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Geography and Growth
- some Empirical Evidence

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Geography and Growth – some Empirical Evidence

Income in the world does not distribute randomly in space. There are geographic clusters of rich and poor countries. Also growth rates tend to be spatially clustered. Spatial regression analyses indicate that geographical clustering may be an inherent ingredient in growth mechanisms: Growth in one country stimulates growth in surrounding countries. A simple exogenous growth model with technology diffusion through trade in capital goods can account for some, but not all of these empirical patterns of growth and income distribution. JEL Classification numbers: O4, O47, F10, F43.

The world's economic activity is clustered in space. Within countries one often observes that some sets of adjacent regions prosper while others stagnate. In the world economy, clustering is also distinct: The North is richer than South, Africa is poorer than Europe and Latin America is poorer than North America. The clustered economic landscape in the world has been subject to surprisingly little research, however. How clustered is the world? Is the clustered global economic landscape stable or changing over time? Has geography become less important as a consequence of economic integration and globalisation? Or is it the opposite?

Almost all economic interactions decrease rapidly with distance. This applies within countries and across countries. Geography influences interaction between pre-located economic agents but also the location of economic activity. However, both in growth economics and in international economics, the importance of geography was more often than not ignored until a few years ago, in particular in theoretical work.

The influence of geography on economic development stems from the fact that geographical distance imposes cost on transactions. These costs are of different types. Venables (2001) classifies costs of distance

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into four classes. These are: i) search costs of identifying potential trading partners, ii) direct shipping costs, iii) time used for transportation and communication and iv) control and management costs. Some costs of distance are convex and increasing, some are concave and increasing. A large part of the literature on economics and distance gives support to a constant (negative) elasticity of interaction with respect to distance. This applies to international trade as well as to foreign direct investments and also to various forms of diffusion of technology.

For international trade, the celebrated gravity model has become well-known.[1] The gravity model assumes that trade between pairs of countries increases with the size of each of them (as measured by total GDP) and falls with the distance between them. The gravity model is so successful in terms of explanatory power that it has challenged traditional trade theory based on comparative advantages.

For foreign direct investment there are fewer studies, but the existing ones give geography a very important role in understanding international real investments. In a similar way as in studies of international trade, an iso-elastic negative influence of distance is found in several studies.[2]

Recently, there has been a set of studies aiming at exploring determinants of international technology flows. Technology flows are harder to measure than international trade and investments. Even so, it is widely believed that technology flows might be as important as the other two for economic growth and the dynamics of world income distribution. Through a variety of approaches, studies of international technology flows support the same conclusion as for trade and investment: distance retards interaction. An important distinction between types of technology flows is whether they are embodied in goods that are due to transactions or whether they are disembodied. Knowledge flows of the first kind refer to the use of products either in consumption or as factors of production developed and produced by others. It is quite natural that embodied knowledge flows are localised to the same extent as the goods that embody them. Disembodied knowledge flows are more diverse. They denote the knowledge available to people and firms without economic transactions as a prerequisite. For disembodied spillovers evidence suggests the same pattern: even if information and communication technology makes it cheaper and easier to reap knowledge developed elsewhere, knowledge flows are nevertheless local in scope.[3]

If disembodied technology spillovers decrease with geographical distance, neighbours to rich and innovative countries or regions should benefit more from technological spillovers than distant regions. In a bounded landscape of regions, there will be a case for

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[1] Linnemann (1966) is the pioneering study of gravity relations in international trade. Recent studies are Baldwin (1994) and Brun *et al.* (2002). For a discussion of trade theory and the gravity equation, see Evenett and Keller (2002).

[2] Brenton and Di Mauro (1999) present evidence for the formerly planned economies. Narvestad (2000) presents results for FDI flows from OECD countries to other countries.

[3] Coe and Helpman (1995) is a study of technology diffusion through trade in goods. Jaffe *et al.* (1993) and Maurseth and Verspagen (2002) make use of patent citations as a measure of knowledge flows and find a localised citations pattern. For an overivew of new growth theory and the possible importance of the scope of knowledge spillovers, see Barro and Sala-i-Martin (1995), Aghion and Howitt (1998) or, for implications for international economics, Grossman and Helpman (1991).

agglomeration in the geographical centre. Many theories of economic growth analyse the case in which growth occurs through invention and introduction of new goods. For production of such goods, availability of a broad knowledge base may be an important determinant for localisation of production. For the use of such goods, income, prices and transportation costs are determinants. Therefore, geography may influence both where production is located and also who gets the benefits of the new goods.

The spread of benefits of technological advances through international trade in capital goods is analysed in Eaton and Kortum (2001a). That model assumes exogenous technological progress and it therefore differs in spirit from the recent growth theorising. On the other hand it yields new insights into the determinants of diffusion of technological progress. Slight modifications of that model enable it to throw some light on the geographical distribution of income and growth.

The rest of this paper is organised as follows: The next section is devoted to a descriptive analyses of the geographical distribution of growth and income in the world economy. Thereafter, a brief sketch of Eaton and Kortum's model and the small modifications imposed on it are described. In section 4 estimation results are presented. Section 5 concludes by summing up the discussion and outlining possible implications for future research.

Geography, income and growth – a description

Data

For the purpose of this paper, data on GDP per capita and population for 1960 and 1990 were extracted from the Penn World Tables mark 5.6. For that period, the database covers 104 countries. For the empirical model presented and estimated in the next section, use was also made of real investments shares and price indexes for GDP, consumption and investments. The GDP data are in constant international prices and therefore constructed to be comparable over time and across economies. The Penn World Tables have been used in most of the cross-country growth studies cited in this paper. The countries covered by the data are listed in appendix B. There are 37 African, 23 Asian, 21 European and 23 American countries in the sample. Some important countries are not included, like (most of) the formerly planned economies in Eastern Europe, including the former Soviet Union. Data for average years of school attainment in 1985 are taken from Barro and Sala-i-Martin (1995). Use of these 'conditioning' data reduces the data set to 78 observations.

