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# Economic geography and international inequality

Stephen Redding\*, Anthony J. Venables<sup>1</sup>

*Department of Economics, LSE Houghton Street London WC2A 2AE, UK*

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## Abstract

This paper estimates a structural model of economic geography using cross-country data on per capita income, bilateral trade, and the relative price of manufacturing goods. We provide evidence that the geography of access to markets and sources of supply is statistically significant and quantitatively important in explaining cross-country variation in per capita income. This finding is robust to controlling for a wide range of considerations, including other economic, geographical, social, and institutional characteristics. Geography is found to matter through the mechanisms emphasized by the theory, and the estimated coefficients are consistent with plausible values for the model's structural parameters.

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## 1. Introduction

In 1996, manufacturing wages at the 90th percentile of the cross-country distribution were more than 50 times higher than those at the 10th percentile. Despite increasing international economic integration, these vast disparities in wages have not been bid away by the mobility of manufacturing firms and plants. There are many potential reasons for the reluctance of firms to move production to low wage countries, including endowments, technology, institutional quality, and geographical location. This paper focuses on the role of geographical location. We estimate its effects using a fully specified model of economic

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\* Corresponding author. Tel.: +44-20-7955-7483; fax: +44-20-7831-1840.

*E-mail addresses:* s.j.redding@lse.ac.uk (S. Redding), a.j.venables@lse.ac.uk (A.J. Venables).

*URLs:* <http://econ.lse.ac.uk/~sredding/>, <http://econ.lse.ac.uk/staff/ajv>.

<sup>1</sup> Tel.: +44-20-7955-7522; fax: +44-20-7831-1840.

geography (that of Fujita et al., 1999) and cross-country data including per capita income, bilateral trade, and the relative price of manufacturing goods.

Geographical location may affect per capita income in a number of ways, through its influence on flows of goods, factors of production, and ideas. In this paper, we concentrate on two mechanisms. One is the distance of countries from the markets in which they sell output, and the other is distance from countries that supply manufactures and provide the capital equipment and intermediate goods required for production. Transport costs or other barriers to trade mean that more distant countries suffer a market access penalty on their sales and also face additional costs on imported inputs. As a consequence, firms in these countries can only afford to pay relatively low wages—even if, for example, their technologies are the same as those elsewhere.

The potential impact of these effects is easily illustrated. Suppose that the prices of output and intermediate goods are set on world markets, transport costs are borne by the producing country, and intermediates account for 50% of costs. Ad valorem transport costs of 10% on both final output and intermediate goods have the effect of reducing domestic value added by 30% (compared to a country facing zero transport costs), the reduction in value added rising to 60% for transport costs of 20%, and to 90% for transport costs of 30%.<sup>2</sup> Transport costs of this magnitude are consistent with recent empirical evidence. For example, using customs data, Hummels (1999) finds that average expenditure on freight and insurance as a proportion of the value of manufacturing imports is 10.3% in US, 15.5% in Argentina, and 17.7% in Brazil. Limao and Venables (2001) relate transport costs to features of economic geography finding, for example, that the median land-locked country's shipping costs are more than 50% higher than those of the median coastal country. Each of these papers focuses on transport costs narrowly defined (pure costs of freight and insurance) and may understate the true magnitude of barriers to trade if there are other costs to transacting at a distance, such as costs of information acquisition and of time in transit.

Our model formalizes the role of economic geography in determining equilibrium factor prices, and the exact specifications suggested by theory are used to estimate the magnitude of these effects. When included by itself, the geography of access to markets and sources of supply can explain much of the cross-country variation in per capita income. After controlling for a variety of other determinants of per capita income, we continue to find highly statistically significant and quantitatively important effects of economic geography.

The methodology we employ is as follows. We develop a theoretical trade and geography model to derive three relationships for empirical study. The first of these is a gravity-like relationship for bilateral trade flows between countries. Estimation of this enables us to derive economically meaningful estimates of each country's proximity to markets and suppliers—measures that we call market access and supplier access, respectively. Market access is essentially a measure of market potential, measuring the export demand each country faces given its geographical position and that of its trading partners; 'supplier access' is the analogous measure on the import side, so is an

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<sup>2</sup> See also Radelet and Sachs (1998).

appropriately distance weighted measure of the location of import supply to each country. The second relationship is a zero profit condition for firms that implicitly defines the maximum level of factor prices a representative firm in each country can afford to pay, given its market access and supplier access. We call this the wage equation and use it to estimate the relationship between actual income levels and those predicted by each country's market access and supplier access. The third relationship is a price index, suggesting how the prices of manufactures should vary with supplier access; we also estimate this as a check on one of the key mechanisms in our approach.

Throughout the paper, we remain very close to the theoretical structure of the trade and geography model. We find that our market access and supplier access measures are important determinants of income, and that the estimated coefficients are consistent with plausible values for the structural parameters of the model. The effects of individual economic and geographical characteristics are shown to be quantitatively important. For example, access to the coast and open-trade policies yield predicted increases in per capita income of over 20%, while halving a country's distance from all of its trade partners yields an increase of around 25%. The results are robust to the inclusion of a wide range of control variables, including countries' resource endowments, other characteristics of physical geography (as used by [Gallup et al., 1998](#)), and additional institutional, social, and political controls (see, for example, [Hall and Jones, 1999](#); [Knack and Keefer, 1997](#); [Acemoglu et al., 2001](#)). We also establish the robustness of the results to instrumenting our market and supplier access measures with exogenous geographical determinants and provide evidence that economic geography matters for per capita income through the mechanisms emphasized by the theory.

The idea that access to markets is important for factor incomes dates back at least to [Harris \(1954\)](#), who argued that the potential demand for goods and services produced in any one location depends upon the distance-weighted GDP of all locations. Early econometric investigations of the relationship between market access and per capita income include [Hummels \(1995\)](#) and [Leamer \(1997\)](#). [Hummels \(1995\)](#) finds that the residuals from the augmented Solow–Swan neoclassical model of growth are highly correlated with three alternative measures of geographical location. [Leamer \(1997\)](#) extends traditional market access measures to improve their treatment of the domestic market and exploit information on the distance coefficient from a gravity model. He finds that Central and Eastern European countries' differing access to Western European markets creates differences in their potential to achieve higher standards of living.

[Gallup et al. \(1998\)](#) and [Radelet and Sachs \(1998\)](#) find that measures of physical geography (e.g., fraction of land area in the geographical tropics) and transport costs (e.g., percentage of land area within 100 km of the coast or navigable rivers) are important for cross-country income. Though the focus is not on market access per se, [Frankel and Romer \(1999\)](#) use geography measures as instruments for trade flows. They find evidence of a positive relationship between per capita income and exogenous variation in the ratio of trade to GDP due to the geography measures. This is different from our approach both conceptually and empirically. For example, the correlation coefficients between the trade/GDP ratio and our preferred measures of market and

supplier access are 0.14 and 0.37, respectively.<sup>3</sup> Our work complements the analysis of market access and wages for US counties by [Hanson \(1998\)](#). It differs from his work in geographical focus (on countries rather than regions), the use of trade data to reveal both observed and unobserved determinants of market access, the introduction of supplier as well as market access, and in having labour immobile between geographical units.<sup>4</sup>

The paper is structured as follows. In the next section, we set out the theoretical model and derive the three structural equations that form the basis of the econometric estimation. Section 3 discusses the empirical implementation of the model. Sections 4 and 5 present our baseline estimates of the trade equation and the wage equation, respectively. Section 5 also undertakes a number of robustness tests. Section 6 exploits the structure of the theoretical model to relate the estimated coefficients to values of the structural parameters, and Section 7 shows how our approach can be used to disentangle the effects of a variety of features of economic geography for per capita income. Section 8 concludes.

## 2. Theoretical framework

The theoretical framework is based on a standard new trade theory model, extended to have transport frictions in trade and intermediate goods in production.<sup>5</sup> The world consists of  $i=1, \dots, R$  countries, and we focus on the manufacturing sector, composed of firms that operate under increasing returns to scale and produce differentiated products.

On the demand side, each firm's product is differentiated from that of other firms and is used both in consumption and as an intermediate good. In both uses, there is a constant elasticity of substitution,  $\sigma$ , between pairs of products, so products enter both utility and production through a CES aggregator taking the form

$$U_j = \left[ \sum_i^R \int_{n_i} x_{ij}(z)^{(\sigma-1)/\sigma} dz \right]^{\sigma/(\sigma-1)} = \left[ \sum_i^R n_i x_{ij}^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}, \quad \sigma > 1, \quad (1)$$

where  $z$  denotes manufacturing varieties,  $n_i$  is the set of varieties produced in country  $i$ , and  $x_{ij}(z)$  is the country  $j$  demand for the  $z$ th product from this set. The second equation makes use of the fact that, in equilibrium, all products produced in each country  $i$  are demanded by country  $j$  in the same quantity, so we dispense with the index  $z$  and rewrite

<sup>3</sup> We also present empirical results linking factor prices to foreign market and supplier access. The correlation coefficients between the trade share and our measures of foreign market and supplier access are 0.20 and 0.24, respectively.

<sup>4</sup> See [Combes and Lafourcade \(2001\)](#) for an analysis of reductions in transport costs and regional inequalities within France, and [Overman et al. \(2003\)](#) for a review of the empirical geography literature.

<sup>5</sup> The exposition follows [Fujita et al. \(1999\)](#), Chapter 14. The full general equilibrium model consists of an agricultural and manufacturing sector. Manufacturing can be interpreted as a composite of manufacturing and service activities.

the integral as a product. Dual to this quantity aggregator is a price index for manufactures in each country,  $G_j$ , defined over the prices of individual varieties produced in  $i$  and sold in  $j$ ,  $p_{ij}$ ,

$$G_j = \left[ \sum_i^R \int_{n_i} p_{ij}(z)^{1-\sigma} dz \right]^{1/1-\sigma} = \left[ \sum_i^R n_i p_{ij}^{1-\sigma} \right]^{1/1-\sigma} \quad (2)$$

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

Country  $j$ 's total expenditure on manufactures we denote  $E_j$ . Given this expenditure, country  $j$ 's demand for each product is (by Shephard's lemma on the price index)

$$x_{ij} = p_{ij}^{-\sigma} E_j G_j^{(\sigma-1)}. \quad (3)$$

Thus, the own price elasticity of demand is  $\sigma$ , and the term and  $E_j G_j^{(\sigma-1)}$ , gives the position of the demand curve facing each firm in market  $j$ . We shall refer to this as the 'market capacity' of country  $j$ ; it depends on total expenditure in  $j$  and on the number of competing firms and the prices they charge, this summarised in the price index,  $G_j$ .

