ISSN 1995-2848
OECD Journal: Economic Studies
Volume 2008

The Contribution of Economic Geography to GDP per Capita

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The authors would like to thank numerous OECD colleagues, in particular Sveinbjörn Blöndal, Sean Dougherty, Jørgen Elmeskov, Christian Gianella, David Haugh, Peter Hoeller, Nick Johnstone, Vincent Koen, Dirk Pilat, Jean-Luc Schneider and Andreas Woergoetter, for their valuable comments as well as Philippe Briard and Martine Levasseur for technical assistance and Caroline Abettan for editorial support. The paper has also benefited from comments by members of the Working party No. 1 of the OECD Economic Policy Committee, as well as the participants to the "The Gravity Model" Conference, Groningen, October 2007.

Introduction and main findings

Over the past several years, the OECD has quantified the impact of structural policies on employment, productivity and GDP per capita (*e.g.* OECD, 2003, 2006). The results from these studies, which have built on a vast academic literature, have contributed to a better understanding of the main channels linking policies to labour and product market outcomes in OECD countries. In doing so, they have also underscored the limits to the understanding of economic growth: only a limited part of the cross-country dispersion in GDP levels and growth rates can be explained by quantifiable policy levers, at least on the basis of standard macro-growth regression analysis.

This paper examines how much of the cross-country dispersion in economic performance can be accounted for by economic geography factors. To do so, an augmented Solow model is used as a benchmark. The choice is motivated by the fact that this model has served as the basic framework in previous work on the determinants of growth, thereby ensuring some continuity. It has long been recognised, however, that while providing a useful benchmark to assess the contributions of factor accumulation as a source of differences in GDP per capita, the basic Solow growth model ignores potentially important determinants. For instance, it leaves a large portion of growth to be explained by the level of technology, which is assumed to grow at a rate set exogenously.

In order to bridge some of the gaps, extensions of the model in the literature have generally taken four types of (partly related) directions: *i*) R&D and innovation, *ii*) goods market integration and openness to international trade, *iii*) quality of institutions, and *iv*) economic geography. The focus of this paper is on economic geography, although this is not totally independent from the other factors, in particular international trade. More specifically, for the purpose of this study, the concept of economic geography is examined through the proximity to areas of dense economic activity.

The key point of this aspect of geography is the recognition that proximity may have a favourable impact on productivity, through various channels operating *via* product and labour markets. In the case of product markets, one of the key channels is that proximity induces stronger competition between producers, thus encouraging efficient use of resources and innovation activity. Another is that an easy access to a large market for consumers and suppliers of intermediate goods allows for the exploitation of increasing returns to scale. Furthermore, the presence of large markets allows for these scale effects to be realised without adversely affecting competition. The scope for exploiting higher returns to scale is hampered by distance to major markets, both within and across countries, due to transportation costs. Transportation costs also reduce the scope for specialisation according to comparative advantage, another important driver of gains from trade along with the ability to reap scale economies.

While the economic geography literature focuses mainly on trade linkages, a parallel literature on urban and spatial economics puts more emphasis on agglomeration externalities as a benefit from operating in an area of dense economic activity. Such externalities may include economies of scale related to infrastructure and other public services, as well as the potential gains associated with the access to a large pool of workers, and localised knowledge spillovers. In principle, it is possible to provide some quantification of these benefits, using standard measures of economic density, such as the share of population living in cities. In practice, such measures are highly endogenous to economic development and finding appropriate instruments to address the endogeneity problem is beyond the scope of this paper. As a result, this aspect is only examined in a very tentative way in the final section of the paper.

The empirical strategy pursued in the paper is as follows. In the next section, the augmented Solow model, which is used as the basic framework, is first briefly described and estimated both in level and in error-correction forms, over a sample of 21 OECD countries over the period 1970-2004. The influence of proximity to major markets on GDP per capita is then investigated in the following section, introducing in the benchmark model various indicators of distance to markets, such as measures of market potential, market and supplier access, as well as the sum of distances to world markets and population density. The various measures of distance to markets are all found to have a statistically significant effect on GDP per capita, with the exception of population density. The estimated economic impact varies somewhat across specifications, but it is far from negligible. For instance, the lower access to markets relative to the OECD average could contribute negatively to GDP per capita by as much as 11% in Australia and New Zealand. Conversely, the benefit from a favourable location could be as high as 6-7% of GDP in the case of Belgium and the Netherlands.