Figures 1 and 2 are box-and-whisker plots of GDP per capita levels in 1960 and 1990 and growth rates over the same period for each continent.[4]

Figure 1 reveals several facets of the continent-wise income distribution in the world. First, the impression of a world divided in continents seems to be a right one. The lines crossing the boxes in the figures indicate the medians. The median ranges from the poor median African country to the very rich median European country. The distinction of continents explains a fair amount of the spread in GDP levels. The boxes in the figures indicate the interquartile ranges, that is the range from the 25th percentile to 75th percentile. The cumulative

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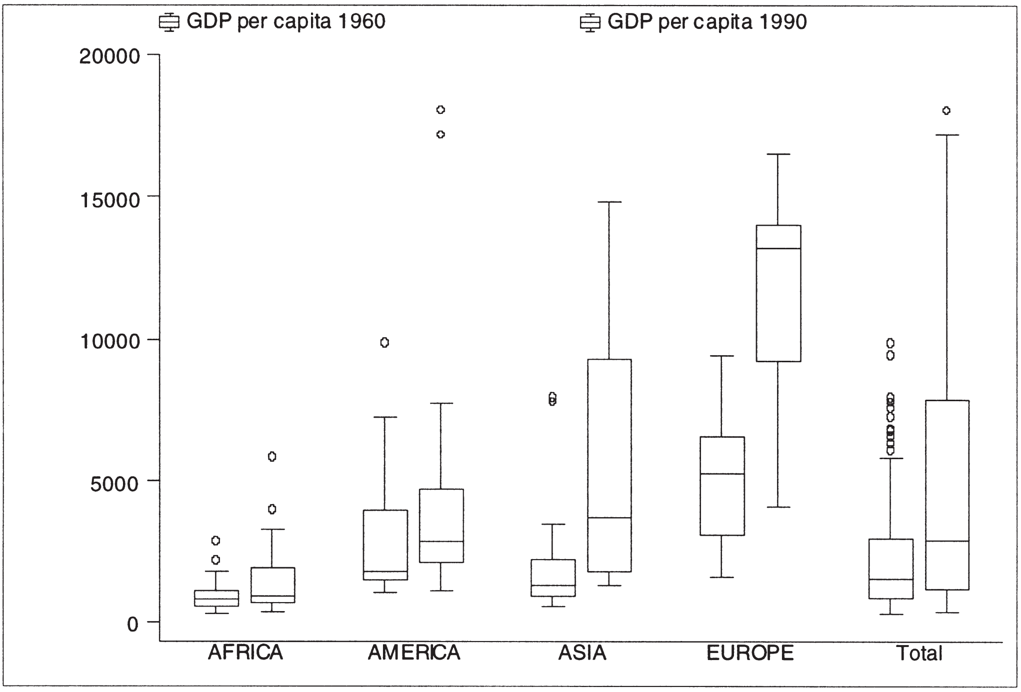
[4] Australia and New Zeland are counted as Asian countries.

Figure 1.
Box plot GDP levels, 1960–90

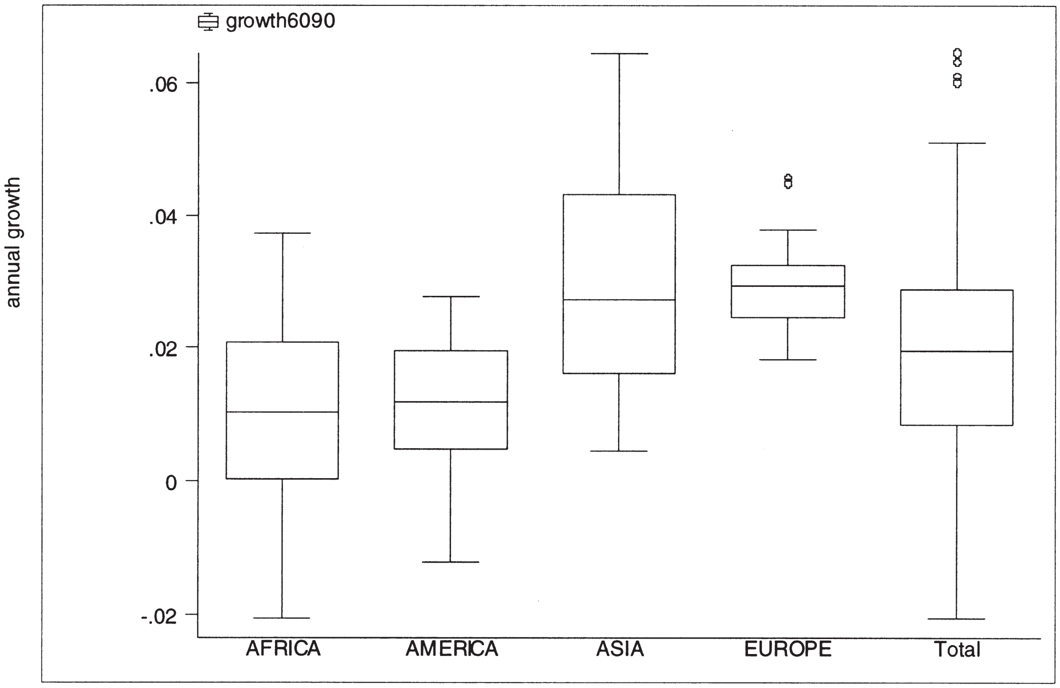


length of the boxes seems to supply a large fraction of the total distribution. Also, except for Asia in 1990, the lengths of the boxes are overlapping to a limited degree. The 'whiskers' in the figures indicate upper and lower adjacent values (defined as the largest (smallest) data point less (larger) than the upper (lower) interquartile range times 1.5). Data points more extreme than this are individually plotted.

Second, the figure indicates a world of increasing differences between countries. This applies both for the world as a whole and within each continent. Inequality between countries in GDP per capita was larger in 1990 than in 1960.

For growth rates, the continental divide is not as suggestive as for levels of GDP per capita. Africa and America seem to do equally well in terms of the median. For Africa, the spread of growth rates is larger than on the American continent. Asia and Europe are forging ahead. Differences between growth rates in Europe are small, while Asia has the largest spread. The growth disasters, countries with negative average growth rates over the 31-year period analysed here, are located (numerous) in Africa and in (Latin) America. It is important to note the large differences in growth rates. The country with the largest negative growth rate had its income per capita level reduced by 47 per cent while the country with the highest growth rate had its income per capita increased more than seven times. In 1960 Bangladesh was richer than South Korea. In 1990 South Korea was 4.8 times as rich as Bangladesh.

Figure 2.
Box plot growth rates, 1960–90



Distance

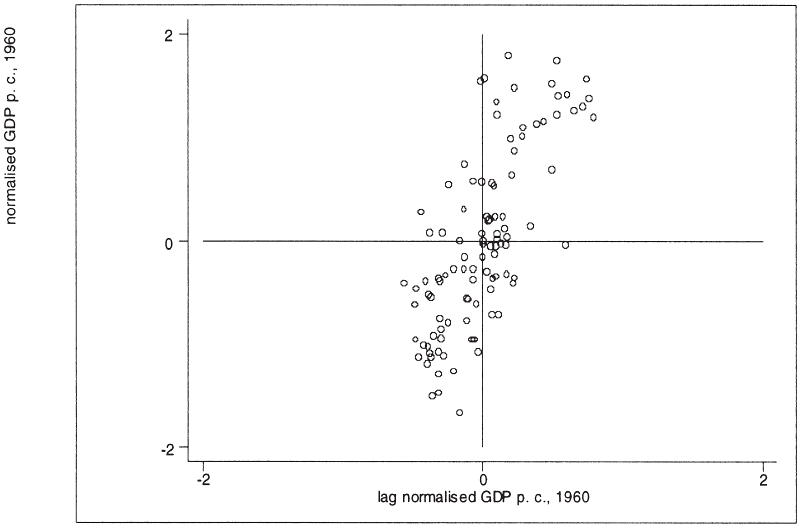
In growth economics, use of geographical data has been very limited. It has been most common, though, to use categorical dummy variables for continents. Dummy variables for groups of countries capture common characteristics for countries in each group. Therefore, such dummies are not suitable for detecting the influence of geography. If geographical distance as such influences the results, Israel and Syria which are Asian, should have more in common with European Greece than with Asian Thailand. Fingleton and McCombie (1998), Maurseth (2001), Attfield *et al.* (2000) and Rey (1999) incorporate full distance matrixes in their analyses of growth (in European regions, countries or American states, respectively).