Turning to supply, each representative country  $i$  firm has profits  $\pi_i$ ,

$$\pi_i = \sum_j^R p_{ij} x_{ij} / T_{ij} - G_i^\alpha w_i^\beta v_i^\gamma c_i [F + x_i]. \quad (4)$$

The final term is costs. The total output of each firm is  $x_i \equiv \sum_j x_{ij}$ , and technology has increasing returns to scale, represented by a fixed input requirement  $c_i F$  and marginal input requirement  $c_i$ , these technology parameters potentially varying across countries. There are three types of inputs, combined in a Cobb–Douglas technology. One is an internationally immobile composite primary factor which we interpret as labour, with price  $w_i$  and input share  $\beta$ . The second is an internationally mobile primary factor with price  $v_i$  and input share  $\gamma$ . The third is a composite intermediate good with price  $G_i$  and input share  $\alpha$ , and we assume  $\alpha + \beta + \gamma = 1$ . The first term in Eq. (4) is revenue earned from sales in all markets.  $T_{ij}$  is an iceberg transport cost factor, so if  $T_{ij} = 1$ , then trade is costless, while  $T_{ij} - 1$  measures the proportion of output lost in shipping from  $i$  to  $j$ .

With demand function Eq. (3), profit-maximising firms set a single f.o.b. price,  $p_i$ , so prices for sale in different countries are  $p_{ij} = p_i T_{ij}$ . The price,  $p_i$ , is a constant markup over marginal cost, given by

$$p_i = G_i^\alpha w_i^\beta v_i^\gamma c_i \sigma / (\sigma - 1). \quad (5)$$

Given this pricing behaviour, profits of each country  $i$  firm are

$$\pi_i = (p_i / \sigma) [x_i - (\sigma - 1)F]. \quad (6)$$

Thus, firms break even if the total volume of their sales equals a constant denoted  $\bar{x} \equiv (\sigma - 1)F$ . From the demand function, Eq. (3), they will sell this many units if price satisfies<sup>6</sup>

$$p_i^\sigma \bar{x} = \sum_j^R E_j G_j^{\sigma-1} (T_{ij})^{1-\sigma}. \quad (7)$$

Substituting the profit maximising price, Eq. (5), firms break even if

$$\bar{x} (G_i^\alpha w_i^\beta v_i^\gamma c_i \sigma / (\sigma - 1))^\sigma = \sum_j^R E_j G_j^{\sigma-1} T_{ij}^{1-\sigma}. \quad (8)$$

We follow Fujita et al. (1999) in calling this the *wage equation*, although more accurately, it is an equation for the price of the composite immobile factor of production. This relationship plays a central role in the empirical analysis below. It says that the maximum value of the wage that each firm in country  $i$  can afford to pay is a function of the sum of distance weighted market capacities. This sum we will refer to as the ‘market access’ of country  $i$ .

The second relationship we use in the empirical analysis is that defining bilateral trade flows between countries. The demand Eq. (3) gives the volume of sales per firm to each location, and expressing these in aggregate value gives exports from  $i$  to  $j$  of

$$n_i p_i x_{ij} = n_i p_i^{1-\sigma} (T_{ij})^{1-\sigma} E_j G_j^{\sigma-1}. \quad (9)$$

The right-hand side of this equation contains both demand and supply variables. The term  $E_j G_j^{\sigma-1}$  is country  $j$  market capacity, as defined above. On the supply side, the term  $n_i p_i^{1-\sigma}$  measures the ‘supply capacity’ of the exporting country; it is the product of the number of firms and their price competitiveness, such that doubling supply capacity (given market capacities) doubles the value of sales. In addition, the term  $(T_{ij})^{1-\sigma}$  measures bilateral transport costs between countries.

The price index forms the third main relationship used in the empirical analysis to follow. This is already defined in Eq. (2), and given our assumption about transportation costs, it becomes

$$G_j = \left[ \sum_i n_i (p_i T_{ij})^{1-\sigma} \right]^{1/(1-\sigma)}. \quad (10)$$

Notice that the term in square brackets is a sum of supply capacities, weighted by transport costs, so measures what we shall term the ‘supplier access’ of country  $j$ . It is important because an increase in this supplier access reduces the price index and the cost of intermediate goods and therefore reduces the costs of production in country  $j$  (Eq. (8)).

<sup>6</sup> The transport cost term enters with exponent  $1 - \sigma$  not  $-\sigma$ , because total shipments to market  $i$  are  $T_{ij}$  times quantities consumed.

Supplier access thus summarises the benefit of proximity to suppliers of intermediate goods.

The full general equilibrium of the model is explored in Fujita et al. (1999) and involves specifying factor endowments and hence factor market clearing to determine income and expenditure ( $E_i$ ), the output levels of each country’s manufacturing (the values of  $n_i$ ), output in other sectors (primary and non-tradable), and payments balance. Here we take  $E_i$  and  $n_i$  as exogenous and simply ask, given the locations of expenditure and of production, what wages can manufacturing firms in each location afford to pay?

### 3. Empirical framework

The empirical analysis proceeds in several stages. First, we estimate the trade equation (Eq. (9)) in order to obtain empirical estimates of bilateral transport costs between countries and of each country’s market and supply capacities. Labelling these  $m_i$  and  $s_i$ , respectively, they are defined as

$$m_i \equiv E_i G_i^{\sigma-1}, \quad s_i \equiv n_i p_i^{1-\sigma}, \tag{11}$$

and allow the trade equation (Eq. (9)) to be rewritten as

$$n_i p_i x_{ij} = s_i (T_{ij})^{1-\sigma} m_j. \tag{12}$$

We estimate this gravity-type relationship on bilateral trade flow data, and from it, we obtain predictions for  $(T_{ij})^{1-\sigma} m_j$  and  $s_i (T_{ij})^{1-\sigma}$  for each exporting country  $i$  and importing partner  $j$ .

Second, we construct the market access of each exporting country  $i$ ,  $MA_i$ , and the supplier access of each importing country  $j$ ,  $SA_j$ . Market access is the appropriately distance-weighted sum of the market capacities of all partner countries, and supplier access is the analogous sum of supplier capacities, so

$$\begin{aligned} MA_i &= \sum_j E_j G_j^{\sigma-1} T_{ij}^{1-\sigma} = \sum_j (T_{ij})^{1-\sigma} m_j, \\ SA_j &= \sum_i n_i (p_i T_{ij})^{1-\sigma} = \sum_i s_i (T_{ij})^{1-\sigma}. \end{aligned} \tag{13}$$

Using predicted values of  $(T_{ij})^{1-\sigma} m_j$  and  $s_i (T_{ij})^{1-\sigma}$  from the trade equation, we construct empirical predictions for these two variables.

Third, using Eqs. (8), (10), (11), and (13), the wage equation for country  $i$  can be written as a log-linear function of its supplier access and market access,

$$\begin{aligned} (w_i^\beta v_i^\gamma c_i)^\sigma &= A G_i^{-\alpha\sigma} \sum_j^R E_j G_j^{\sigma-1} T_{ij}^{1-\sigma} = A \left[ \sum_j s_j (T_{ij})^{1-\sigma} \right]^{\frac{\alpha\sigma}{\sigma-1}} \left[ \sum_j (T_{ij})^{1-\sigma} m_j \right] \\ &= A (SA_i)^{\frac{\alpha\sigma}{\sigma-1}} (MA_i) \end{aligned} \tag{14}$$

where the left-hand side of Eq. (14) contains the wage,  $w_i$ , the price of the internationally mobile factor of production,  $v_i$ , and a measure of technology differences,  $c_i$ ; the constant  $A$  on the right-hand side combines constants from Eq. (8). The equation says that countries with high market access and high supplier access pay relatively high wages. We estimate this equation using predicted values of supplier access and market access as right-hand side variables, and cross-country data on factor incomes as the dependent variable. This estimation establishes the extent to which observed variation in factor incomes can be explained by these geographical determinants, and the estimated coefficients on these variables can be clearly related to the values of the structural parameters of the model.

Finally, from Eqs. (10) and (13), the price index for manufacturing goods,  $G_j$ , may be written as a function of supplier access,  $SA_j$ ,

$$G_j = [SA_j]^{1/(1-\sigma)}. \quad (15)$$

We estimate Eq. (15) using predicted values of supplier access as the right-hand side variable and data on the relative price of manufacturing goods on the left-hand side.

## 4. Trade equation estimation

### 4.1. Data sources and sample size

Data on bilateral trade flows for a cross-section of 101 countries are obtained from the World Bank's COMTRADE database. We combine the trade data with information on geographical characteristics (e.g., bilateral distance, existence of a common border) and data on GDP and population from the World Bank. See Appendix A for further details.