Later in the text, the impact of distance is alternatively examined *via* the more specific channel of transportation and telecommunication costs. To this end, broad indicators of weight-based transportation costs covering maritime, air and road shipping have been constructed for 21 OECD countries over the period 1973-2004, along with an indicator of the cost of international telecommunications. Based on these indicators, there is little evidence that the importance of distance in the transportation of goods has diminished during the past two or three decades (though transport costs may have fallen relative to the value of transported goods). In contrast, the cost of international telecommunications has fallen in all countries to the point where it is basically no longer significant anywhere. Overall, transportation costs are found to have a negative and significant effect on GDP per capita through their effect on international trade. Based on these estimates, differences in transport costs relative to the OECD average contribute to reduce GDP per capita by between 1.0% and 4.5% in Australia and New Zealand. At the other end, the lower transport costs for Canada and the United States contribute to raise GDP per capita relative to the average OECD country, but only by a small margin varying between 0.5% and 2.5%. The quantitatively smaller effects than those found on the basis of measures of economic distance are consistent with transportation costs being only one aspect of costs related to distance.

Most of the geography factors discussed in this paper cannot be influenced by policy or are only affected by policy in indirect ways. Nevertheless, a number of policy issues are addressed in the penultimate section, which also provides a summary of the combined economic impact of the geographic variables used in the empirical analysis.

General empirical framework

A basic empirical framework is required in order to assess the importance of economic geography in determining GDP per capita. Against the background of earlier OECD analysis in this area, this section briefly reviews the basic determinants of GDP per capita, discusses alternative specifications in terms of levels and changes over time, and reports the results of an empirical analysis using only the basic determinants. The remainder of the paper will then examine whether economic geography variables can account for some of the variance in GDP per capita left unexplained by the basic determinants.

The basic determinants of GDP per capita

The empirical framework used to assess the influence of economic geography determinants is the Solow (1956) model augmented with human capital. The model has been widely used in the empirical growth literature, owing largely to its simplicity and flexibility. For instance, despite being derived from a specific framework, the empirical version of model is sufficiently general to be consistent with some endogenous growth models (Arnold *et al.*, 2007).

The Solow model has been widely used as a theoretical framework to explain differences across countries in income levels and growth patterns. The model is based on a simple production function with constant returns-to-scale technology. In the augmented version of the model (Mankiw, Romer and Weil, 1992), output is a function of human and physical capital, as well as labour (working-age population) and the level of technology. Under a number of assumptions about the evolution of factors of production over time, the model can be solved for its long-run (steady-state) equilibrium whereby the path of output per capita is determined by the rates of investment in physical and human capital, the level of technology, and the growth rate of population (see Annex for a detailed derivation). In the steady-state, the growth of GDP per capita is driven solely by technology, which is assumed to grow at a (constant) rate set exogenously in the basic model.

The long-run relationship derived from the augmented Solow model can be estimated either directly in its level form, or through a specification that explicitly takes into account the dynamic adjustment to the steady state. Estimates of the long-run relationship in static form have been used in the literature (*e.g.* Mankiw, Romer and Weil, 1992; Hall and Jones, 1999; Bernanke and Gürkaynak, 2001), in particular in studies focusing on income level differentials across countries. However, since the model has often been used in the empirical growth literature to examine issues of convergence, some form of dynamic specification has been more common. The two types of specification – static or dynamic – can be expected to yield similar results if countries are not too far from their steady states or if deviations from the latter are not too persistent.

In principle, a dynamic specification is preferable, even when the interest is mainly on the identification of long-run determinants. This is because persistent deviations from steady state are more likely to lead to biased estimates of the long-run parameters in static regressions, especially when the time-series dimension of the sample is relatively short. In practice, estimating dynamic panel equations is also fraught with econometric problems (Durlauf and Quah, 1999). Furthermore, a major drawback with the most common techniques based on dynamic fixed-effect estimators is that only the intercepts are allowed to vary across countries, implying that all countries converge to their steady-state at the same speed, an assumption unlikely to hold even among developed countries.[1]

To address the latter issue, previous studies have relied on the Pooled Mean Group (PMG) estimator, which allows for short-run coefficients and the speed of adjustment to vary across countries, while imposing homogeneity on long-run coefficients (OECD, 2003). However, even though the PMG estimation technique is intuitively appealing and perhaps the most suitable under some conditions, it is not without limitations especially when such conditions are not met. For instance, due to the large number of parameters and the non-linear constraints, the maximum likelihood estimation technique is prone to problems of convergence on local optima. And, experience suggests that parameter estimates can be particularly sensitive in presence of multi-collinearity among regressors, with some parameter values being in such cases too large (and unstable) to be plausible.

