^M=\mathrm{d}T_{ij}^A/T_{ij}^A=\gamma>0$. The increase in agricultural trade costs ($T_{ij}^A$) enters directly into the agricultural zero profit condition and directly shifts the isoprice line for this sector inwards in Fig. 2. For given values of production and expenditure in each location (i.e. for given values of market capacity, $m_j$, and supply capacity, $s_i$), the increase in manufacturing trade costs ($T_{ij}^M$) reduces market and supplier access (since $\sigma>1$ in Eqs. (22) and (23)). As a result, the manufacturing isoprice line also shifts inwards in Fig. 2. Though nominal wages both fall (in terms of the numeraire), the effect of these shifts on the relative wage—and human capital accumulation—appears ambiguous.

This analysis yields a number of important insights. When both manufacturing and agriculture face trade costs, the effect of increased remoteness on skill accumulation depends upon both relative skill intensity and relative trade costs. If, as in Section 3, *ad valorem* trade costs are more important in the skill intensive sector, remote locations will experience reduced incentives to invest in skill. However, the same outcome can still emerge even if *ad valorem* trade costs are lower in the skill intensive sector because of asymmetries in the effect of trade costs on agriculture and manufacturing.

First, even if shipping costs are lower for skill-intensive sectors, other trade costs, including all search, communication, and monitoring costs, are likely to be relatively high in these sectors.[20]

Second, a given level of *ad valorem* trade costs has a stronger effect on manufacturing than agriculture because input–output linkages require firms to incur trade costs on both imported intermediates as well as exported output. Indeed, because intermediate inputs account for a substantial proportion of costs, even relatively small trade costs can become large as a proportion of value added.[21] The relative importance of trade costs in manufacturing due to intermediate inputs can be seen by noting that the change in trade costs enters once in the agricultural zero profit condition (31) but twice in the manufacturing zero profit condition (32) via its effect on both market and supplier access.

Third, skill-intensive manufacturing is increasing returns to scale, while low-skill agriculture is constant returns to scale. The presence of increasing returns to scale in manufacturing means that market size is important: in equilibrium, firms must sell enough units of output in order to cover the fixed costs of production. Hence, trade costs do not enter the manufacturing zero profit condition (32) directly, but instead enter through market and supplier access, which respectively weight market size and supply capacity in all of a country's trade partners by bilateral trade costs. In agriculture in contrast, the presence of constant returns to scale means that it is per unit trade costs which are important, and these enter directly into the agricultural zero profit condition.

The importance of this distinction can be seen by holding a country's bilateral trade costs constant but moving production and expenditure from neighboring to distant locations. This will have no effect in the agricultural zero profit condition where only per unit trade costs matter (Eq. (31)), where $\mathrm{d}T_{ij}^{A}/T_{ij}^{A}=0$. However, reducing market and supply capacity at neighboring locations and increasing them by the same amount at distant locations (i.e. increasing a country's *economic remoteness* rather than its *geographical remoteness*) unambiguously reduces a country's market and supplier access (i.e. $\mathrm{dMA}_i/\mathrm{MA}_i<0$ and $\mathrm{dSA}_i/\mathrm{SA}_i<0$ in the manufacturing zero profit condition, Eq. (32)). As in Section 3, the fall in market and supplier access will unambiguously reduce the relative wage and equilibrium supply of skilled workers if manufacturing is skill intensive relative to agriculture.

Fourth, in general equilibrium, changes in agricultural and manufacturing trade costs will themselves influence the distribution of production and expenditure across locations (of market capacity, $m_j$, and supply capacity, $s_i$), with the resulting changes in economic remoteness influencing the skill premium and incentives to invest in human capital in the way discussed above.

[20] New technologies (e.g. the internet) may reduce trade costs in some skill intensive sectors. One prominent example is the emergence of Bangalore as a software programming centre in India. See Leamer and Storper (2001) and Venables (in press) for further discussion of geography and new technologies.

[21] Consider a stylized example where prices are determined on world markets, intermediate inputs account for 50% of costs and transport costs are borne by the producing country. *Ad valorem* trade costs of 10% on both final output and intermediate inputs reduce domestic value-added by 30%, with the reduction in value-added rising to 60% for trade costs of 20%. See Radelet and Sachs (1998) for further discussion.