### 4.2. Econometric estimation

The value of bilateral trade flows in the trade equation, Eq. (12), depends upon exporting country characteristics (supply capacity,  $s_i$ ), importing partner characteristics (market capacity,  $m_j$ ), and bilateral transportation costs ( $T_{ij}$ ). In the main econometric specification, these exporting and importing country characteristics (supply and market capacity) are captured with country and partner dummies (denoted by  $cty_i$  and  $ptn_j$ , respectively). The use of dummies addresses the fact that we cannot observe economic variables that correspond exactly to the theory and also controls for any component of transport costs or trade policy that is common across all partners for a particular exporting country or common across all suppliers of an importing country. Section 7 of the paper repeats the analysis using economic and geographical measures of supply and market capacity and shows that the main results of the paper are robust to either approach. The bilateral component of transportation costs is modelled using data on



the distance between capital cities ( $\text{dist}_{ij}$ ) and a dummy for whether an exporting country and importing partner share a common border ( $\text{bord}_{ij}$ ). Eq. (12) thus becomes<sup>7</sup>

$$\ln(X_{ij}) = \theta + \mu_i \text{cty}_i + \lambda_j \text{ptn}_j + \delta_1 \ln(\text{dist}_{ij}) + \delta_2 \text{bord}_{ij} + u_{ij} \quad (16)$$

where  $X_{ij}$  denotes the value of exports from country  $i$  to partner  $j$ , and  $u_{ij}$  is a stochastic error. There are a number of observations of zero bilateral trade flows and, throughout the following, we add 1 to all trade flows before taking logarithms.<sup>8</sup>

Column (1) of Table 1 presents the results of estimating Eq. (16) on 1994 data using OLS. The distance between capital cities and common border variables are correctly signed according to economic priors and statistically significant at the 1% level. The null hypothesis that the coefficients on either the country dummies or the partner dummies are equal to zero is easily rejected at the 1% level with a standard  $F$ -test, and the model explains approximately 80% of the cross-section variation in bilateral trade flows. However, the specification in column (1) does not take into account the fact that the trade data is left-censored at zero. In column (2), we reestimate the model for the censored sample using OLS. Column (3) explicitly takes into account the truncated nature of the data by using the Tobit estimator. This increases the absolute magnitude of the coefficient on the distance variable and reduces the size of the coefficient on the common border dummy. We use the Tobit estimates as the basis for our next step.

#### 4.3. Construction of market and supplier access

The coefficients of the country and partner dummies in the trade equation (Eq. (16)) provide estimates of the market and supply capacities of each country,  $m_j$  and  $s_i$ , capturing all factors that determine countries' propensities to demand imports from or supply exports to all partners. The distance and border coefficients provide estimates of the bilateral transport cost measure,  $(T_{ij})^{1-\sigma}$ . These give the weights that combine market capacities in the construction of market access and combine supply capacities in the construction of supplier access (see Eq. (13)) and are the basis for the spatial variation of market access and supplier access.<sup>9</sup> Predicted values of market access and supplier access are therefore, from Eq. (13),

$$M\hat{A}_i = D\hat{M}A_i + F\hat{M}A_i = (\exp(\text{ptn}_i))^{\hat{\lambda}_i} (T_{ii})^{1-\sigma} + \sum_{j \neq i} (\exp(\text{ptn}_j))^{\hat{\lambda}_j} \text{dist}_{ij}^{\hat{\delta}_1} \text{bord}_{ij}^{\hat{\delta}_2} \quad (17)$$

$$S\hat{A}_j = D\hat{S}A_j + F\hat{S}A_j = (\exp(\text{cty}_j))^{\hat{\lambda}_j} (T_{jj})^{1-\sigma} + \sum_{i \neq j} (\exp(\text{cty}_i))^{\hat{\lambda}_i} \text{dist}_{ij}^{\hat{\delta}_1} \text{bord}_{ij}^{\hat{\delta}_2} \quad (18)$$

<sup>7</sup> This specification is more general than the standard gravity model, in which country and partner dummies are replaced by income and other country characteristics. The partner dummies capture the manufacturing price index,  $G_j$ , and thus control for the effects of what Anderson and van Wincoop (2003) term 'multilateral resistance.'

<sup>8</sup> The COMTRADE database records the values of bilateral trade flows to a high degree of accuracy; these zeros are genuine zeros rather than missing values. The trade data are in thousands of dollars, and thus, we add \$1000 before taking logarithms.

<sup>9</sup> If  $T_{ij} = 1$  for all  $i, j$ , then all countries have the same market and supplier access (Eq. (13)).

Table 1  
Trade equation (country, partner dummies)

$\ln(X_{ij})$	(1) <sup>a</sup>	(2) <sup>a</sup>	(3) <sup>b</sup>
Observations	10,100	8079	10,100
Year	1994	1994	1994
$\ln(\text{dist}_{ij})$	-1.538** (0.041)	-1.353** (0.032)	-1.738** (0.043)
$\text{bord}_{ij}$	0.976** (0.195)	1.042** (0.141)	0.917** (0.179)
Country dummies	yes	yes	yes
Partner dummies	yes	yes	yes
Estimation	OLS	OLS	Tobit
$F(\cdot)$	249.63	159.67	–
Prob>F	0.000	0.000	–
R-squared	0.789	0.786	–
Root MSE	2.214	1.688	–
Log Likelihood	–	–	-20,306.379
LR $\chi^2$ (206)	–	–	15,231.38
Prob> $\chi^2$	–	–	0.000
Pseudo- $R^2$	–	–	0.273

$\ln(X_{ij})$  is log bilateral exports from country  $i$  to partner  $j$  plus 1;  $\ln(\text{dist}_{ij})$  is bilateral distance between countries  $i$  and  $j$ ;  $\text{bord}_{ij}$  is a dummy for whether the two countries share a common border. All specifications include exporting country and importing partner dummies.

\*Denotes statistical significance at the 10% level. \*\*Denotes statistical significance at the 5% level.

<sup>a</sup> Huber–White heteroscedasticity robust standard errors in parentheses.

<sup>b</sup> 2021 left-censored observations  $\leq 0$ , 8079 uncensored observations.

Notice that we have split each of these into a domestic and foreign part (DMA and FMA, respectively). The reason is that the trade equation does not provide us with estimates of ‘intra-country’ transport cost measures,  $(T_{ii})^{1-\sigma}$ . We consider three alternative ways of getting hold of these measures. First, we assume that internal trade costs are equal to the cost of shipping to a foreign country 100 km away and with a common border; using these, we develop series  $\hat{D}\hat{M}A_i(1)$  and  $\hat{D}\hat{S}A_i(1)$ .<sup>10</sup> Second, we link intra-country transport costs to the area of the country, by using the formula  $\text{dist}_{ii} = 0.66(\text{area}/\pi)^{1/2}$ , to give the average distance between two points in a circular country; we construct series  $\hat{D}\hat{M}A_i(2)$  and  $\hat{D}\hat{S}A_i(2)$  using  $T_{ii}^{1-\sigma} = \text{dist}_{ii}^{\delta_i}$ . Third, to capture the likelihood that internal transport costs are less than international, we construct series  $\hat{D}\hat{M}A_i(3)$  and  $\hat{D}\hat{S}A_i(3)$  using  $T_{ii}^{1-\sigma} = \text{dist}_{ii}^{\delta_i/2}$ .

## 5. Wage equation estimation

### 5.1. Econometric specification

Having obtained predicted values for market and supplier access, we move on to the econometric estimation of the wage equation. From Eq. (14), factor incomes in country  $i$  are related to market and supplier access as follows,

$$\ln w_i = \xi + \varphi_1 \ln SA_i + \varphi_2 \ln MA_i + \eta_i, \quad (19)$$

<sup>10</sup> The minimum bilateral distance between any two trade partners in our data set is 42 km.

and substituting predicted for actual values of market and supplier access,

$$\ln w_i = \zeta + \varphi_1 \ln \hat{S}A_i + \varphi_2 \ln \hat{M}A_i + \varepsilon_i. \quad (20)$$

In our main estimation results, we take GDP per capita as a proxy for  $w_i$ , the price of immobile factors. GDP includes the income of all immobile factors and has the advantage of being available for all 101 countries in our sample. We also estimate Eq. (20) using the manufacturing wage per worker from the UNIDO Industrial Statistics Database, although these data are only available for 85 countries.

The stochastic error in Eq. (19),  $\eta_i$ , includes the prices of mobile factors of production,  $\ln(v_i)$ , and levels of technical efficiency,  $\ln(c_i)$ . For those factors of production that are perfectly mobile,  $\ln(v_i) = \ln(v_k) = \ln(v)$  for all  $i, k$ , and the first term is captured in the regression constant. To begin with, we consign cross-country differences in technology to the residual and examine how much of the variation in cross-country per capita income can be explained when only including market and supplier access and without resorting to exogenous technology differences.<sup>11</sup> This provides the basis for our first set of regression estimates and will yield consistent parameter estimates if cross-country technology differences are uncorrelated with the right-hand side variables.

Clearly, this assumption may not be satisfied, and our subsequent baseline specification explicitly allows for this possibility while also controlling for the potential existence of other shocks to the dependent variable that are correlated with measures of economic geography. Drawing on the results of the cross-country growth literature, we capture cross-country variation in technology by including a number of control variables thought to be exogenous determinants of levels of technical efficiency. Our concern here is with fundamental determinants of levels of per capita income (such as physical geography and institutions) rather than proximate sources of income differences (such as human and physical capital which are ultimately endogenous; see, for example, Hall and Jones, 1999).

To abstract from contemporaneous shocks that affect both left- and right-hand side variables, we use trade equation estimates for 1994 to construct the predicted values for market and supplier access. These are then used to explain the cross-country distribution of manufacturing wages in 1996.<sup>12</sup> There may be unmodelled (third) variables not included in our list of controls that are persistent over time, that vary across countries, and that are correlated with both manufacturing wages and market/supplier access. This is a particular problem for domestic market/supply capacity; any third variable which affects domestic market/supply capacity may also have a direct effect on wages. To control for this possibility, we present estimation results with both total market/supplier access (as defined in Eqs. (17) and (18)) and with only foreign market/supplier access (i.e., excluding all domestic information).

<sup>11</sup> Even in the absence of exogenous technology differences, measured TFP may vary substantially across countries due to differences in the transport cost inclusive price of manufacturing inputs and output. A ‘true’ measure of TFP requires a multisector model with intermediate inputs, combined with disaggregated data on the transport cost inclusive price of manufacturing goods.

<sup>12</sup> Since all data are in current price US\$ the move from 1994 to 1996 \$ prices is captured in the constant  $\zeta$  of the wage equation.

However, this does not eliminate the possibility of unmodelled (third) variables not included in our list of controls that are correlated with both foreign market/supplier access and manufacturing wages. In order to address this possibility, we present two-stage least squares estimates where we instrument market and supplier access with exogenous geographical determinants. The instruments are distance from the three main markets and sources of supply for manufactures around the world (the United States, Western Europe, and Japan). This enables us to test an identifying assumption of the theoretical model—namely, that after controlling for the exogenous determinants of technology, distance from other countries matters for manufacturing wages through access to markets and sources of supply. This assumption would be violated if there were unmodelled (third) variables not captured in our list of controls that have an independent effect on manufacturing wages but are correlated with distance from other countries (and hence, with market/supplier access). We test the validity of this identifying assumption using a Sargan test of the model's overidentifying restrictions.