For the purpose of this paper, great circle distances (in miles) between all countries in the data set were calculated by means of the latitude and longitude of the capital in each country. In analyses of geography in general (and for economic growth in particular), the hypothesis is that some variable x in entity i influence some variable y in entity j as a decreasing function of the distance from i to j, d_{ij}. Therefore, a distance weights matrix was constructed according to:

$$w_{ij} = \frac{1/d_{ij}}{\sum_{j=1}^{n} 1/d_{ij}}$$

The resulting weight matrix postulates that the influence of any variable between two countries decreases with the inverse of the

Figure 3.
Moran Scatterplot of GDP levels, 1960



distance between them. The weights are standardised so that they sum to one for each country. This makes it easier to construct weighted averages of variables for countries.[5]

By use of the distance weights, three such weighted averages are constructed. These are the weighted averages of normalised GDP levels for 1960 and 1990 and weighted average of normalised growth rates, 1960–90.[6] These averages are to be compared with the same numbers for each individual country. Scatter plots of these pair-wise observations indicate the degree of spatial correlation in the world. Figures 3–5 show the results. The countries themselves are represented along the y-axis. The weighted averages are graphed along the x-axis. The figures reveal that for all the three variables, the levels in 1960 and 90 and the growth rates, there is a preponderance of observations in the first and third quadrant. This means that, generally, high-income countries are located near each other and so are low-income countries. If there was no spatial clustering, there would not be any clear correlation between the two variables. In all the figures most data points are closer to zero along the x-axis than along the y-axis. This is because the x-axis measures averages for several countries.

Although visually difficult to conclude from the figures, the correlation for GDP

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5. In the spatial econometrics literature, several other types of distance weights have been proposed, like the one above with distance raised to the power of more than one and contiguity matrixes. The formulation above was chosen for illustrative purposes and because of its simplicity. Results with other weights matrixes are available upon request.
6. Therefore, the weighted average of variable X_i for region i is given by $\sum w_{ij}(X_j\text{-}X)$ in which X denotes the average of the X_js. The normalised *level* variables are the logs of the ratio of GDP per capita to the average. The normalised *growth* variable is growth minus the average growth rate.

Figure 4.
Moran Scatterplot of GDP levels, 1990

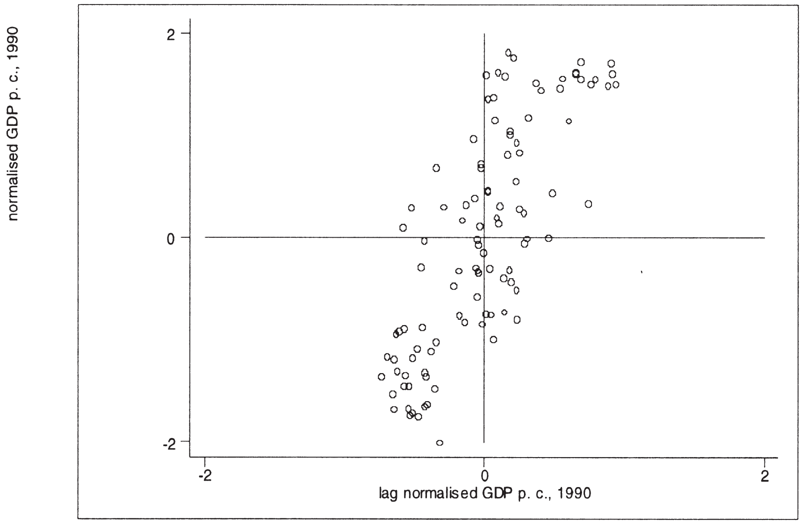

Figure 5.
Moran Scatterplot of growth rates, 1960–90

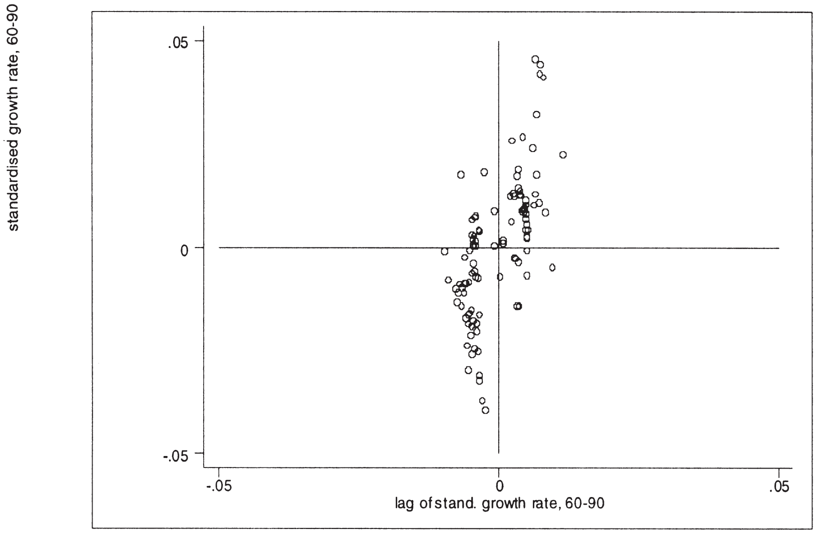

Table 1.
Moran's I for data used (p values in parantheses).

	104 countries	78 countries
growth	0.20 (0.000)	0.22 (0.000)
ln(gdp60)	0.27 (0.000)	0.23 (0.000)
ln(gdp90)	0.30 (0.000)	0.27 (0.000)
ln(invest)	0.17 (0.000)	0.09 (0.000)
ln(school)		0.16 (0.000)

levels became stronger over the period so the world was more clustered in 1990 than in 1960.[7] This indicates that the world is becoming more clustered over time. The increased spatial correlation of GDP per capita is a result of the development shown in figure 5. Growth itself is spatially clustered.

Investments and human capital

In the empirical investigation below, use is made of the data on average investment rates for the period 1960 to 1990 and for school attainment. The nature and explanatory power of these data for levels of GDP and growth are explored at length elsewhere. Their geographical distribution is not, however. Table 1 presents Moran's I and its significance for the data used in this paper. Moran's I is a widely used measure of spatial dependence. Its definition is described in appendix A.