For the purpose of this study, the model is first re-estimated with only the basic determinants included in the specification, *i.e.* proxies for investment in physical and human capital, population growth and technical progress. Then, a number of determinants are added to the benchmark specification throughout the rest of the paper, but the set of additional variables is limited to those related to economic geography factors. One exception is the measure of exposure to international trade which, given the importance of geography on trade, is used to assess the impact of transportation costs on GDP per capita (see later in the text). The reason for leaving other potential variables out is essentially one of parsimony, *i.e.* to limit the number of specifications, which quickly runs up as each additional determinant is considered.[2] However, this implies that potentially significant control variables are not included, with the risk that this entails in terms of biases and robustness of the results as regards the determinants of economic geography. In order to minimise those risks, all specifications include various combinations of country and year fixed-effects and/or linear time trends, all of which are introduced in part to capture omitted variables.

Benchmark specification and empirical results

The empirical version of the augmented-Solow model is re-estimated over a panel data set comprising 21 countries and 35 years of observations (1970-2004). In what will serve as the reference model for the rest of the paper, the level of GDP per working-age person in country i and year t (y_{it}) is regressed on the rate of investment in the total economy ($s_{K,it}$), the average number of years of schooling of the population aged 25-64, which is used as a proxy for the stock of human capital (hc_{it})[3] and the growth rate of population (n_{it}) augmented by a constant factor introduced as a proxy for the sum of the trend growth rate of technology and the rate of capital depreciation ($g + d$), with all variables expressed in logs.[4] Technological progress is captured alternatively by a linear time trend or time dummies.

The results presented in this paper are based on both a level specification, using a least-square estimator (that corrects for heteroskedasticity and contemporaneous correlations), and an error correction specification, using the pooled mean group (PMG) estimator. Due to persistence in the series, control for first-order serial correlation is systematically made when the level specification is estimated. The functional forms of the equations estimated in level and error-correction forms are respectively specified as follows (see Annex for derivation):

Level specification (AR1)

$$Log\ y_{it} = \alpha.Log\ s_{K,it} + \beta.Log\ hc_{it} + \varphi.\Delta Log\ hc_{it} + \gamma.Log(n_{it} + g + d) + \varsigma_i t + e_i + e_t + u_{it}$$
$$u_{it} = \rho.u_{it-1} + \varepsilon_{it} \quad , \quad \varepsilon_{it} \quad i.i.d. \tag{1}$$

Error-correction specification (Pooled Mean Group)

$$\Delta Log\ y_{it} = -\lambda_i.\left[Log\ y_{it-1} - \left(\alpha.Log\ s_{K,it} + \beta.Log\ hc_{it} + \gamma.Log(n_{it} + g + d)\right)\right]$$
$$+ \ a_{0i}.\Delta Log\ s_{K,it} + a_{1i}.\Delta Log\ hc_{it} + a_{2i}.\Delta Log(n_{it} + g + d) + e_i + \varsigma_i.t + \varepsilon_{it} \tag{2}$$

where e_i and e_t are country and year fixed-effects, respectively, and t is a linear time trend. The parameters α, β, γ, and ζ are the long-run parameters on the three basic determinants and the time trend. The parameter σ is the first-order autocorrelation coefficient used in the level specification.[5] The other parameters capture short-run dynamics and will not be reported in the table of results. Finally, u_{it} and ε_{it} are the residuals.