Since the predicted values for market and supplier access are generated from a prior regression (the trade equation), the stochastic error in Eq. (20),  $\varepsilon_{it}$ , includes the trade equation residuals. The presence of generated regressors (Pagan, 1984) means that, as in two-stage least squares, the OLS standard errors are invalid. We employ bootstrap techniques (Efron and Tibshirani, 1993) to obtain standard errors that explicitly take into account the presence of generated regressors.<sup>13</sup>

Finally, predicted market and supplier access are, in practice, highly correlated.<sup>14</sup> Therefore, we begin by regressing log GDP per capita on log market access and log supplier access separately. In Section 6 of the paper, we include both measures and exploit a theoretical restriction on the relative value of the estimated coefficients.

## 5.2. *Economic geography and income per capita: preliminary estimates*

Table 2 presents our first set of estimates of the wage equation where we examine the unconditional relationship between GDP per capita and measures of economic geography. Column (1) regresses log GDP per capita on log predicted foreign market access using OLS. The estimated coefficient on foreign market access is positive and statistically significant at the 5% level. Taking into account the presence of generated regressors raises the standard error of the estimated coefficient, but this remains highly statistically significant. When included on its own, foreign market access alone explains approximately 35% of the cross-country variation in GDP per capita. Our theory-based measure of foreign market access dominates an ad hoc approach based on distance weighted GDP in other countries from the traditional geography literature. If the specification in column (1)

<sup>13</sup> Each bootstrap replication resamples over 10,000 country-partner observations in the data set, estimates the first-stage trade regression, generates predicted values for market and supplier access, and estimates the second-stage wage equation. The conventional number of bootstrap replications used to estimate a standard error is 50–200 (Efron and Tibshirani, 1993). The standard errors reported in the paper are based on 200 bootstrap replications.

<sup>14</sup> The correlation coefficient between our preferred measures of market and supplier access (MA(3) and SA(3)) is 0.88.

Table 2  
Market access and GDP per capita

ln(GDP per capita)	(1)	(2)	(3)	(4)	(5)
Observations	101	101	101	101	101
Year	1996	1996	1996	1996	1996
ln(FMA <sub><i>i</i></sub> )	0.476** (0.066) [0.076]	–	–	–	0.311** (0.062) [0.086]
ln(MA <sub><i>i</i></sub> ) = ln(DMA <sub><i>i</i></sub> (1) + FMA <sub><i>i</i></sub> )	–	0.558** (0.042) [0.064]	–	–	–
ln(MA <sub><i>i</i></sub> ) = ln(DMA <sub><i>i</i></sub> (2) + FMA <sub><i>i</i></sub> )	–	–	0.512** (0.048) [0.072]	–	–
ln(MA <sub><i>i</i></sub> ) = ln(DMA <sub><i>i</i></sub> (3) + FMA <sub><i>i</i></sub> )	–	–	–	0.395** (0.023) [0.035]	–
ln(DMA <sub><i>i</i></sub> (3))	–	–	–	–	0.146** (0.037) [0.057]
Estimation	OLS	OLS	OLS	OLS	OLS
R <sup>2</sup>	0.346	0.642	0.552	0.732	0.591
F(·)	52.76	174.46	112.09	294.39	48.90
Prob>F	0.000	0.000	0.000	0.000	0.000

First-stage estimation of the trade equation using Tobit (column (3) in Table 1). Huber–White heteroscedasticity robust standard errors in parentheses. Bootstrapped standard errors in square parentheses (200 replications). FMA<sub>*i*</sub> is Foreign Market Access obtained from the trade equation estimation and defined in Eq. (17); DMA<sub>*i*</sub>(1) is our first measure of Domestic Market Access, assuming internal trade costs are equal to the cost of shipping to a foreign country 100 km away and with a common border; DMA<sub>*i*</sub>(2) combines information on internal distance with the coefficient on distance from the trade equation estimation to obtain a measure of Domestic Market Access that takes into account cross-country differences in internal areas; DMA<sub>*i*</sub>(3) is our preferred measure of Domestic Market Access that uses internal area information but allows the coefficient on internal distance to be lower than that on external distance in the trade equation estimation.

\*Denotes statistical significance at the 10% level. \*\*Denotes statistical significance at the 5% level.

is reestimated using the ad hoc measure, the  $R^2$  of the regression falls by around a third to 0.24.<sup>15</sup>

In column (2), we use total market access (foreign plus domestic), employing our first measure of domestic market access. The estimated coefficient is again positive and statistically significant at the 5% level, and the  $R^2$  of the regression rises to 0.64. In columns (3) and (4), cross-country variation in internal area is incorporated in the construction of DMA, corresponding to our second and third measures. Estimated

<sup>15</sup> An ad hoc measure of market potential is  $MP_i = \sum_{j \neq i} GDP_j / dist_{ij}$ . This fails to use information contained in the trade data. Reestimating the specification in column (1) using the ad hoc measure, the estimated coefficient (standard error) is 0.958 (0.177).

coefficients are positive and statistically significant at the 5% level, and with DMA(3) included on its own, the model explains 73% of the cross-country variation in GDP per capita. Finally, as a robustness test, column (5) enters log foreign and log domestic market access (DMA(3)) as separate terms in the regression equation. Theory tells us that this regression is misspecified, and we see that the  $R^2$  is lower than with the correct specification (column (4)). However, both terms are positively signed and statistically significant at the 5% level.

Figs. 1–4 plot log GDP per capita against the four alternative measures of log market access considered in columns (1)–(4) of Table 2. Each country is indicated by a three-letter code (see Appendix A for details). It is clear from these figures that the relationship between GDP per capita and market access is very robust and is not due to the influence of a few individual countries. In Fig. 1, using FMA alone, the main outliers are remote high per capita income countries (Australia, New Zealand, Japan, and the USA). Remaining figures use estimates of DMA, as required by theory, and each illustrates a different treatment of the internal transportation costs. In Fig. 2, DMA is included with the same measure of internal transport costs for all countries—making large countries outliers to the right (India, China, USA) and small ones outliers to the left (e.g., Israel), exactly as would be expected. Letting internal transport costs vary with area, and treating internal distance identically to external distance (Fig. 3) seems to overcompensate—Singapore and Hong Kong come to have much better market access than Germany or the USA. In Fig. 4, we let internal transport costs vary with area, but allow the costs of transporting goods a given distance internally to be lower than for the same external distance. This is the solution which produces the best fit, as well as according with economic priors on the relative magnitudes of internal and external transport costs.

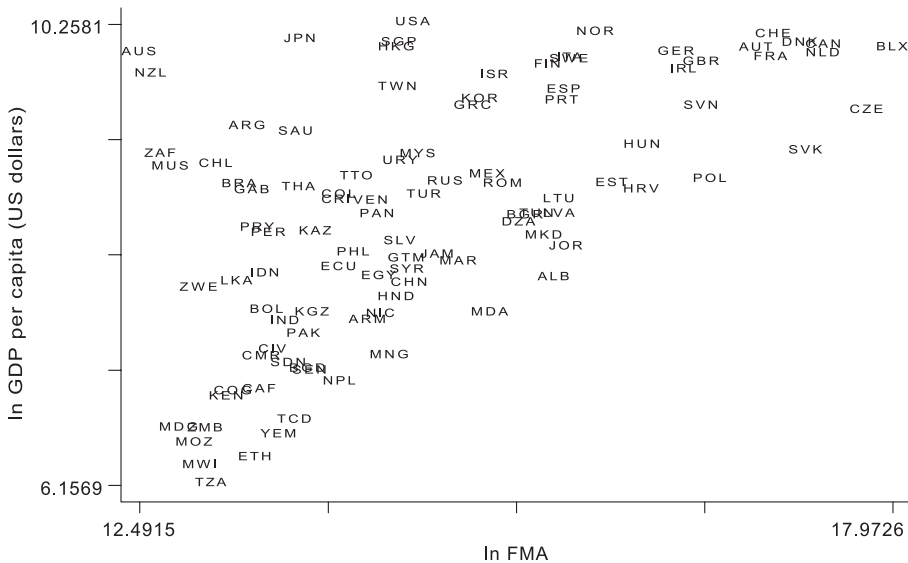


Fig. 1. GDP per capita and FMA.

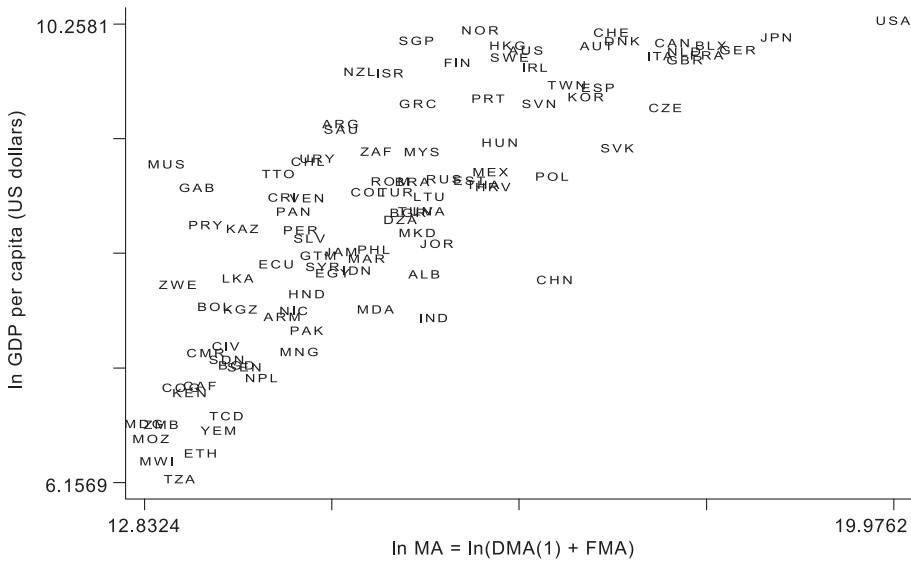


Fig. 2. GDP per capita and MA=DMA(1)+FMA.