The table indicates strong spatial clustering of all the variables.[8] It should be noted that GDP levels per capita and growth rates are more spatially clustered than their commonly used explanatory variables, like investments and schooling.

Geography, income and growth – an empirical model

The modelling framework

Eaton and Kortum (2001a) present a model of trade based on geography and technological advantage. In this section the intuition of that model is described. Some modifications and simplifications make Eaton and Kortum's model consistent with empirical observations on the geographical distribution of income and growth. These are described below together with regression equations that are to be estimated. It should be noted that Eaton and Kortum's model has richer empirical implications than the version presented here. They use estimates of cost levels together with data on trade, geography and income in a more detailed empirical study for a smaller sample of countries. In appendix B a rough sketch of the model is provided. The interested reader should confer the original paper in which the model is developed and Maurseth (2003) for a more detailed discussion.

The model is for a set of countries with two separate main sectors: production of

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[7] The coefficent of correlation for income levels increased from 0.73 to 0.78 from 1960 to 1990.

[8] Moran's I is similar, but not equivalent to a correlation coefficient. It is not symmetric around zero and its expected value (when there is no clustering) is negative. A Moran's I larger than its expected value indicates positive spatial correlation and the significance is based on assumptions about its standardised value being normal.

consumption goods and capital goods. Both sectors use a set of heterogeneous capital goods (a CES aggregate) and labour according to a Cobb-Douglas production function. Consumption and capital goods are traded between the countries. Trade between countries is costly and costs increase with the distance between a pair of countries. The costs are modelled as iceberg costs that increase with distance according to $t_{ni}=d_{ni}^{\varphi}>1$. That is, t_{ni} units of a good have to be shipped from the exporting country i if the importing country n is to receive one unit. Distance is normalised so that $d_{nn}=1$. The parameter φ is assumed to indicate concavity in transportation costs, so that $0<\varphi<1$.

Capital goods are available in different qualities and technology progresses exogenously in terms of increased quality of the distinct capital goods. Technology diffuses through trade in capital goods. Countries with low levels of technology specialise in production of consumption goods while countries with high levels of technology specialise in production of capital goods.

Quality of capital good j produced in country i, z_{ij}, is the realisation of a random variable drawn from an extreme value distribution. Two parameters enter in the distribution. The first is the country specific parameter, $T_i>0$, which represents the country's stock of technological knowledge. This parameter determines the average quality in country i. Another parameter, common to all countries, $\theta>1$, reflects the inverse of the variability in quality. The stock of knowledge grows in each country at a constant rate, g_T.

There is free competition so that costs determine prices. If country n were to buy capital good j from country i it would therefore cost d_{ni}^{φ}/z_{ij} in terms of efficiency units of capital. Country n will actually buy this good from country i only in the case that this cost is the lowest available, so actual costs are $P_{nj}=\min_i\{d_{ni}^{\varphi}/z_{ij}\}$. The distribution of actual prices inherits the functional form of the extreme value distribution. Therefore, exact formulations for the share of goods that country n buys form country i can be calculated (see appendix B). These trade shares also govern the price levels of capital goods in country n. Countries that face a low price index of capital goods have better access to capital goods than other countries. This constitutes the core mechanism in the model. Since trade costs increase with distance, countries that are located near capital goods producing countries have better access to technology.

Under the above assumptions, it can be shown that an exact price index for capital goods in country n will be given by:

$$1)\ P_{kn} = \gamma\Phi_n^{-1/\theta}, \quad \Phi_n \equiv \sum_{i=1}^{N} T_i d_{ni}^{-\theta\varphi}$$

It is seen that the price index of capital goods in country n is a function of all countries' technology stocks weighted negatively by the geographical distance to these countries. Being close to main capital goods producing countries therefore translates into a lower price index of capital goods. In steady state, the price index falls at the rate $g=g_T/\theta$.

GDP levels

In Eaton and Kortum (2001a and b) the implications for trade, the price indexes and productivity as a function of prices on capital goods are explored. In this paper, two other implications of the model will be investigated. The first relates to production per capita. As demonstrated by Eaton and Kortum (2001a), the steady state GDP per capita in country is given as a function of investment rates, the price index of capital goods and the consumer price index. It is shown in appendix B that the exact formulation for this expression is:

$$2)\qquad y_n = \left(\frac{s_n}{\left(\frac{g}{1-\alpha}\right)\left(\frac{P_{kn}}{P_{cn}}\right)} \right)^{\alpha/_{1-\alpha}} = \left(\frac{s_n P_{cn}}{\gamma\left(\frac{g}{1-\alpha}\right)} \right)^{\alpha/_{1-\alpha}} \left(\sum_{i=1}^{N} T_i d_{ni}^{-\varphi\theta} \right)^{\alpha/_{\theta(1-\alpha)}}$$

Above, P_{cn} denotes the consumer price index in country n and α is capital's share in production. s_n represents country n's savings rate.

The first equation in 2) expresses that the level of GDP per capita is an increasing function of the savings rate and a decreasing function of the relative price of capital. In the second equation, the formula for the price index of capital is inserted. In that expression, therefore, the level of GDP per capita is an increasing function of the savings rate, the consumer price index and an invertedly distance weighted function of the level of technology in all countries.

So far, the level of knowledge in each country, T_i, has not been defined. In growth literature, knowledge stocks are often defined as accumulated R&D or as GDP per capita level. For global data, accumulated R&D data are not available and if they were, they would probably not be very useful for poor countries. GDP per capita levels as proxy for knowledge stocks assume that small rich countries have the same technological level as large rich countries. This is a doubtful assumption, at least in the present context in which knowledge stocks in country i enter in the expression for the share of what country n buys from country i. Here the total level of GDP in a country is used as an approximation for knowledge stocks. This implies that a small rich country might have the same knowledge stock as a large poorer country. This assumption is in line with the growth models of Frankel (1962) and Romer (1986).[9] With use of this definition of a country's knowledge stock, GDP per capita in a country becomes a function of total GDP in all countries and the distance between the country in question and all other countries. This definition is parallel to the definition of market potential in the economic geography literature.[10] The empirical counterpart of this literature often presumes a formulation of market potential where the products of the parameters θ and φ are equal to one. Here this tradition restriction is assumed to hold. This is a rough approximation, but it has the benefit of simplifying estimation. It is important, however, that the underlying theory in this case does not relate to a country's export markets (like in models of economic geography) but rather to the geography of the origin of its imports.

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[9] Also, use of total GDP-levels as technology proxy makes the bilateral trade flows in the model consistent with the gravity model of international trade. GDP-levels as technology proxy has been harshly criticised in some authors however, as e.g. in Jones (1995).