The importance of input–output linkages and increasing returns to scale in skill-intensive manufacturing suggests that our earlier finding that remote countries have lower incentives to invest in human capital accumulation carries over to a world where trade costs are paid on both agricultural and manufacturing goods. The analysis also suggests that reductions in trade costs in relatively skill-intensive sectors (through, for example, trade liberalization) may be particularly important in elevating human capital investments in peripheral countries.

## 5. Other determinants of human capital investment

The discussion so far has emphasized the importance of geographical location for incentives to invest in human capital. In this section, we return to the baseline model of Sections 2 and 3, and examine the effects of changes in other parameters of the model which are related to potential determinants of human capital investment emphasized in the existing literature. To isolate the effects of these other variables, we consider the effect of parameter changes holding constant a country's market and supplier access. We continue to assume countries are incompletely specialized in agriculture and manufacturing (the conditions for which are derived above).

**Proposition 4.** *The critical level of ability $a_i^*$ above which individuals become skilled is monotonically increasing and the equilibrium supply of skilled workers $S_i$ is monotonically decreasing in (a) productivity in agriculture $\theta_i^Y$ (b) the cost of manufacturing production parameter $c_i$ and (c) the cost of education parameter $h_i$.*

**Proof.** See Appendix A. □

Intuitively, increases in agricultural productivity $\theta_i^Y$ act like a rise in the price of the agricultural good. By analogy with the Stolper–Samuelson theorem, an increase in agricultural productivity reduces the relative skilled wage and hence reduces equilibrium human capital investments. Our theoretical framework, therefore, formalizes the idea that a productive agricultural sector or, more generally, an abundance of agricultural land and other natural resources may both hinder the development of manufacturing and impede investments in human capital (see, for example, the analysis of Latin America in Engerman and Sokoloff, 1997; Leamer et al., 1999).

The model also captures the idea that technology and, in particular, the transfer of technology from advanced countries is important for economic development. Technology transfer that reduces manufacturing production costs, $c_i$, raises the maximum skilled and unskilled wage that a manufacturing firm in country *i* can afford to pay given market and supplier access. In terms of Fig. 2, the manufacturing isoprice lines shifts outwards away from the origin. Since manufacturing is skill intensive relative to agriculture, this increases the relative wage of skilled workers, and hence raises equilibrium human capital investments.

Thus, there is an important general equilibrium complementarity between technology and skills. The transfer of technology to skill-intensive manufacturing industries in developing countries not only directly raises output per capita but also has positive indirect effects through induced human capital investment.[22] The incentive to transfer technology depends, in part, on a country's institutions and policy environment (see, for example, Acemoglu et al. 2001). Hence, the analysis is consistent with an important effect of institutions on the process of economic development and with a complementarity between institutions and human capital investment.

Finally, institutions are also important via their effects on the cost of education parameter, $h_i$. Changes in institutions or government policies that reduce the costs of education, $h_i$, increase equilibrium investments in human capital. As the supply of skilled workers rises, output of the skill-intensive manufacturing sector also rises.

## 6. Empirical measurement of market and supplier access

Using bilateral trade flow data compiled by Feenstra et al. (1997), we construct theoretically consistent measures of MA and SA for all countries at five-year intervals from 1970 to 1995 using Eqs. (22) and (23). To ensure that these measures are not driven by small countries that trade very little with the rest of the world, we restrict our sample to the 137 countries that trade with at least 5 partners.

From the trade equation (**T**), the model predicts that bilateral trade flows depend upon exporting country characteristics (i.e. supply capacity, $s_i \equiv n_i p_i^{1-\sigma}$), importing partner characteristics (i.e. market capacity, $m_j \equiv E_j G_j^{\sigma-1}$) and bilateral transportation costs ($T_{ij}^M$). We use country dummy variables (denoted by $d_i$ and $d_j$, respectively) to capture market and supply characteristics for each pair of countries $i$ and $j$. This has the advantage of controlling for all observed and unobserved variables that affect market and supply capacity.[23] The dummy variables also capture any component of transport costs or trade policy that is common across all of a particular country's export partners and import suppliers. We model the bilateral component of trade costs as depending upon distance (distance$_{ij}$) and whether or not two countries share a common border (border$_{ij}$). Distance is the great circle distance, in kilometers, between the two countries' largest cities. Thus, the empirical counterpart of Eq. (21) is:

$$\ln(X_{ijt}) = \delta_{1t}\ln(\text{distance}_{ij}) + \delta_{2t}\text{border}_{ij} + \eta_{it}d_i + \psi_{jt}d_j + u_{ijt}. \quad (33)$$

for each time period separately. $X_{ijt}$ denotes the value of exports from $i$ to $j$ at time $t$; $\eta_{it}$ are the coefficients on the exporting country dummies, which capture supply capacity at time $t$; $\psi_{jt}$ are the coefficients on the importing partner dummies, which capture market capacity at time $t$; and $u_{ijt}$ is a stochastic error.

Table 1 presents the results of estimating this equation on the sample of non-zero trade flows, by year. The distance and common border variables have the expected sign and are

[22] See Redding (1996) for an analysis of technology-skill complementarity within industries in advanced countries.

[23] In particular, the dummies capture the role of the manufacturing price index, $G_j$. They control, therefore, for what Anderson and van Wincoop (2003) term 'multilateral resistance' (a country's average trade barrier with all partners).

Table 1
Trade equation estimation

| Regressor | 1970 $\ln(X_{ij})$ | 1975 $\ln(X_{ij})$ | 1980 $\ln(X_{ij})$ | 1985 $\ln(X_{ij})$ | 1990 $\ln(X_{ij})$ | 1995 $\ln(X_{ij})$ |
|---|---|---|---|---|---|---|
| $\ln(\text{distance}_{ij})$ | −1.18 | −1.27 | −1.27 | −1.33 | −1.37 | −1.49 |
| | −36.98 | −39.82 | −42.09 | −44.83 | −49.96 | −58.50 |
| $\ln(\text{border}_{ij})$ | 0.48 | 0.41 | 0.42 | 0.31 | 0.42 | 0.44 |
| | 2.96 | 2.85 | 2.99 | 2.25 | 3.27 | 2.96 |
| Exporter and importer dummies | yes | yes | yes | yes | yes | yes |
| Observations | 9191 | 9936 | 9717 | 9551 | 10302 | 11182 |
| $R^2$ | 0.94 | 0.94 | 0.96 | 0.96 | 0.97 | 0.97 |

Table displays OLS coefficients and *T*-values based upon Huber–White robust standard errors. Each column represents a regression of bilateral exports on distance between partners and whether partners share a common border for the noted year. Regressions include exporter and importer dummy variables.

statistically significant at the 1% level. The null hypothesis that the coefficients on either the exporter dummies or the importer dummies are equal to zero is easily rejected at conventional significance levels using a standard *F*-test, and the model explains over 90% of the cross-sectional variation in bilateral trade flows. The economic importance of distance appears to grow with time: whereas a 1% increase in distance is associated with a 1.2% reduction in bilateral exports in 1970, it is associated with a 1.5% reduction in exports by 1990.

Estimated market access ($\widetilde{\text{MA}}_{it}$) for exporter $i$ and supplier access ($\widetilde{\text{SA}}_{jt}$) for importer $j$ can be constructed using coefficient estimates from Eq. (33) and Eqs. (22) and (23) from Section 3:

$$\widetilde{\text{MA}}_{it} = \sum_{j \neq i} (\text{distance}_{ij})^{\hat{\delta}_{1t}} (\exp(\text{border}_{ij}))^{\hat{\delta}_{2t}} (\exp(d_j))^{\hat{\psi}_{jt}} \tag{34}$$

$$\widetilde{\text{SA}}_{jt} = \sum_{i \neq j} (\text{distance}_{ij})^{\hat{\delta}_{1t}} (\exp(\text{border}_{ij}))^{\hat{\delta}_{2t}} (\exp(d_i))^{\hat{\eta}_{it}} \tag{35}$$

A country's market and supplier access will evolve over time, as the coefficients on distance and the existence of a common border change, and as market and supply capacities in its trade partners change as captured in the time-varying coefficients $\hat{\psi}_{jt}$ and $\hat{\eta}_{it}$.