5.3. Economic geography and per capita income: preferred specification

We now move on to present our preferred specification of the relationship between economic geography and per capita income, where we control for cross-country variation

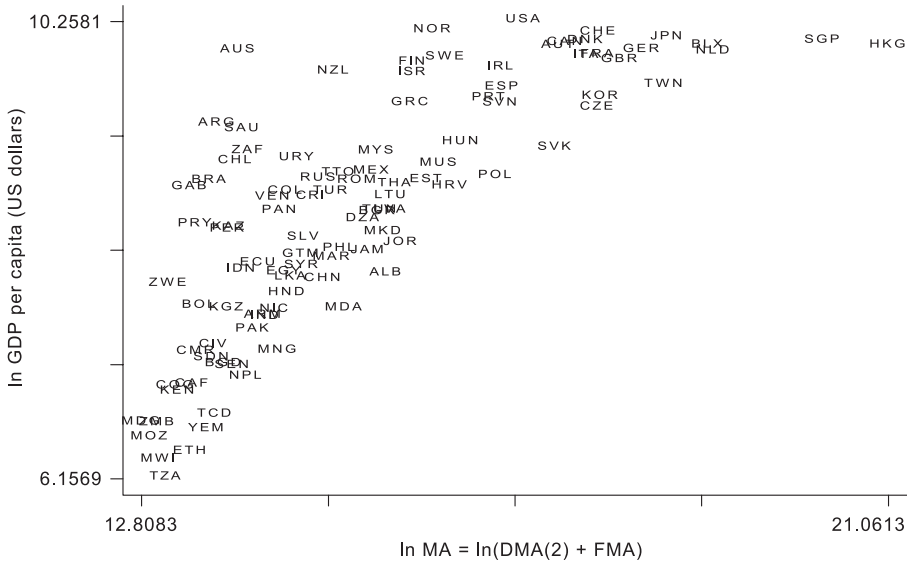


Fig. 3. GDP per capita and MA=DMA(2)+FMA.

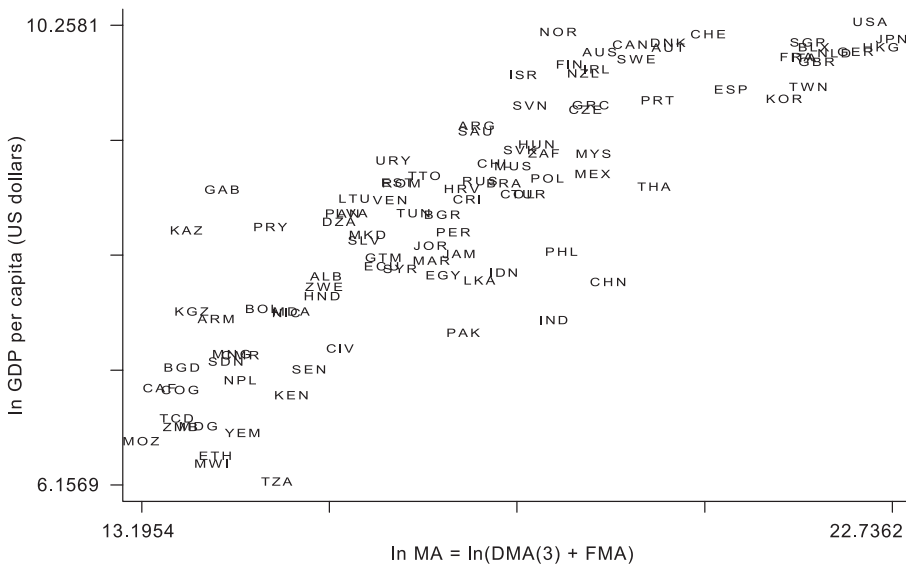


Fig. 4. GDP per capita and MA=DMA(3)+FMA.

in technology and other determinants of income levels by including a series of control variables drawn from the literature on fundamental determinants of cross-country income levels (including Acemoglu et al., 2001; Gallup et al., 1998; Hall and Jones, 1999; Knack and Keefer, 1997). In order to address the potential endogeneity of domestic market and supply capacity, we follow Table 2 in presenting results with both total market access and with foreign market access alone. In the interests of brevity, we restrict consideration to our preferred measure of total market access (with DMA(3)).

The first set of control variables we introduce are measures of countries' primary resource endowments. These include arable land area per capita, hydrocarbons per capita and a broader measure of mineral wealth (see Appendix A). We also control for two other features of physical geography emphasised in the work of Gallup et al. (1998): the fraction of a country's land area in the geographical tropics and the prevalence of malaria. Finally, a number of studies have emphasized the role of institutions, 'social capability,' or 'social infrastructure' in determining levels of per capita income.<sup>16</sup> Therefore, we augment the specification further by considering a number of other institutional, social, and political characteristics of countries. These are a measure of the risk of expropriation or protection of property rights (perhaps the most widely used measure of institutions or 'social capability'), socialist rule during 1950–1995 and the occurrence of an external war.

Columns (1) and (3) of Table 3 report estimation results including all three sets of controls for foreign and total market access, respectively. The availability of the data on

<sup>16</sup> See, for example, Acemoglu et al. (2001), Hall and Jones (1999), and Knack and Keefer (1997).



Table 3

Economic geography, physical geography, institutions, and GDP per capita

ln(GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Observations	91	91	91	91	101	101	69	69
Year	1996	1996	1996	1996	1996	1996	1996	1996
ln(FMA <sub><i>i</i></sub> )	0.215** [0.063]	0.229** [0.083]	–		0.148** [0.061]	–	0.269** [0.112]	0.189** [0.096]
ln(MA <sub><i>i</i></sub> = DMA <sub><i>i</i></sub> (3) + FMA <sub><i>i</i></sub> )	–	–	0.307** [0.066]	0.256** [0.124]		0.337** [0.063]		
ln(hydrocarbons per capita)	0.019 [0.015]	0.019 [0.015]	0.018 [0.021]	0.019 [0.024]	–	–	0.026 [0.018]	0.026 [0.018]
ln(arable land area per capita)	–0.050 [0.066]	–0.050 [0.070]	0.161 [0.103]	0.126 [0.136]	–	–	–0.078 [0.085]	–0.107 [0.088]
Number of minerals	0.016** [0.008]	0.016 [0.010]	–0.017 [0.013]	–0.013 [0.015]	–	–	0.015 [0.014]	0.012 [0.014]
Fraction land in geographical tropics	–0.057 [0.239]	–0.041 [0.257]	0.128 [0.293]	0.056 [0.347]	–	–	0.175 [0.294]	0.077 [0.286]
Prevalence of malaria	–1.107** [0.282]	–1.097** [0.284]	–1.008** [0.376]	–1.052** [0.403]	–	–	–1.105** [0.318]	–1.163** [0.325]
Risk of expropriation	–0.445** [0.091]	–0.441** [0.093]	–0.181 [0.129]	–0.236 [0.172]	–	–	–0.361** [0.116]	–0.376** [0.116]
Socialist rule 1950–1995	–0.210 [0.191]	–0.218 [0.192]	–0.050 [0.208]	–0.056 [0.214]	–	–	–0.099 [0.241]	–0.069 [0.248]
External war 1960–1985	–0.052 [0.169]	–0.051 [0.174]	0.001 [0.312]	–0.012 [0.307]	–	–	–0.078 [0.209]	–0.093 [0.210]
Full sample	yes	yes	yes	yes	yes	yes		
Non-OECD							yes	
Non-OECD + OECD FMA								yes
Regional dummies					yes	yes		
Sargan ( <i>p</i> -value)	–	0.980	–	0.721	–	–	–	–
Estimation	OLS	IV	OLS	IV	OLS	OLS	OLS	OLS
R <sup>2</sup>	0.766	0.766	0.842	0.839	0.688	0.837	0.669	0.654
F(·)	47.77	53.00	59.07	64.76	58.00	67.53	18.23	17.80
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

First-stage estimation of the trade equation using Tobit (column (3) in Table 1). Bootstrapped standard errors in square parentheses (200 replications). FMA<sub>*i*</sub> is Foreign Market Access obtained from the trade equation estimation and defined in Eq. (17); DMA<sub>*i*</sub>(3) is our preferred measure of Domestic Market Access that uses internal area information but allows the coefficient on internal distance to be lower than that on external distance in the trade equation estimation. See Appendix A for definitions of and sources for the control variables. The availability of the hydrocarbons per capita and risk of expropriation data reduces the sample size in columns (1)–(4) to 91 observations. The regional dummies in columns (5) and (6) are Sub-Saharan Africa, North Africa and the Middle East, Latin America and the Caribbean, Southeast Asia, Other Asia, and Eastern Europe and the former USSR. The excluded category is the industrialized countries of North America, Western Europe, and Oceania. See Appendix A for the country composition of each regional grouping. The excluded exogenous variables in columns (2) and (4) are log distance from the US, log distance from Belgium (as a central point in the European Union), and log distance from Japan. Sargan is a Sargan test of the model's overidentifying restrictions. In column (7), FMA is computed using all countries, estimation on the non-OECD. In column (8), FMA is computed excluding non-OECD countries, estimation on the non-OECD.

\*Denotes statistical significance at the 10% level. \*\*Denotes statistical significance at the 5% level.

hydrocarbons per capita and the risk of expropriation reduces the sample to 91 countries. In both cases, the estimated market access coefficient remains positively signed and highly statistically significant. Among the control variables, the coefficients on the prevalence of malaria and risk of expropriation are negatively signed and statistically significant at the 5% level. These findings are entirely consistent with the theoretical model presented above if the effect of malaria and lack of protection of property rights is to reduce levels of technical efficiency, as indeed is argued in the literature on cross-country income differences. As an additional robustness test, we also reestimated the specification, replacing the fraction of a country's land area in the geographical tropics with Hall and Jones's (1999) measure of distance from the equator. Again, a very similar pattern of results was observed.