The results from re-estimating the empirical version of the augmented-Solow model are presented in Table 1. The first three columns refer to the level specification and the last two are based on the error-correction specification. Focusing on the level specification, the

Table 1. **Basic framework: Regression results**

Augmented-Solow model[1]

Dependant variable GDP per capita	Level AR(1)	Level AR(1)	Level AR(1)	Error correction PMG	Error correction PMG
	(1)	(2)	(3)	(4)	(5)
Common parameters					
Physical capital	0.184***	0.156***	0.199***	0.292***	0.572***
	(0.019)	*(0.024)*	*(0.017)*	*(0.030)*	*(0.059)*
Human capital	0.334***	0.792***	–0.063	0.861***	–0.006
	(0.127)	*(0.053)*	*(0.156)*	*(0.199)*	*(0.189)*
Population growth[2]	–0.006	–0.016	–0.003	–0.392***	–0.661***
	(0.018)	*(0.028)*	*(0.018)*	*(0.067)*	*(0.101)*
Time trend					0.015***
					(0.002)
Rho[3]	0.884	0.911	0.775		
Country-specific parameters					
Lambda[4]				–0.190***	–0.086***
				(0.025)	*(0.017)*
Time trend	No	No	Yes	Yes	No
Fixed effects					
Country	Yes	No	Yes	Yes	Yes
Year	Yes	Yes	Yes	No	No
Sample size					
Total number of observations	696	696	696	695	695
Number of countries	21	21	21	21	21

Note: Standard errors are in parentheses. *: significant at 10% level; ** at 5% level; *** at 1% level.

1. The functional forms corresponding to the "level" and "error-correction" specifications are reported earlier in the text. In the level specification, standard errors are robust to heteroscedasticity and to contemporaneous correlation across panels. In the error-correction specification, only long term parameters are reported.
2. The population growth variable is augmented by a constant factor *(g + d)* designed to capture trend growth in technology and capital depreciation. This constant factor is set at 0.05 for all countries.
3. *Rho* is the first-order auto-correlation parameter.
4. The parameter *lambda* is the average of the country-specific speed adjustment parameter, λ_i.

coefficient on human capital is quite sensitive to the control for fixed effects and or time trends. In particular, it comes out significantly higher when country fixed effects are excluded (column 2), suggesting that an important part of the information contained in the average number of years of schooling is related to differences in average levels across countries. Moreover, it completely drops out when country-specific time trends are included in the regression in addition to country- and year-fixed effects (column 3).

Turning to the error-correction specification, the results shown in the fourth column are similar to those obtained in the earlier OECD analysis based on an almost identical specification (with country fixed effects and country-specific parameters on the time trend) and the same estimation method (PMG).[6] The speed of adjustment parameter suggests rapid convergence to the steady-state, a result which is influenced by the introduction of country-specific time trend parameters.[7] Also, the parameter estimate on human capital suggests a strong effect, with one extra year of schooling leading to an increase in GDP per capita by around 8% in the long run for the average OECD country. However, here again, the significance of the human capital coefficient depends on whether or not the trend is assumed to be common or country specific (column 5).[8]

Figure 1 presents the contribution of physical capital, human capital and fixed effects to the gap in GDP per capita relative to the average OECD country and on average over the 2000-04 period.[9] The results presented in the two panels are based on the specifications shown in columns 1 and 4, respectively. Not surprisingly, the contribution of physical and human capital is small relative to that of the fixed effects. Indeed, the latter account for 72% and 87% of the GDP per capita variance (over this average period) for the level and the error correction specification respectively. Some of the highest fixed effects are in both specifications recorded for Norway and, to a lesser extent, the United States and Sweden. Portugal, Greece, New Zealand and Japan have the largest negative effects. The position of Ireland and Switzerland is particularly sensitive to whether common or country-specific time trends are introduced.

The rest of the paper investigates whether some of these large fixed effects can be accounted for by indicators of economic geography and, more generally, the extent to which such indicators can explain part of income levels which is not explained by the usual determinants.