Empirically, market and supplier access are highly correlated. As a result, we use $\widetilde{\text{MA}}_{it}$ as a proxy of countries' distance from world economic activity in our empirical analysis below. Very similar results are obtained if $\widetilde{\text{SA}}_{jt}$ is used instead.

$\widetilde{\text{MA}}_{it}$ and $\widetilde{\text{SA}}_{jt}$ have a number of advantages compared to traditional estimates of distance. Most important, they are derived from a general equilibrium model of international trade that incorporates economic geography. Second, they rely upon bilateral trade data to uncover *revealed* access to markets and sources of supply, and are thereby able to incorporate the effects of unobservable transportation costs, trade barriers and determinants of market and supply capacity. Finally, they capture in a single measure several dimensions of physical distance.

Table 2
OLS regression of market access on the physical distance of countries from three economic centers

| Regressors | ln(market access) |
|---|---|
| ln(distance to U.S.) | −0.53*** |
| | 8.22 |
| ln(distance to Belgium) | −0.77*** |
| | 22.40 |
| ln(distance to Japan) | −0.70*** |
| | 11.01 |
| Observations (countries) | 137 |
| Adjusted $R^2$ | 0.90 |

Table displays OLS coefficients. *T*-values are listed below coefficient estimates and are based on Huber–White robust standard errors. See text for definition of MA. ***, ** and * signify statistical significance at the 1%, 5% and 10% levels. Results on the included constant are suppressed.

Table 2 reports the results of regressing $\widetilde{\mathrm{MA}}_{it}$ on countries' great circle distance from the U.S., Japan and Belgium in kilometers. Distance from these three economic centers explains 90% of the variation in market access. Of the three locations, market access is most negatively correlated with distance from Brussels; coefficient estimates imply that a 1% increase in a country's distance from that Brussels reduces market access by 0.77%. Fig. 3 provides a visual representation of this correlation in 1990. Notable outliers in the figure, including Canada and several Asian countries, are located near either the U.S. or Japan. Low levels of market access in, for example, Australia and New Zealand reflect their remoteness from other markets around the world.

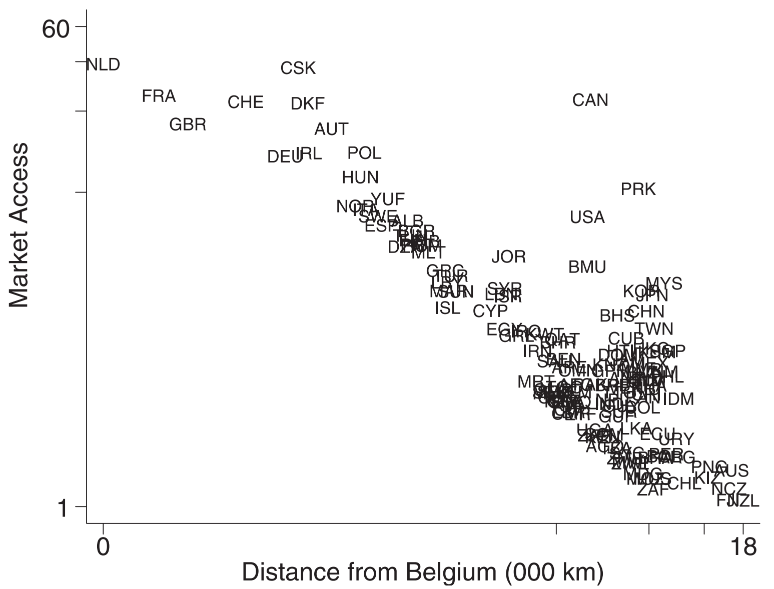


Fig. 3. Market access vs. distance to Belgium, 1990.

Table 3
The relative distribution of countries' market access over time, 1970–1995

| Year | Ratio of market access percentiles | | |
|---|---|---|---|
| | 75th/25th | 80th/20th | 90th/10th |
| 1970 | 2.5 | 3.4 | 6.8 |
| 1975 | 2.6 | 3.5 | 7.3 |
| 1980 | 2.6 | 3.7 | 7.2 |
| 1985 | 2.6 | 3.8 | 7.4 |
| 1990 | 2.7 | 4.2 | 8.6 |
| 1995 | 2.9 | 4.2 | 10.3 |

Table displays the ratio of various percentiles of the distribution of MA across countries over time. See text for definition of market access. Each year contains 137 country observations.