[10] Cf. for instance Dicken and Lloyd (1990)

Taking logs and imposing the above restrictions gives the log of income per capita as the linear regression equations:

$$3)\quad \ln(y_n) = X_n\delta + \frac{\alpha}{1-\alpha}\ln(s_n) - \frac{\alpha}{1-\alpha}\ln\left(\frac{P_{kn}}{P_{cn}}\right) + \varepsilon_n$$

$$= X_n\delta + \frac{\alpha}{1-\alpha}\ln(s_n) - \frac{\alpha}{1-\alpha}\ln(P_{cn}) + \frac{\alpha}{\theta(1-\alpha)}\ln\left(\sum_{i=1}^{N} T_i d_{ni}^{-1}\right) + \varepsilon_n$$

In equation 3), **X** is a set of conditioning variables (including a constant term) and δ is its coefficient vector. ε_n is an error term. The first equation in 3) describes the (log of) GDP per capita in a country as a function of the conditioning variables, the country's savings rate and the relative price of capital. In the second equation, the theoretical index for the price index of capital is inserted. This corresponds to inclusion of market potential as an explanatory variable of income per capita. This was not done in the studies by e.g. Mankiw *et al.* (1992) or Hall and Jones (1999). In the estimations reported in table 2 below, equation 3) will be estimated with and without (log of) investment rates, and the conditioning variables will experimentally include continental dummies and, on the smaller data set, (the log of) human capital.

Growth

Growth is assumed to be the result of exogenous increase in the quality of capital goods, by the rate g_T. In appendix B it is shown that growth in quality translates into falling price levels of capital goods and therefore into growth in income per capita. The relation between growth in quality and growth in income per capita, g_y, is $g_y=\alpha g_T/\theta(1-\alpha)$. By differentiating equation 3) with respect to time, solving for g_{yn} (which occurs on both sides of the equation), we get the expression for the growth rates in country n:

$$4)\quad g_{yn} = \frac{\dot{y}_n}{y_n} = \frac{\sum_{i\neq n}^{N} g_{yi}\, T_i d_{ni}^{-1}}{\sum_{i\neq n}^{N} T_i d_{ni}^{-1}}$$

Now, growth in country n is expressed as a weighted average of growth rates in all other countries with weights depending on these countries' weights in the price index of capital goods in country n. Therefore equation 4) is a spatial lag model of growth rates. In this case the lags are not functions of distance alone, but on the product of total GDP in the other countries and the inverse of the distance between country n and the other countries. The formulation expresses the hypothesis that growth in other countries translates into growth in country n with a coefficient that corresponds to that country's market potential.

Since countries seldom are in their assumed steady state, but instead are supposed to approach it, other variables will be included in the growth regression. One variable is the convergence term, as indicated by the (log of) initial GDP. This variable is often included in growth regressions in order to capture the speed of convergence towards steady state. Because of errors of measurement and random shocks in the distribution, this interpretation might be wrong, however.[11] Included are also (log of) real investments rates and (log of) the human capital variables for some of the regressions. In addition, dummy variables for continents will be included. The growth equation to be estimated is therefore:

$$5) \quad g_{yn} = U_n \eta + \rho W_{MP} g_y + v_n$$

In equation 5) g_{yn} is the growth rate in country n. **U** is a vector of conditioning variables (see below) and η is its coefficient vector. ν_n is an error term. ρ denotes the spatial auto-regressive coefficient and W_{MP} denotes the constructed weights used, as given in equation 4) above.

Since equation 5) is a spatial lag model it cannot be estimated by the usual OLS procedure. OLS estimates will be biased and inferences will be incorrect. One therefore has to estimate the model by an autoregressive estimation procedure that takes into account the spatial lags. The literature proposes two methods. One is to use instrumental variables. The other is to use a maximum likelihood estimation procedure. The second strategy is the one followed here.

The weights following from the theory predict that the lags are decreasing functions of other countries' contribution to country n's market potential. In the spatial econometrics literature, weights are usually constructed on the basis of distance alone, like the weights introduced in section 3 above. For illustrative purposes, results based on use of these weights will also be presented.

Estimation results

Tables 2 and 3 summarise the regression results. The results for *levels* of GDP per capita (table 2) are obtained through OLS while the results for *growth* (table 3) are obtained through a maximum likelihood procedure by use of the software package Spacestat.[12]

In table 2 results from three sets of regressions are shown. The first set is from regressions when the relative price of capital was used. The second is from regressions when the price index of capital is approximated by the complete market potential, including the country's own total GDP. The model by Eaton and Kortum (as it is presented above) implies that countries' own total GDP should enter market potential without being retarded by distance (as d_{nn}=1). Countries are not dimensionless points as this assumption would imply, however. In some studies (as in Redding and Venables, 2002) this is taken into account by weighting own total GDP with a measure of average distance within the country. Here, the counter-strategy is followed in the third set of regressions. In these regressions, own GDP was completely left out of the expression of market potential.

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[11] As emphasised by Friedman (1992) and thoroughly by Quah (1993), a negative relationship between initial GDP per capita and its growth rate may be caused by stochastic disturbance.

[12] The resulting likelihood function is of the form:

$$L = \sum 1n(1-\rho\varpi) - N/2\ 1n\ (2\pi) - N/2\ 1n\ \sigma^2 - (g_y - \rho W g_y - \mathbf{Z}\gamma)'(g_y - \rho W g_y - \mathbf{Z}\gamma)/2\sigma^2$$

with ω as the eigenvalues of w, the spatial weights matrix used, σ^2 the error variance , g_y denotes growth and **Z** denotes all explanatory variables. See e.g. Anselin (1988) or Anselin (1992).

Table 2.
Estimation results for levels of (log of) GDP per capita, 1990.
Heteroscedasticity-consistent p values in paranthesis.

		Price Index of Capital		
ln(Pk/Pc)	-1.42 (0.000)	-0.28 (0.354)	0.57 (0.064)	0.62 (0.032)
ln(inv.60-90)		0.98 (0.000)	0.62 (0.014)	0.55 (0.023)
ln(school 85)			1.52 (0.000)	1.07 (0.000)
Continents	No	No	No	Yes
R2	0.42	0.52	0.69	0.79
n	104	104	78	78
		Compl. Market Potential		
ln(MP90)	0.41 (0.000)	0.25 (0.000)	0.18 (0.000)	0.13 (0.003)
ln(inv.60-90)		0.63 (0.000)	0.02 (0.883)	0.01 (0.949)
ln(Pc)		0.64 (0.000)	0.40 (0.006)	0.33 (0.120)
ln(school 85)			1.05 (0.000)	0.80 (0.001)
Continents	No	No	No	Yes
R2	0.36	0.70	0.77	0.81
n	104	104	78	78
		External Market Potential		
ln(MP90)	1.24 (0.000)	0.56 (0.001)	0.46 (0.001)	0.28 (0.100)
ln(inv.60-85)		0.82 (0.000)	0.13 (0.489)	0.07 (0.693)
ln(Pc)		0.42 (0.005)	0.23 (0.145)	0.33 (0.111)
ln(school85)			1.16 (0.000)	0.81 (0.001)
Continents	No	No	No	Yes
R2	0.30	0.63	0.75	0.80
n	104	104	78	78

Note: Continental dummies are for Africa, Latin America, North America, Asia, Europe and Oceania.