In columns (2) and (4), we investigate the potential existence of other shocks to the dependent variable that may be correlated with our measures of economic geography. We instrument foreign and total market access with distance from the United States, from Belgium (as a central point in the European Union), and from Japan. These capture countries' proximity to the three main markets and sources of supply for manufactured goods. The instruments are highly statistically significant in the first-stage regression: for both measures of market access, the  $p$ -value for an  $F$ -test of the null hypothesis that the coefficients on the excluded exogenous variables are equal to zero is 0.00. In the second-stage wage equation, we again find positive and highly statistically significant effects of economic geography, with the IV estimate of the market access coefficients close to those estimated using OLS.

We examine the validity of the instruments using a Sargan test of the model's overidentifying restrictions: for both measures of market access, we are unable to reject the null hypothesis that the excluded exogenous variables are uncorrelated with the wage equation residuals. These results provide evidence that the estimated market access effects are not being driven by unmodelled (third) variables missing from our list of controls and correlated with both market access and GDP per capita. They provide support for the mechanisms emphasized by the theoretical model: namely, that after controlling for the exogenous determinants of technology, distance from other countries matters for GDP per capita through our measures of economic geography.

#### 5.4. Robustness

Instead of seeking to model the fundamental determinants of levels of technical efficiency, we also consider an alternative approach where we replace the economic variables with a full set of region dummies.<sup>17</sup> The dummies control for all observed and unobserved heterogeneity across regions, so parameters of interest are identified solely from variation in market access within regions. Columns (5) and (6) of Table 3 report the results for

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<sup>17</sup> The regions are Sub-Saharan Africa; North Africa and the Middle East; Latin America and the Caribbean; Southeast Asia; Other Asia; Eastern Europe and the former USSR; where the excluded category is the industrialised countries of North America, Western Europe, and Oceania. See Appendix A for a list of the countries included in these regions.

foreign and total market access, respectively. In each case, the estimated coefficients on all dummy variables are negative, as is expected given the excluded category and the fact that this is a regression for levels of per capita income. The market access coefficients remain positive and highly statistically significant. Thus, even if we identify the relationship between market access and per capita income using only variation within regions, we find a positive and statistically significant effect.

One potential concern about the econometric results is that GDP per capita in one country is being explained using measures of demand and supply capacity in other countries (foreign market access) that are likely to be correlated with their GDP. Are the results just picking up that rich countries tend to be located next to rich countries, particularly within the OECD? Are our measures of transport costs (distance between countries and the existence of a common border) really important for the results, or is everything being driven by common shocks to GDP across countries? These concerns have been addressed by the IV estimates in [Table 3](#), where we have shown that distance from the three centres of world economic activity both matters for income per capita and is important because it affects foreign market access. However, to provide further evidence that our results are due to the geography of access to markets and sources of supply, we consider a number of additional robustness tests.

First, are the results being driven by the OECD? Column (7) of [Table 3](#) reestimates the baseline foreign market access specification for the sample of non-OECD countries, including our full set of control variables.<sup>18</sup> The coefficient on foreign market access (defined as above) remains of a similar magnitude and is highly statistically significant. Furthermore, [Figs. 1–4](#) presented evidence of a positive relationship between GDP per capita and market access that held at all levels of GDP per capita—for both rich and poor countries.

Second, are the results being driven by the fact that, even outside the OECD, richer countries tend to be located next to each other? In column (8) of [Table 3](#), we again present estimation results for the non-OECD, but this time, foreign market access is calculated only using information on market capacity in OECD countries, together with distance and common border information. Here, we examine the extent to which variation in income per capita across non-OECD countries can be explained by differential access to OECD markets. Again, we find a positive and statistically significant effect of foreign market access.

Third, are our measures of transport costs (distance between countries and the existence of a common border) really important for the results, or is everything being driven by common shocks to GDP across countries? As is clear from [Eq. \(13\)](#), market access only varies across countries because countries have different transport cost weights—these generate the spatial variation in market access that we use to identify the parameters of interest. We demonstrate the importance of the transport cost weights in two additional ways. First, by replacing a country's true measures of distance and the existence of a common border in the first-stage trade equation with randomly

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<sup>18</sup> Since the concern is about the industrialized OECD countries, we exclude 22 of the 23 original members of the OECD (the missing country is Iceland which is not in our sample). The results are very similar if we instead exclude all current OECD members.

generated measures. Second, by replacing the distance and common border variables in the first-stage trade equation with information on whether one country was a former colony of another. These robustness tests are discussed further in the working paper version of this paper (Redding and Venables, 2001). Each demonstrates that it is the geography of countries' locations relative to markets and sources of supply that is driving our results.

Finally, as noted above, one of the advantages of using GDP information as the basis for our left-hand side variable is that it includes the income of all immobile factors. As an additional robustness test, we also considered a narrower definition of the income of immobile factors based on the manufacturing wage per worker from the Unido Industrial Statistics Database, available for a subsample of 85 countries. This yielded an extremely similar pattern of estimation results. For example, reestimating our baseline foreign market access specification (column (1) of Table 3) with the manufacturing wage per worker as the left-hand side variable and our full set of controls yields an estimated coefficient (bootstrapped standard error) of 0.239 (0.098). The corresponding estimated coefficient (bootstrapped standard error) for our preferred measure of total market access (domestic plus foreign, column (3) of Table 3) is 0.394 (0.109). Whether a narrow or broad definition of the income of immobile factors is used, we find a strong relationship with measures of economic geography.

## 6. Supplier access

### 6.1. Supplier access and intermediates goods prices

One of the key theoretical mechanisms by which location affects income per capita is through the manufacturing price index,  $G_i = [SA_i]^{1/(1-\sigma)}$ . Countries which are remote from sources of supply of manufactured goods incur greater transport costs, and have higher values of the price index,  $G_i$ , reducing the wage that they can afford to pay. This provides an independent and empirically verifiable prediction of the model. Since some cross-country data are available on manufacturing prices, we now turn to examine this theoretical mechanism.

Our empirical proxy for  $G_i$  is the relative price of machinery and equipment, a sector whose output is used as an input in many other industries. The data on the relative price of machinery and equipment are obtained from Phase V of the United Nations International Comparisons (ICP) project (United Nations, 1994) that contains information on the price of a large number of individual commodities in local currency units per dollar. Our measure of the relative price of machinery and equipment is thus the PPP for machinery and equipment divided by the PPP for GDP as a whole. Data are available for 46 countries for the year 1985. The relative price of machinery and equipment is 1 in the United States and reaches a maximum of 4.68 in Sri Lanka.

Table 4 presents the results of regressing the relative price of machinery and equipment against our measure of supplier access,  $SA_i$ . Column (1) considers foreign supplier access,  $FSA_i$ , alone, while column (2) introduces both domestic and foreign supplier access using our third measure of supplier access. Column (3) presents the

Table 4  
Supplier access and the relative price of machinery and equipment

ln(machinery and equipment relative price)	(1)	(2)	(3)
Observations	46	46	45
Year	1985	1985	1985
ln(FSA <sub><i>i</i></sub> )	– 0.150** [0.060]	–	–
ln(SA <sub><i>i</i></sub> =DSA <sub><i>i</i></sub> (3)+FSA <sub><i>i</i></sub> )	–	– 0.070** [0.030]	– 0.083** [0.025]
Estimation	OLS	OLS	OLS
R <sup>2</sup>	0.260	0.192	0.283
F(·)	19.31	14.08	30.78
Prob>F	0.000	0.001	0.000

First-stage estimation of the trade equation using Tobit (column (3) in Table 1). Bootstrapped standard errors in square parentheses (200 replications). FSA<sub>*i*</sub> is Foreign Supplier Access obtained from the trade equation estimation and defined in Eq. (18). DSA<sub>*i*</sub>(3) is our preferred measure of Domestic Supplier Access that uses internal area information but allows the coefficient on internal distance to be lower than that on external distance in the trade equation estimation.

\*Denotes statistical significance at the 10% level. \*\*Denotes statistical significance at the 5% level.

results excluding Tanzania, which is an outlier. In all three columns, the estimated coefficient on supplier access is negative and statistically significant at the 5% level. As predicted by the theoretical model, countries with higher levels of supplier access are characterised by a lower relative price of machinery and equipment.

## 6.2. Market and supplier access

The wage equation (Eq. (20)) contains both market access and supplier access, and we now extend the analysis of this relationship to incorporate information on supplier access, SA<sub>*i*</sub>, and relate the estimated coefficients to underlying structural parameters of the model. Again, we present results with both total market/supplier access and with foreign market/supplier access alone. The first column of Table 5 reports the unconditional relationship between income per capita and foreign supplier access and is the analogue of the foreign market access specification in column (1) of Table 2. The estimated coefficient is positive and highly statistically significant, and when included on its own foreign supplier access explains 38% of the cross-country variation in income per capita. Column (4) of Table 5 presents the results using total supplier access; once again, the estimated coefficient is positive and highly statistically significant, and the model now explains approximately 70% of the cross-country variation in per capita income.

While the high degree of correlation between market access and supplier access means that it is difficult to separately identify their individual effects, we can proceed by exploiting a theoretical restriction on the relative magnitude of their estimated coefficients. From Eq. (14), the estimated values of  $\varphi_1$  and  $\varphi_2$  in Eq. (20) are related to the structural parameters of the model as follows:

$$\varphi_1 = \frac{\alpha}{\beta(\sigma - 1)}, \quad \varphi_2 = \frac{1}{\beta\sigma}, \quad \text{implying } \varphi_1 = \varphi_2\alpha\sigma/(\sigma - 1) \quad (21)$$

Table 5  
Market access, supplier access, and GDP per capita

ln(GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Observations	101	101	91	101	101	91
Year	1996	1996	1996	1996	1996	1996
$\alpha$		0.5	0.5		0.5	0.5
$\sigma$		10	10		10	10
ln(FMA <sub><i>i</i></sub> )	–	0.320	0.143	–	–	–
ln(FSA <sub><i>i</i></sub> )	0.532**	0.178**	0.080**	–	–	–
	[0.114]	[0.039]	[0.039]			
ln(MA <sub><i>i</i></sub> )=ln(DMA <sub><i>i</i></sub> (3)+FMA <sub><i>i</i></sub> )	–	–	–	–	0.251	0.202
ln(SA <sub><i>i</i></sub> )=ln(DSA <sub><i>i</i></sub> (3)+FSA <sub><i>i</i></sub> )	–	–	–	0.368**	0.139**	0.112**
				[0.034]	[0.012]	[0.022]
Control variables	no	no	yes	no	no	yes
Estimation	OLS	OLS	OLS	OLS	OLS	OLS
$R^2$	0.377	0.360	0.765	0.696	0.732	0.848
$F(\cdot)$	57.05	54.56	47.21	250.07	285.69	60.40
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000

First-stage estimation of the trade equation using Tobit (column (3) in Table 1). Bootstrapped standard errors in square parentheses (200 replications). See notes to previous tables for variable definitions. Columns (3) and (6) include the baseline set of control variables from columns (1) and (4) of Table 3. In columns (2), (3), (5), and (6), we assume specific values for the share of intermediate inputs in unit costs ( $\alpha$ ) and the elasticity of substitution ( $\sigma$ ), implying a linear restriction on the market and supplier access coefficients.