Comparison of the distributions of market access from 1970 to 1995 indicates that peripheral countries are becoming more economically remote over time. Table 3 reports the ratios of various percentiles of these distributions at 5-year intervals and indicates that the distributions are characterized by increasing inequality. All three ratios—90th/10th, 80th/20th and 75th/25th—increase with time. This trend is interesting in its own right and worthy of further inquiry. Potential explanations include an increasingly uneven distribution of market and supply capacities across countries over time and the rising coefficient on distance in the trade equation estimation.

## 7. Empirical relationship between geography and human capital

In this section, we check whether the human capital implications of the model are supported by the data. Consistent with the model, we provide evidence that educational attainment is higher in countries with greater market access. Data on educational attainment for a large cross-section of developed and developing countries in 1990 is available from Barro and Lee (2001). These data record the percent of each country's over-15 population that has attained secondary and tertiary education.[24] Data on both market access and educational attainment are available for approximately 100 countries, depending upon the year. More detail on the data used in this section is provided in Appendix B.

Table 4 reports the results of regressing higher education attainment—defined as the proportion of the population who have attained secondary or tertiary education—on market access for a cross-section of countries in 1990. Because the proportion of the population with higher education is bounded between 0 and 1, we employ a logistic transformation:

$$\ln\left(\frac{\text{Higher Education}}{1-\text{Higher Education}}\right) = \kappa_{0t} + \kappa_{1t}\ln(\widetilde{\text{MA}}_{it}) + \varepsilon_{it}. \tag{36}$$

The first column of the table reports results of this bivariate regression for the 105 countries for which data are available in 1990. The estimated coefficient on market access is positive and statistically significant at the 1% level.

[24] For further information, see Barro and Lee (1993, 2001). De la Fuente and Domenech (2000) provides a complementary source of information for OECD countries.

Table 4
OLS regression of higher education attainment on market access, 1990

| Regressors | (1) Higher education | (2) Higher education | (3) Higher education | (4) Higher education | (5) Higher education | (6) Higher education |
|---|---|---|---|---|---|---|
| ln(market access) | 0.66*** | 0.61*** | 0.30** | 0.59** | | |
| | 5.98 | 4.32 | 2.22 | 2.16 | | |
| Risk of expropriation | | | −0.58*** | −0.41*** | | −0.56*** |
| | | | 4.40 | 3.13 | | 4.44 |
| Percent of land in tropics | | | −0.67 | −0.55 | | −0.82 |
| | | | 1.18 | 0.98 | | 1.42 |
| Socialist rule (1950–1995) | | | 0.28 | −0.01 | | 0.33 |
| | | | 0.78 | 0.03 | | 0.94 |
| External war (1960–1985) | | | −0.13 | −0.14 | | −0.14 |
| | | | 0.30 | 0.34 | | 0.31 |
| ln(distance to U.S.) | | | | | −0.65*** | −0.51*** |
| | | | | | 2.85 | 2.73 |
| ln(distance to Belgium) | | | | | −0.29*** | −0.09 |
| | | | | | 3.12 | 0.92 |
| ln(distance to Japan) | | | | | −0.95*** | −0.55*** |
| | | | | | 4.59 | 3.28 |
| US, Japan and Belgium excluded | no | yes | yes | yes | yes | yes |
| OECD excluded | no | no | no | yes | no | no |
| Observations (countries) | 105 | 66 | 66 | 49 | 66 | 66 |
| Adjusted $R^2$ | 0.23 | 0.24 | 0.43 | 0.28 | 0.26 | 0.45 |

Table displays OLS coefficients and *T*-values based upon Huber–White robust standard errors. Dependent variable is a logistic transformation of higher education (i.e. ln(Higher/(1−Higher)), defined as the over 15-year-old population share attaining secondary or tertiary education. See text for definition of MA. Risk of expropriation is a measure of a lack of property rights protection and varies from 1 (low risk) to 5 (high risk). Data on this measure, the percent of land in tropics, and dummies for socialist rule and external war are from the Center for International Development at Harvard (http://www.cid.harvard.edu/). Great circle geographic distance measures, derived from the latitude and longitude coordinates of a country's largest city, are in thousands of kilometers. ***, ** and * signify statistical significance at the 1%, 5% and 10% levels. Results on the included constant are suppressed.