The results raise some doubt on the quality of the price indexes used for capital. The relative price of capital alone explains a large amount of the variation of levels in GDP significantly and with the right sign. Also, when investments rates are included, the sign of the relative price of capital is negative (as expected), but not significant. In the other regressions, the sign is positive and significant, which is counter-intuitive.[13]

The use of the theory-based price index of capital is more encouraging. The market potential variable is significant in most of the regressions, though naturally larger in magnitude but less significant when own GDP is left out. The crude measures of market potential used here alone explain about one third of variation in income levels for countries. The table also supports the hypothesis that investments in real (not

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[13] These results are in line with those obtained by Eaton and Kortum (2001a). It should be noted that the predicted correlation between the price index of capital and the expresssion for market potential is present and significant. The coefficient of correlation is -.37 and in a linear regression, the obtained coefficient is -.36 and highly significant.

Table 3.
Estimation results for growth in GDP per capita, 1960–90.

			Weight=WMP		
l(gdp60)	0.004	-0.003	-0.008	-0.009	-0.007
	(0.020)	(0.101)	(0.001)	(0.006)	(0.003)
ln(inv.60-90)		0.015	0.010	0.007	0.005
		(0.000)	(0.003)	(0.024)	(0.060)
ln(scho85)			0.014	0.012	0.006
			(0.007)	(0.011)	(0.171)
Continents	No	No	No	Yes	Yes
tiger	No	No	No	No	Yes
ρ	0.87	0.86	0.86	0.61	0.07
	(0.000)	(0.000)	(0.000)	(0.000)	(0.775)
AIC	-565.7	-602.4	-451.38	-466.0	-489.20
n	104	104	78	78	78
			Weight=W		
l(gdp60)	0.002	-0.004	-0.005	-0.005	
	(0.227)	(0.007)	(0.002)	(0.011)	
ln(inv.60-90)		0.014	0.012	0.009	
		(0.000)	(0.000)	(0.000)	
Continents	No	No	Yes	Yes	
tiger	No	No	No	Yes	
ρ	0.92	0.90	0.64	0.51	
	(0.000)	(0.000)	(0.001)	(0.028)	
AIC	-580.1	-615.9	-617.5	-644.1	
n	104	104	104	104	

Note: Continental dummies are for Africa, Latin America, North America, Asia, Europe and Oceania. The tiger economies denote Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Taiwan and Thailand.

robust) and human capital (robust) are important for income. It is important, however, that regression results like the ones above do not reveal the direction of causality.

It should be noted that the finding that market potential significantly influences income levels is robust to inclusion of continental dummies, in the sense that significance levels (at or) below 0.10 are maintained. The result that market potential is important for income levels is therefore not driven entirely by the continental divide of income as illustrated in figure 1.

Table 3 presents results from regressions of growth rates on different explanatory variables.[14] By and large, the results support the hypothesis that growth in one country is contagious to the country's neighbours. The auto-regressive coefficient is positive and significant in most of the regressions. This applies when conditioning variables are included and when continental dummies are included. Inclusion of continental dummies is a severe test for the influence of geography: The results do not only reflect different conditions for growth in the different continents in the world. They indicate that even when continental factors are controlled for, the contagious effect of growth is still present.

The result on geography is not robust, however, for inclusion of a dummy variable for the East Asian miracle economies. In the smaller data set with all the conditioning variables included, the spatial lag effect disappears altogether. It is not obvious what to conclude from this result. If one succeeded in identifying all clusters in the world, the auto-regressive coefficient would not be significant. Including the tiger economies is the same as inclusion of one very important cluster. In the lower part of table 3, estimation results when the inverse weight matrix presented in Section 3 was included instead of the one based on elements of market potential. The results suggest that the auto-regressive coefficient is large and significant when weights are based on distance alone.

The other results in table 3 are in line with several other regression-based studies of growth and its determinants: Investment in real and human capital correlates positively and most often significantly with economic growth per capita. Again the warning about direction of causality applies. The initial level of GDP per capita is unrelated to growth when no other variables are included and negatively and significantly when additional explanatory variables are included in the regressions. As mentioned, this result does not necessarily imply a trend towards a collapse in the cross-section distribution of income levels across countries.

To demonstrate this point and at the same time demonstrating the importance of distance in the world income distribution, the σ-convergence concept is useful. σ denotes the standard deviation of the distribution of income (the log of) per capita. σ-convergence denotes a falling standard deviation over time. σ-divergence, on the other hand, implies that the standard deviation is increasing. In contrast to regression-based approaches, studies of the standard deviation of the income distribution reveal (aspects of) the dynamics of world inequality. In most studies use is made of the standard deviation of (the log of) income per capita divided by the world average. In figure 6, the standard deviation of (the log of) income per capita normalised to the world average from 1960 to –90 is shown. The figure indicates strong divergence in the world economy. Figure 6 also graphs the standard deviation of income normalised to the distance-weighted averages presented above. This figure shows a similar, but less pronounced trend. Firstly, differences measured as deviations from distance-weighted neighbours are lower than the unconditional differences. This is a consequence of the clustered global landscape described above.

Secondly, also differences within the 'clusters' are increasing. Therefore, even if the world is getting more clustered, in the sense of a neater correlation between income in

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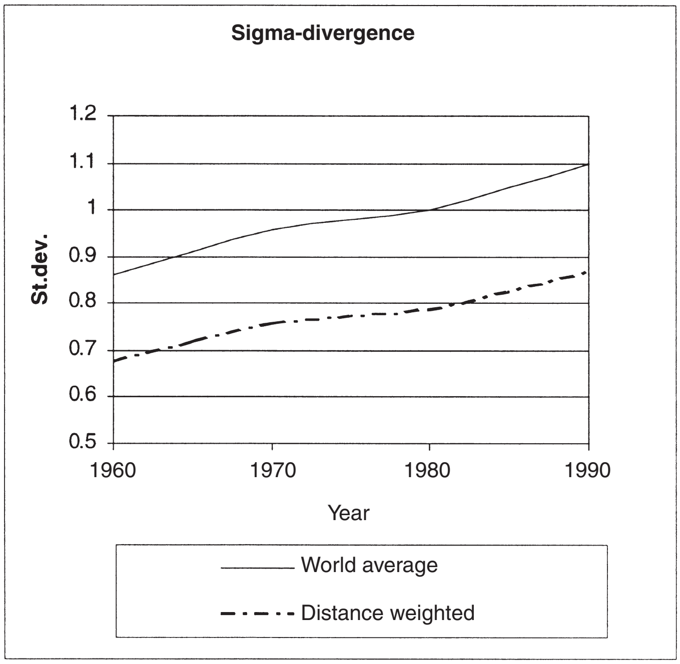
14. The constructed weights used are based on the average of total GDP in 1960 and 1990. Using GDP for 1960 increases the significance of the spatial lag to a level below 10 per cent. Using GDP for 1990 reduces the spatial lag even further.