\*Denotes statistical significance at the 10% level. \*\*Denotes statistical significance at the 5% level.

Thus, if we select values of  $\alpha$  and  $\sigma$  (the cost share of intermediates and the elasticity of substitution between varieties), a linear restriction is imposed on the values of  $\varphi_1$  and  $\varphi_2$ . We estimate Eq. (20) subject to this restriction, for a series of different values of  $\alpha$  and  $\sigma$ . From the estimated value of  $\varphi_2$ , we then compute the implied value of  $\beta$  (the share of labour in unit costs).

Column (2) of Table 5 reports the regression results for foreign market access and foreign supplier access using a share of intermediates in unit costs of  $\alpha=0.5$  and an elasticity of substitution between manufacturing varieties of  $\sigma=10$ . Column (3) reestimates this specification including our baseline set of controls for exogenous determinants of technical efficiency from Table 3. Columns (5) and (6) of Table 5 estimate analogous specifications for total market and supplier access.<sup>19</sup> Table 6 reports a range of values for  $\sigma$  and  $\alpha$  in the rows and columns, and the implied values of  $\beta$  in the body of the table. An intermediate share of 50% ( $\alpha=0.5$ ) and an elasticity of

<sup>19</sup> As noted above, the high degree of correlation between market and supplier access means that it is hard to separately identify their individual effects. If the specification in column (5) of Table 5 is reestimated without imposing the theoretical restriction on the relative value of the coefficients, the estimated coefficients (bootstrapped standard errors) on market and supplier access are 0.328 (0.111) and 0.067 (0.109), respectively. The insignificance of supplier access in this specification is solely due to its very high degree of correlation with market access. If supplier access is included on its own, as shown in column (4) of Table 5, we find a positive and highly statistically significant effect (the estimated coefficient (bootstrapped standard error) are 0.368 (0.034)).

Table 6  
Foreign market access, supplier access, and implied structural parameters

$\alpha$	0.4	0.5	0.6
$\sigma = 6$	0.495 ( $\varphi_2 = 0.337$ )	0.531 ( $\varphi_2 = 0.314$ )	0.569 ( $\varphi_2 = 0.293$ )
$\sigma = 8$	0.364 ( $\varphi_2 = 0.343$ )	0.393 ( $\varphi_2 = 0.318$ )	0.417 ( $\varphi_2 = 0.300$ )
$\sigma = 10$	0.291 ( $\varphi_2 = 0.344$ )	0.308 ( $\varphi_2 = 0.325$ )	0.330 ( $\varphi_2 = 0.303$ )

The table reports implied values of labour's cost share ( $\beta$ ) from the expression for  $\varphi_2$  in Eq. (21) and the coefficients on market and supplier access estimated for given values of the intermediate share ( $\alpha$ ) and demand elasticity ( $\sigma$ ). The parameter estimates are taken from the specification with Foreign Market Access and Foreign Supplier Access in Column (2) of Table 5.

substitution of 8 is consistent with a share of payments to immobile factors of 39% (78% of value added). If the elasticity of substitution is raised to 10, the implied share of payments to immobile factors is 31% (62% of value added).

An intermediate share of 50% is in line with data on gross output and intermediate useage in the manufacturing sector, while an elasticity of substitution of 8 or 10 is broadly consistent with independent econometric estimates of this parameter. For example, [Head and Ries \(2001\)](#) find values of between 7.9 and 11.4; [Hummels \(1999\)](#) estimates a value of 7.6; [Feenstra \(1994\)](#) reports values of between 2 and 9. Assuming a smaller elasticity of substitution results in a higher implied share of payments to immobile factors of production. Since immobile factors include but are not limited to labour, and the share of labour payments in value-added is typically 60–70%, values for the share of payments to immobile factors in excess of 60% or 70% are not implausible. Although the model of economic geography that we consider is extremely parsimonious, the estimated coefficients we obtain are broadly consistent with plausible values for the model's structural parameters.

## 7. Economic structure and policy analysis

The estimates of the trade equation that we have used so far are based on country and partner dummies. This approach has the advantage of capturing relevant country characteristics that are not directly observable but are nevertheless revealed through trade performance (for example the degree of openness of the country, and the values of prices and prices indices within the country). However, it does not allow us to quantify the effects on per capita income of particular country characteristics (for example, being land-locked), since all such effects are contained in the dummies. This section, therefore, considers an alternative econometric specification in which we replace country dummies by economic and geographic variables. This additional economic structure in the modelling of supply capacity and market capacity enables us to calculate the predicted effects of these country characteristics on per capita income.

Thus, in Eq. (22), supply capacity,  $s_i$ , and demand capacity,  $m_j$  are modelled using country and partner GDP data ( $Y_i$  and  $Y_j$ , respectively). Trade barriers and transportation costs are captured by dummy variables for whether exporting countries and importing partners are land-locked ( $llock_i$  and  $llock_j$ , respectively), islands ( $isl_i$  and  $isl_j$ , respectively),

and pursue open-trade policies ( $\text{open}_i$  and  $\text{open}_j$ , respectively).<sup>20</sup> As before, the country-partner pair specific elements of transportation costs are captured by distance between capital cities ( $\text{dist}_{ij}$ ) and a dummy variable for whether or not an exporting country and importing partner share a common border ( $\text{bord}_{ij}$ ). The first-stage trade regression therefore becomes

$$\ln(X_{ij}) = \theta + \mu \ln(Y_i) + \lambda \ln(Y_j) + \delta_1 \ln(\text{dist}_{ij}) + \delta_2 (\text{bord}_{ij}) + \delta_3 \text{isl}_i + \delta_4 \text{isl}_j + \delta_5 \text{llock}_i + \delta_6 \text{llock}_j + \delta_7 \text{open}_i + \delta_8 \text{open}_j + u_{ij}. \quad (22)$$

This trade equation is again estimated using 1994 data and the Tobit estimator. All variables are correctly signed according to economic priors and statistically significant at the 5% level. The distance and land-locked variables have a negative effect on trade, while the common border, island and [Sachs and Warner \(1995\)](#) openness variables have positive effects. Predicted values of market access and supplier access are obtained from Eq. (22) in an exactly analogous manner to before. Estimating the wage equation with both total market/supplier access and foreign market/supplier access yields an extremely similar pattern of results to before.<sup>21</sup>

We focus here on the effects of country characteristics on predicted income per capita. The trade equation estimates are used to evaluate the effect of a particular economic variable (e.g., whether a country is land-locked, or whether it pursues open-trade policies) on market and supplier access. Combining this with the estimated coefficients from the wage equation gives the effect of each variable on predicted income per capita. We present predictions based on foreign market and supplier access (excluding domestic information), assuming an intermediate share of  $\alpha = 0.5$  and an elasticity of substitution of  $\sigma = 10$  (shown earlier to be consistent with plausible values for the share of labour in unit costs,  $\beta$ ) and including our baseline set of control variables.<sup>22</sup>

[Table 7](#) reports the results of undertaking such an analysis for five countries. Two of these are islands, three of the countries are land-locked, and four are to some degree closed on the [Sachs and Warner \(1995\)](#) definition of international openness. Changes in one geographic or economic characteristic (such as whether a country is land-locked) have the same proportional effect on foreign market and supplier access for all countries, and we find that access to the coast raises predicted per capita income by 24%, while loss of island status has a more modest effect, reducing predicted income by 7%. The effect of pursuing open-trade policies is to raise predicted per capita income by around 25%, with the effect now varying across countries because they differ according to their initial levels of openness.

<sup>20</sup> We employ the [Sachs and Warner \(1995\)](#) measure of international openness. This is based on tariff barriers, non-tariff barriers, the black market exchange premium, the presence of a state monopoly on major exports, and the existence of a socialist economic system.

<sup>21</sup> Full estimation results for the trade and wage equation are available from the authors on request.

<sup>22</sup> The use of different values for the intermediate share and elasticity of substitution has very small effects on predictions. For example, an intermediate share of 0.5 and an elasticity of substitution of 5 raises the predicted effect of gaining access to the coast from 24.03% to 24.08%.



Table 7  
Economic magnitudes

Country	Variable (%)				
	(1) Access to coast	(2) Loss of island status	(3) Become open	(4) Distance (Central Europe)	(5) Distance (50% closer to all partners)
Australia		7.34			27.06
Sri Lanka		7.34	20.66	67.40	27.06
Zimbabwe	24.03		27.65	79.74	27.06
Paraguay	24.03		25.28	58.29	27.06
Hungary	24.03		26.46		27.06

The table reports the predicted effect on GDP per capita of a change in the economic and geographical characteristics that determine market and supplier access in the trade equation estimation (Eq. (22)). The predictions are based on parameter estimates using Foreign Market Access and Foreign Supplier Access assuming an intermediate share of  $\alpha=0.5$  and an elasticity of substitution of  $\sigma=10$ , and including the baseline set of control variables from column (1) of Table 3. The predicted effect of becoming open varies across countries because they begin from different values for the *Sachs and Warner (1995)* openness index: 1 in Australia, 0.231 in Sri Lanka, 0 in Zimbabwe, 0.077 in Paraguay, and 0.038 in Hungary. To provide an indication of the advantages of a location on the borders of Western Europe, column (4) reports the results of giving each country Hungary's vector of distances to all other countries. Column (5) reports the results of the hypothetical experiment of halving a country's distance from all of its trade partners.