The second column of Table 4 shows that this relationship is robust to restricting attention to a smaller set of countries where we have data on additional control variables The third column of the table indicates that market access retains a significant positive relationship with higher education even in the presence of indicators thought to be important in cross country studies of development (e.g. Gallup et al., 1998; Hall and Jones 1999). The indicators, available from the Center for International Development,[25] consist of a measure of the risk of expropriation by the government, the percent of countries' land that is tropical, and dummies for socialist rule and external wars. Including these variables in column (3) reduces the magnitude of the market access coefficient from 0.61 to 0.30

[25] http://www.cid.harvard.edu/.

although it remains statistically significant at conventional critical values. Among the controls, only risk of expropriation is statistically significant: greater risk of expropriation is negatively associated with higher education attainment.[26] For comparison, the final three columns of Table 4 report similar results when OECD countries are excluded or when geographic distances from three centers of world economic activity are used in place of market access.

These results provide evidence of a positive correlation between countries' human capital investments and measures of access to centers of world economic activity. Shedding further light on the mechanisms behind this correlation is an interesting area for future research. Potentially fruitful avenues for further inquiry include looking for a similar relationship across regions within countries[27]; analyzing the relationship between changes in educational attainment and changes in market access within countries and regions; using richer identification strategies with cross-country and cross-region data (see, for example, the analysis of spatial income inequality in Redding and Venables, 2001); and exploiting exogenous changes in market access associated with shifts in policy regime such as trade liberalization (see, for example, the analysis of spatial income inequality and Mexican trade liberalization in Hanson, 1996).

## 8. Conclusion

We present a model which ties a country's human capital accumulation to its distance from global economic activity. If skill intensive sectors are relatively trade-cost intensive, feature more pervasive input–output linkages, or are characterized by stronger increasing returns to scale, relatively peripheral countries will experience a lower skill premium and reduced incentives to educate their workers. Consistent with the predictions of theory, we provide empirical evidence that countries with lower market access have lower levels of educational attainment.

To the extent that human capital accumulation accelerates development, our analysis suggests that remoteness impedes income convergence with developed nations. An obvious policy implication is that peripheral countries need to get closer to the center of global economic activity. Though countries obviously cannot move, and thereby reduce their physical distance, it is possible to reduce the costs of remoteness. Perhaps, most important in this regard is the need for advanced economies to lower formal and informal trade barriers to the world's more isolated economies. The planned dismantling of the global Multifiber Arrangement in 2005, for example, is a step in this direction.

[26] Similar results are obtained for various definitions of higher education (e.g. just secondary education attainment) as well as for variations on the additional control variables used (e.g. distance from the equator in place of percent of tropical land). The U.S., Belgium and Japan are excluded in columns (2) to (5) to keep the sample size consistent with results reported in the last two columns. Results in earlier columns are similar if these three countries are included. All additional results, omitted to conserve space, are available from the authors upon request.

[27] Across countries, the model's assumption of factor immobility is relatively plausible. Within countries, peripheral regions may also be disadvantaged by the migration of skilled workers to more central regions (the 'brain drain').

Also likely to be important are efforts to reduce transport costs directly via improvements in infrastructure (e.g. roads, ports, etc.) or the frequency of port calls by shipping lines. Shipping routes themselves, of course, are endogenous to economic activity, but there may be a role for developed countries to subsidize the establishment of such routes as a way of elevating opportunity on the periphery. Further evaluation of these policy options is needed to identify the relevant market failures and examine how they compare in cost-benefit terms to other policies, such as subsidizing education directly.