Figure 6.



neighbour countries, also differences between neighbour countries are increasing.

Conclusions

It is well known that there are large differences in income per capita in the world. Also, it is well known that income per capita does not distribute randomly in space. Rather, rich countries are clustered together and apart from poorer countries. Recent advances in theories on economic growth and economic geography have updated and refined economists' tools for understanding the clustered economic landscape in the world. In this paper, the dynamics of the geographical income distribution in the world have been discussed. A simple economic model in which technological progress in production of capital goods influences their prices and therefore their productivity as factors of production demonstrates that both income and growth may depend on geography. This result occurs because trade is costly and costs increase with distance. Therefore, nearby trade partners benefit more from a country's technological progress than distant trade partners. Contagious productivity through trade in capital goods is one possible source of the (static and dynamic) pattern of the geographical distribution of income.

The empirical evidence lends support to two main conclusions: Firstly, other countries' *income* influences income in a country, to a degree which tapers off with the distance between the countries. Secondly, regression-based analyses indicate that geography influences *growth*. Growth performance in a country spills positively over to surrounding countries. This result is robust to continental dummies, but not to special treatment of the cluster of fast-growing East Asian tigers.

Still, the model does not explain all empirical regularities. Firstly, it is not an endogenous growth model. What the estimations imply is that the given growth rates are clustered in space, but there is no explanation for why growth occurs. Secondly, the model does not explain why the world is getting more clustered. In the model, steady state growth rates should be equal among countries but perturbations of the steady states will imply different consequences for countries depending on distance. Economic integration as such (defined as proportional decreases in transport costs) should reduce income differentials between countries. Still, divergence has been an important ingredient in world economic dynamics for the last three decades. These are topics that should stimulate future research.

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Appendix A. Moran's I

Define the weighted average of variable X for region i in year t as $\sum w_{ij}(X_j\text{-}X)$ in which X denotes the average of the X_j. Moran's I, is defined as $I=(N/S)\{[\mathbf{X'WX}]/\mathbf{X'X}\}$, where **X** is the vector of the variable, N is the number of observations, S is the sum of all spatial weights and **W** is the distance weight matrix. The transformation $z=\{I\text{-}E(I)\}/\{V(I)^{1/2}\}$, where E(I) and V(I) is the mean and the variance of I respectively, yields a standard normal variable when the variable in question is itself normally distributed. Confer Anselin (1992).

Appendix B.

A model of trade, growth and geography

There are two types of goods, capital goods, denoted by the subscript k and consumer goods, denoted by c. There are transportation costs so that an exporter in country n must ship $d_{ni}^{\varphi} > 1$ units of a good for one unit to arrive in country i. Let L denote labour, K a CES aggregate of capital goods, A total factor productivity and Q production. Production of goods r in country i is assumed to be Cobb-Douglas and is given by the production function in eq. A1. There is intersectoral labour mobility but immobility of labour and capital between countries. Resource constraints are given by eq. A2 and eq. A3.

A1) $Q_{ri} = A_{ri}K_{ri}^{\alpha}L_{ri}^{1-\alpha}, \quad r = k, c$

A2) $L_i = L_{ci}+L_{ki},$

A3) $K_i = K_{ci}+K_{ki},$

The model focuses on technological change in the capital goods sector as a driving force for growth. Therefore A_{ci} is set equal to one. There is perfect competition so that effective costs determine prices. When $A_{kn} \neq A_{ki}$ there is a case for international trade (no goods are assumed to be 'intensive' in any factors of production). Let P_{cn} denote prices on (homogenous) consumer goods in country n and P_{kn} be a price index for capital goods. Assume two countries, s and n and that A_{ks} is so low that country s specialises completely in consumer goods. Normalise prices so that $P_{cs}=1$. Since there is perfect competition we have that $P_{cn}=d_{ns}^{\varphi}P_{cs}=d_{ns}^{\varphi}$. Furthermore, prices of capital goods in country n (the capital producing country) is given by: $P_{kn}=P_{cn}/A_{kn}=d_{ns}^{\varphi}/A_{kn}$. Since country s imports capital goods, prices of capital goods here will equal $P_{ks}=d_{ns}^{\varphi}P_{kn}=(d_{ns}^{\varphi})^2/A_{kn}$.

In terms of prices of consumer goods in country s, income levels of country s and n are given by:

A4) $Y_s = K_{sc}^{\alpha}L_{sc}^{1-\alpha} = L_s\left(\frac{K_s}{L_s}\right)^{\alpha} = L_s k_s^{\alpha}$

A5) $$Y_n = P_{nk}A_{nk}K_{nk}^{\alpha}L_{nk}^{1-\alpha} + P_{nc}K_{nc}^{\alpha}L_{nc}^{1-\alpha} =$$

$$d_{ns}^{\varphi}L_{nk}\left(\frac{K_{nk}}{L_{nk}}\right)^{\alpha} + d_{ns}^{\varphi}L_{nc}\left(\frac{K_{nc}}{L_{nc}}\right)^{\alpha}$$

$$= d_{ns}^{\varphi}L_n\left(\frac{K_n}{L_n}\right)^{\alpha} = d_{ns}^{\varphi}L_n k_n^{\alpha}$$

Eq. A4 is straight forward when (K/L) is defined as k. Eq A5 is obtained from inserting the prices and utilising the fact that the capital labour ratio equalises between sectors.

Investments and depreciation govern the evolution of the capital stock according to eq. A6. Expenditure on capital goods is $P_{jk}I_j$. The driving force for growth is technological progress at the rate g in the capital goods producing sector. This rate of growth is assumed to be exogenous in the present model. The growth rate in the capital goods producing sector translates into price decrease of capital goods at the same rate. Denote the growth rate of national income g_y. Because consumption and expenditures on capital goods sum to national income, in steady state these variables grow at the same rate, g_y. Real investments correspondingly grow at the rate $g+g_y$. With the assumed production functions, we therefore have $g_y=\alpha/(1-\alpha)g$. With constant savings rates, s, the capital stock per worker grows according to eq. A7. In that equation account is taken for price differences between consumer goods and capital goods.

A6) $$\dot{K}_j = I_j - \delta K_j$$

A7) $$\dot{k}_j = s_j \frac{P_{jc}}{P_{jk}} k_j^{\alpha} - \delta K_j$$

A8) $$y_j = \left(\frac{s_j}{\left(\delta + \frac{g}{1-\alpha}\right)\left(\frac{P_{jk}}{P_{jc}}\right)} \right)^{\frac{\alpha}{1-\alpha}}$$

We have two equations for the growth rate in physical capital. The first says this equals g_y+g. The second is derived from eq. A7). These two equations can be used to derive a steady state income level, as in eq. A8). Equation A8) says that the steady state income level per person is an increasing function of the savings rate and a negative function of the relative price of capital goods.