To evaluate the quantitative importance of proximity to large markets and sources of supply, column (4) of Table 7 undertakes the hypothetical experiment of moving three developing countries located far from centres of world economic activity (Sri Lanka, Zimbabwe, and Paraguay) to Central Europe.<sup>23</sup> Gains vary from 80% for Zimbabwe to 58% for Paraguay. This emphasises the economic advantages conveyed on the transition economies of Central and Eastern Europe by their location on the edge of high-income Western Europe. Column (5) considers the effect of halving a country's distance from all of its trade partners. Once again, the gains are substantial, and the predicted increase in income of 27% is of a similar magnitude to gaining a coastline or pursuing open-trade policies. Increases in trade volumes are associated with these changes, so it is possible to calculate the elasticity of income with respect to the volume of trade. On the basis of Column (5), this elasticity is 0.23, a number comparable with the estimate of one-third found by *Frankel and Romer (1999)*. We stress, however, that the changes in both income and trade are endogenous responses to the hypothetical reduction in distance.

The importance of geographical proximity is shown again in Table 8, which examines the effect of having a common border. Common borders between Germany and the Czech Republic and the United States and Mexico have substantial effects on predicted income per capita in the smaller countries. Thus, removing the common border gives a fall in predicted income per capita in the Czech Republic of 26%, and in Mexico of 27%. However, the effect of eliminating of a common border between low-income developing countries who trade relatively little with one another, such as Zimbabwe and Zambia, is small. This suggests that the gains from closer regional integration between

<sup>23</sup> Specifically, we replace a country's distance and common border vectors by those of Hungary.

Table 8  
The effect of removing a common border

Removal of common border	Effect on per capita income	
Germany–Czech Republic	Germany –0.08%	Czech Republic –25.66%
US–Mexico	US –0.52%	Mexico –27.21%
Zimbabwe–Zambia	Zimbabwe –0.05%	Zambia –0.11%

The table reports the predicted effect on GDP per capita of eliminating a common border between countries. That is, when calculating market and supplier access using the estimates from Eq. (22), we change the value of the common border dummy variable to zero for the countries in question. The predictions are based on parameter estimates using Foreign Market Access and Foreign Supplier Access assuming an intermediate share of  $\alpha=0.5$  and an elasticity of substitution of  $\sigma=10$ , and including the baseline set of controls from column (1) of Table 3.

low-income developing countries may be relatively small compared to those to be had from closer integration with high-income developed countries.

## 8. Conclusions

The increasing integration of world goods and financial markets has not caused the enormous cross-country differences in income per capita and manufacturing wages to be arbitrated away by the mobility of firms and plants. There are many potential reasons for the reluctance of firms to move production to low wage locations, one of which is remoteness from markets and sources of supply. This paper has demonstrated the importance of these effects using a structural model of economic geography.

Estimates based on bilateral trade flows provide measures of market and supplier access for each country, which in turn determine the factor prices that manufacturing firms can afford to pay. When included by themselves, these measures were shown to explain much of the cross-country variation in per capita income. After controlling for a variety of other determinants of per capita income, including countries' resource endowments, other characteristics of physical geography, and additional institutional, social, and political controls, the effects of economic geography remained highly statistically significant and quantitatively important. Similar results were obtained when we instrumented our market and supplier access measures with exogenous geographical determinants, and we provided evidence that economic geography matters for per capita income through the mechanisms emphasized by the theory.

We presented a variety of additional evidence that the mechanisms of economic geography are at work. Results were found to be robust for a variety of different samples, across a number of alternative econometric specifications, to the inclusion of a wide range of control variables, and to using both narrow and broad measures of the income of immobile factors. As predicted by the model, the relative price of manufacturing goods was shown to be negatively and statistically significantly related to a country's supplier access. The estimated regression coefficients were consistent with plausible values for the structural parameters of the model. The effects of individual economic and geographical determinants of market and supplier access were quantitatively important, with, for example, access to the coast raising per capita income by over 20%.

Our results may seem rather pessimistic for developing countries, suggesting that even if tariff and institutional obstacles to trade and investment are removed the penalty of distance will continue to hold down the incomes of remote regions. However, it is important to recall that our results are derived for a given location of production and expenditure. As new markets and centres of manufacturing activity emerge, so the market and supplier access of neighbouring countries improves. Our results point to the importance of understanding the role of geography in shaping the evolution of the cross-country distribution of income.

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## Appendix A

**Bilateral Trade:** data on bilateral trade flows are from the World Bank COMTRADE database. This provides information for the 101 countries listed below during 1992–1996.

**GDP per capita:** data on current price (US dollars) GDP and on population are from the World Bank and are available for the 101 countries listed below during 1992–1996.

**Geographical variables:** data on bilateral distance, internal area, arable land area, existence of a common border, and whether a country is an island or land-locked are from the World Bank. These data are also available for the 101 countries listed below.

**Manufacturing wage per worker:** data on number of employees and wages and salaries (current price US dollars) in total manufacturing are from the UNIDO Industrial Statistics Database. Information is available for 85 countries during 1992–1996.

**Relative price of machinery and equipment:** data on the price of machinery and equipment and GDP in local currency units per US dollar are from Phase V of the United Nations International Comparisons Project (United Nations, 1994). The data are available for 46 countries and are for 1985.

**Number of Minerals:** the total number of minerals of which a country has reserves from the list of 44 main minerals compiled by Parker (1997).

**Risk of Expropriation:** extent of protection of property rights, measured on a scale from 1 to 5, where a higher score indicates weaker protection of property rights. Source: Holmes et al. (1997). These data are unavailable for Central African Republic, Guatemala, Kazakhstan, Kyrgyz Republic, Madagascar, Macedonia, Mauritius, and Chad.

**Physical Geography and Institutional, Social, and Political Characteristics:** data on hydrocarbons (deposits of petroleum and natural gas) per capita, fraction of land area in the geographical tropics, prevalence of malaria, socialist rule, and the occurrence of an external war are from Gallup et al. (1998). Information is available for all 101 countries in our data set, except for the data on hydrocarbons per capita which are unavailable for Moldova and Yemen. The data can be downloaded from <http://www.cid.harvard.edu/ciddata.ciddata.html>.

**International Openness:** data on international openness are from Sachs and Warner (1995) and are available for 98 countries. Information is unavailable for Panama, Saudi Arabia, and Yemen (see <http://www.cid.harvard.edu/ciddata.ciddata.html>).

**Sub-Saharan Africa:** Central African Republic, Cote d'Ivoire, Cameroon, Congo Republic, Ethiopia, Gabon, Kenya, Madagascar, Mozambique, Mauritius, Malawi, Sudan, Senegal, Chad, Tanzania, South Africa, Zambia, and Zimbabwe.

**North Africa and the Middle-East:** Algeria, Egypt, Israel, Jordan, Morocco, Saudi Arabia, Syria, Tunisia, and Yemen.

**Latin America and the Caribbean:** Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Paraguay, El Salvador, Trinidad and Tobago, Uruguay, and Venezuela.

**Southeast Asia:** China, Hong Kong, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Thailand, and Taiwan.

**Other Asia:** Bangladesh, India, Sri Lanka, Mongolia, Nepal, and Pakistan.

**Eastern Europe and the former USSR:** Albania, Armenia, Bulgaria, Czech Republic, Estonia, Croatia, Hungary, Kazakhstan, Kyrgyz Republic, Lithuania, Latvia, Moldova, Macedonia, Poland, Romania, Russia, Slovak Republic, and Slovenia.

**Country codes:** Albania (ALB), Argentina (ARG), Armenia (ARM), Australia (AUS), Austria (AUT), Bangladesh (BGD), Bulgaria (BGR), Belgium/Luxembourg (BLX), Bolivia (BOL), Brazil (BRA), Central African Republic (CAF), Canada (CAN), Switzerland (CHE), Chile (CHL), China (CHN), Cote d'Ivoire (CIV), Cameroon (CMR), Congo Republic (COG), Columbia (COL), Costa Rica (CRI), Czech Republic (CZE), Germany (DEU), Denmark (DNK), Algeria (DZA), Ecuador (ECU), Egypt (EGY), Spain (ESP), Estonia (EST), Ethiopia (ETH), Finland (FIN), France (FRA), Gabon (GAB), UK (GBR), Greece (GRC), Guatemala (GTM), Hong Kong (HKG), Honduras (HND), Croatia (HRV), Hungary (HUN), Indonesia (IDN), India (IND), Ireland (IRL), Israel (ISR), Italy (ITA), Jamaica (JAM), Jordan (JOR), Japan (JPN), Kazakhstan (KAZ), Kenya (KEN), Kyrgyz Republic (KGZ), South Korea (KOR), Sri Lanka (LKA), Lithuania (LTU), Latvia (LVA), Morocco (MAR), Moldova (MDA), Madagascar (MDG), Mexico (MEX), Macedonia (MKD), Mongolia (MNG), Mozambique (MOZ), Mauritius (MUS), Malawi (MWI), Malaysia (MYS), Nicaragua (NIC), Netherlands (NLD), Norway (NOR), Nepal (NPL), New Zealand (NZL), Pakistan (PAK), Panama (PAN), Peru (PER), Philippines (PHL),

Poland (POL), Portugal (PRT), Paraguay (PRY), Romania (ROM), Russia (RUS), Saudi Arabia (SAU), Sudan (SDN), Senegal (SEN), Singapore (SGP), El Salvador (SLV), Slovak Republic (SVK), Slovenia (SVN), Sweden (SWE), Syria (SYR), Chad (TCD), Thailand (THA), Trinidad and Tobago (TTO), Tunisia (TUN), Turkey (TUR), Taiwan (TWN), Tanzania (TZA), Uruguay (URY), United States of America (USA), Venezuela (VEN), Yemen (YEM), South Africa (ZAF), Zambia (ZMB), and Zimbabwe (ZWE).

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