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## Appendix A. Theory appendix

### *A.1. Proof of Proposition 2*

**Proof.** From Eq. (27), the zero profit condition in agriculture implies,

$$\frac{\mathrm{d}w_i^U}{w_i^U} = -\left(\frac{\phi}{1-\phi}\right)\frac{\mathrm{d}w_i^S}{w_i^S} \tag{37}$$

Substituting this expression into the zero profit condition in manufacturing (Eq. (28)), we have,

$$\left(\alpha - \frac{\beta\phi}{1-\phi}\right)\frac{\mathrm{d}w_i^S}{w_i^S} = -\left[\frac{1}{\sigma} + \frac{(1-\alpha-\beta)}{(\sigma-1)}\right]\gamma$$

Note that $\left(\alpha - \frac{\beta\phi}{1-\phi}\right) > 0, \Leftrightarrow \frac{\alpha}{\beta} > \frac{\phi}{1-\phi}$. Therefore, if $\frac{\alpha}{\beta} > \frac{\phi}{1-\phi}$

$$\frac{\mathrm{d}w_i^S}{w_i^S} < 0,\ \frac{\mathrm{d}w_i^U}{w_i^U} > 0, \frac{\mathrm{d}(w_i^S/w_i^U)}{w_i^S/w_i^U} < 0$$ □

### A.2. Proof of Proposition 3

**Proof.** (a) Follows immediately from Propositions 1 and 2; (b) follows immediately from the fact that the equilibrium number of skilled workers is negatively related to the critical level of ability $a_i^*$, while the equilibrium number of unskilled workers is positively related to $a_i^*$.

$$S_i = \int_{a_i^*}^{\bar{a}} \lambda(a)\bar{L}_i \mathrm{d}a, \quad L_i = \int_{\underline{a}}^{a_i^*} \lambda(a)\bar{L}_i \mathrm{d}a - \int_{a_i^*}^{\bar{a}} \frac{h_i}{a} \lambda(a)\bar{L}_i \mathrm{d}a \qquad \square$$

### A.3. Proof of Proposition 4

**Proof.** Proposition 4 is most easily proved combining Fig. 2 and the results in Proposition 1.

(a) an increase in $\theta_i^Y$ shifts the agriculture isoprice line in Fig. 2 outwards. For given values of market and supplier access, which determine the position of the manufacturing isoprice line, this unambiguously reduces the relative wage of skilled workers. From Proposition 1, the fall in the relative wage of skilled workers increases $a_i^*$ and hence reduces the equilibrium supply of skilled workers $S_i = \int_{a_i^*}^{\bar{a}} \lambda(a)\bar{L}_i \mathrm{d}a$
(b) an increase in $c_i$ shifts the manufacturing isoprice line in Fig. 2 inwards for given values of market and supplier access. This unambiguously reduces the relative wage of skilled workers. From Proposition 1, the fall in the relative wage of skilled workers increases $a_i^*$ and hence reduces the equilibrium supply of skilled workers $S_i = \int_{a_i^*}^{\bar{a}} \lambda(a)\bar{L}_i \mathrm{d}a$
(c) following an increase in $h_i$, the agriculture and manufacturing isoprice lines in Fig. 2 are unchanged for given values of market and supplier access. Hence, the equilibrium relative wage of skilled workers is unchanged. For a given relative wage of skilled workers, Proposition 1 implies that an increase in $h_i$ increases $a_i^*$ and hence reduces the equilibrium supply of skilled workers $S_i = \int_{a_i^*}^{\bar{a}} \lambda(a)\bar{L}_i \mathrm{d}a$. $\square$

## Appendix B. Data appendix

Bilateral trade data are from Feenstra et al (1997) at 5-year intervals from 1970 to 1995. To ensure that our results are not driven by small countries that trade relatively little with the rest of the world, we restrict our sample to the 137 countries that trade with at least 5 partners. Distance is the great circle distance, in kilometers, between two countries' largest cities using latitude and longitude coordinates from the Getty Thesaurus of Geographic Names, http://www.getty.edu/research/tools/vocabulary/tgn/index.html. Common border information is from the CIA World Factbook: http://www.cia.gov/cia/publications/factbook/.

Educational attainment data from Barro and Lee (2001). Higher education is defined as the proportion of the over-15 population that has attained secondary or tertiary education.

Development indicators from Gallup et al. (1998) and Hall and Jones (1999), and include: risk of expropriation by the government, the per cent of countries' land that is tropical and dummies for socialist rule and external wars. These data can be downloaded from http://www.cid.harvard.edu.

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