Economic distance

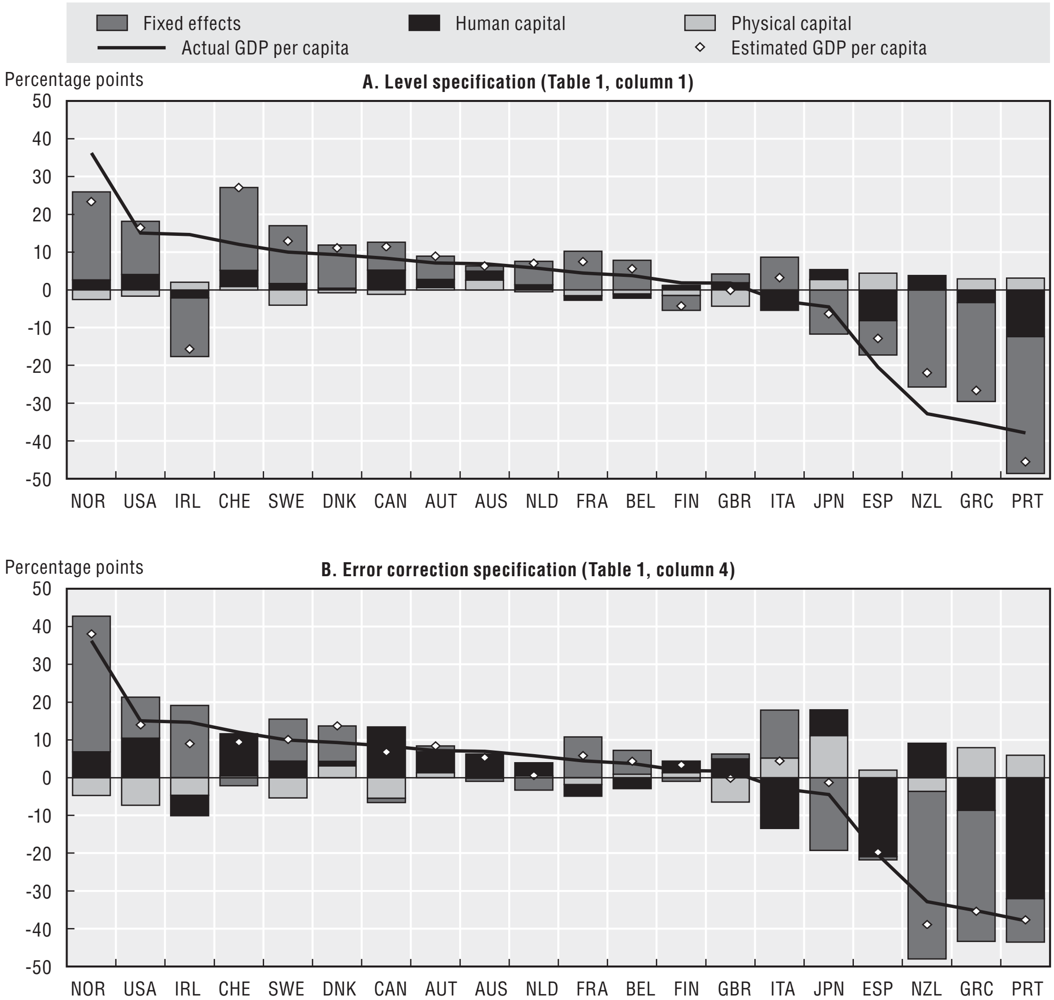
In this section, different measures of proximity to markets or centrality are introduced and tested in the empirical analysis as potential determinants of GDP per capita. Some of them are simple measures based on GDP, country size, population and distances *vis-à-vis* other countries. The others are model-based measures derived from bilateral trade flows.

Why proximity matters

The role of geographic distance and the influence of neighbouring countries have largely been neglected in traditional growth theory which relies essentially on national characteristics, *e.g.* factor endowments and technological progress. Yet, the clustering of economic activities is a well-known phenomenon that raises questions about the extent to which the proximity to high-income neighbours matters for a country's own income. The development process might indeed be hindered in countries that are distant from centres of economic activities.

Figure 1. **Basic framework: Contributions of explanatory variables**[1]

Difference to average country, 2000-2004



1. These charts show the contribution of each explanatory variable to GDP per capita based on Table 1. The contributions are computed as differences to the average country and on average over the period 2000-04. The contribution of fixed effects is the sum of country and year fixed effects in Panel A, and the sum of country fixed effects and country specific time trends in the Panel B. For Norway and Panel A, as an example, the chart reads as following: On average between 2000-04, Norway had a GDP per capita which was 36% above the average across countries, whereas the estimated difference to the average is 23% based on Table 1, column 1. These 23% are broken down according to the contribution of fixed effects (23%), physical capital (–3%) and human capital (3%). Because of a break in the series due to the reunification, data for Germany were used only for the period 1970-89. Therefore, Germany is not included in the figure.