Now, the capital stock in a country is a CES aggregate of differentiated capital goods:

A9) $$K = \left[\int_0^1 K_j^{\frac{\sigma-1}{\sigma}} d_j \right]^{\frac{\sigma}{\sigma-1}}$$

Assume that country i produces capital good j with quality $z_i(j)$. Buying capital good j from country i therefore faces country n with the cost $P_{kni}(j)=d_{ni}^{\varphi}/z_i(j)$. Country n will actually buy good j from country i if it is indeed the cheapest among all countries, so $P_{kn}(j)=\min(P_{kni}(j))$. Assume that the qualities $z_i(j)$ are realisations of random variables drawn from the extreme value distribution $\Pr(z_i \leq z)=\exp(-T_i z^{-\theta})$. In that expression, T_i represents the stock of knowledge, or the knowledge base, in country i and θ is a parameter governing (inversely) the variability. We assume that the knowledge base grows at the exogenous rate g_T. By use of the assumed probability distribution for the z's, the cost in country n of buying good j from country i is drawn from $\Pr(P_{kni}<p)= 1-\exp(-T_i d_{ni}^{-\varphi\theta} p^{\theta})$. The minimum across all countries is therefore:

A10) $$\Pr[P_{kn} \leq p] = 1 - \exp(-\Phi_n p^{\theta})$$

$$\Phi_n = \sum_{i=1}^{N} T_i d_{ni}^{-\varphi\theta}$$

Under the above assumptions, the fraction of capital goods that country n buys from country i is given by:

A11) $$\pi_{ni} = \frac{T_i d_{ni}^{-\theta\varphi}}{\sum_{i=1}^{N} T_i d_{ni}^{-\theta\varphi}} = \frac{T_i d_{ni}^{-\theta\varphi}}{\Phi_n},$$

$$\Phi_n \equiv \sum_{i=1}^{N} T_i d_{ni}^{-\theta\varphi}$$

Now it can be shown that an exact price index for capital goods in country will be given by:[15]

$$\text{A12)}\quad P_{kn} = \gamma \Phi_n^{-\frac{1}{\theta}}$$

$$\gamma = \Gamma\left(1 - \frac{\sigma - 1}{\theta}\right)^{\frac{1}{1-\sigma}}$$

Now, take logs of equation A8) and insert the expression for the price index into the obtained expression:

$$\text{A13)}\quad \ln y_j = \frac{\alpha}{\alpha - 1} \ln\left[\delta + \frac{g}{1-\alpha}\right] + \frac{\alpha}{1-\alpha} \ln P_{jc} + \frac{\alpha}{\theta(1-\alpha)} \ln P_{jk} + \frac{\alpha}{1-\alpha} \ln s_j$$

$$\text{A14)}\quad \ln y_j = \frac{\alpha}{\alpha - 1} \ln\left[\delta + \frac{g}{1-\alpha}\right] + \frac{\alpha}{1-\alpha} \ln P_{jc} + \frac{\alpha}{\theta(1-\alpha)} \ln\left[\gamma \sum_{i=1}^{N} T_i d_{ji}^{-\theta\varphi}\right] + \frac{\alpha}{1-\alpha} \ln s_j$$

With the described interpretation of T, eq. A13 and eq. A14 correspond to eq. 3 reported in the text.

Now, insert eq. A12 into eq. A8 and formulate it in reduced form as:

$$\text{A15)}\quad y_j = B\left[\sum_{i=1}^{N} T_i d_{ji}^{-\theta\varphi}\right]^{\frac{\alpha}{\theta(1-\alpha)}}$$

$\Rightarrow$

$$\frac{\dot{y}_j}{y_j} = \frac{\alpha}{\theta(1-\alpha)} \frac{\sum_{i=1}^{N} \frac{\dot{T}_i}{T_i} T_i d_{ji}^{-\theta\varphi}}{\left[\sum_{i=1}^{N} T_i d_{ji}^{-\theta\varphi}\right]}$$

$\Rightarrow$

$$\text{A16)}\quad g_{yi} = \frac{\sum_{i \neq j}^{N} g_{yi} T_i d_{ji}^{-\theta\varphi}}{\sum_{i \neq j}^{N} T_i d_{ji}^{-\theta\varphi}}$$

Eq. A15 is just a reduced form of eq. A8. In the below equation, this equation is derivated w.r.t. time and the growth rate is derived. In eq. A16, the relationship between g_y and g_T is used (which is now $g_y = (\alpha/\varphi(1-\alpha))g_T$) and the growth rate for country j is solved for as a function of other countries' growth rate. The derived expression is similar in vein to regression equation 4 and 5 reported in the text. These regression equations are spatial lag models where the spatial weights are adjusted for the technology base in each country.

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[15] This price index is valid under some assumptions only, outlined in Eaton and Kortum (2001b) and Maurseth (2002).

Appendix B. Countries included in analysis

ALGERIA
ARGENTINA
AUSTRALIA
AUSTRIA
BANGLADESH
BELGIUM
BENIN
BOLIVIA
BRAZIL
BURKINAFASO
BURUNDI
CAMEROON
CANADA
CAPEVERDE
CENTRALAFR
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTARICA
CYPRUS
CZECHOSLOVAKIA
DENMARK
DOMINICANREP
ECUADOR
EGYPT
ELSALVADOR
FIJI
FINLAND
FRANCE
GABON
GAMBIA
GERMANYWEST
GHANA
GREECE
GUATEMALA
GUINEA
GUINEABISS
GUYANA
HONDURAS
HONGKONG
ICELAND
INDIA
INDONESIA
IRAN
IRELAND
ISRAEL
ITALY
IVORYCOAST
JAMAICA
JAPAN
JORDAN
KENYA
KOREA
LESOTHO
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MAURITANIA
MAURITIUS
MEXICO
MOROCCO
MOZAMBIQUE
NAMIBIA
NETHERLANDS
NEWZEALAND
NICARAGUA
NIGERIA
NORWAY
PAKISTAN
PANAMA
PAPUANGUINEA
PARAGUAY
PERU
PHILIPPINES
PORTUGAL
RWANDA
SENEGAL
SEYCHELLES
SINGAPORE
SOUTHAFRICA
SPAIN
SRILANKA
SWEDEN
SWITZERLAND
SYRIA
TAIWAN
THAILAND
TOGO
TRINIDAD& TOBAGO
TUNISIA
TURKEY
UGANDA
UK
URUGUAY
USA
VENEZUELA
YUGOSLAVIA
ZAMBIA
ZIMBABWE