Distance can affect productivity and income levels through various channels, including trade, foreign investment and technology diffusion. There is ample evidence showing the importance of distance for trade and FDI flows (*e.g.* Nicoletti *et al.,* 2003), as well as for technology spillovers (Keller, 2002). Furthermore, trade and FDI are obvious channels of knowledge spillovers (Eaton and Kortum, 1994 and 1996), which reinforces the impact of distance on productivity.

Focusing on the trade channel, distance directly raises transport and other trade costs and is an obstacle to both domestic and foreign trade. There are a number of inter-related ways through which this channel affects productivity. Greater proximity to world markets increases the opportunity to concentrate resources in activities of comparative advantage. It also encourages specialisation of firms that can attain efficient scale and more generally exploit increasing returns in specific fields of production. Moreover, stronger competition pressures force companies to use available inputs efficiently and encourage them to innovate and maintain a competitive advantage.

In addition to influencing GDP per capita *via* its impact on technical efficiency, distance can also affect external terms of trade. A relatively remote and sparsely populated country has to internalise transport costs into producer prices of tradeable goods in order to remain competitive in world markets or otherwise suffer lower sales. Because, by definition, the factor prices of mobile factors tend to be equalised across locations, the costs of remoteness are born by the immobile factors, *i.e.* mostly labour in an international perspective. Indeed, even if technologies are the same everywhere, firms in more remote countries can only afford to pay relatively lower wages (Redding and Venables, 2004).

In addition to its direct impact on incomes, geography might have an influence through other factors such as physical or human capital. Returns to physical and human capital might be higher in countries having a better access to large markets (Redding and Scott, 2003). In turn, a high return to skills increases the incentive to invest. As regards human capital, Redding and Scott provide some evidence that the world's most peripheral countries have relatively low levels of education, a feature found also in the case of European regions (Breinlich, 2007).

The distance of OECD countries to world markets

In this section, four measures of proximity to markets or centrality are constructed and compared. The first one is population density. The second one depends solely on distances between countries. The third one is a simple measure based on distances *vis-à-vis* other countries and the size of their GDPs, and the last one is a model-based measure derived from bilateral trade flows. The next section is specifically dedicated to the effects of economic distance measured by transport costs.

Population density, sum of distances and market potential

Population density, defined as the ratio of population to surface area, is an indicator of proximity to the domestic market. The higher the density the lower the aggregated domestic transport costs. However, the critical shortcoming of this measure is its failure to take into account the effective access to foreign markets.

A simple measure of distance to markets that does so is one based on bilateral distances. From the perspective of empirical analysis, this measure is attractive because it is based on exogenous characteristics of geography. Although the sum of the distances of each country to Tokyo, Brussels and New York has been commonly used in the empirical literature, the choice of these three locations is arbitrary and creates issues of endogeneity.

Hence, a better alternative is to sum the distances to all countries (Head and Mayer, 2007):

$$Distsum_i = \sum_j d_{ij} \tag{3}$$

In order to compute ***Distsum***, the world was divided in 32 areas: Africa, Australia, Austria, Belgium, Brazil, Canada, China, CIS countries, Denmark, Eastern Europe, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Latin America (other than Brazil and Mexico), Mexico, the Middle East, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States and Asia (other that the countries already included). Pure distance measures, however, fail to take into account the size of markets. Moreover, this measure depends on how geographic areas are constructed. For example, a different picture would be obtained if the European Union was considered as one entity or, alternatively, the North America was disaggregated into states/provinces.

Therefore, a more refined measure of proximity to markets is market potential, which is defined as the sum of all countries' GDP weighted by the inverse of the bilateral distance (Harris, 1954):

$$Market\ Potential_i = \sum_j \frac{GDP_j}{d_{ij}} \quad (4)$$

The market potential measure must take into account, for a given country, the domestic market and include its own GDP weighted by the inverse of internal distance. Because the internal distance is generally smaller than external distances, it is associated with a greater weight and is therefore a sensitive parameter for measures of centrality. The most commonly used distance indicators combine geodesic capital-to-capital distances between countries and internal distances based on surface areas.[10] It follows that market potential is likely to be positively correlated with population density due to the domestic component.

Market and supplier access

Although it is an intuitive indicator of centrality, market potential is an *ad-hoc* way of capturing the influence of distance to markets. In particular, the weighting of foreign markets in the market potential computation is based solely on distances, regardless of the true accessibility of these markets. In that respect, market *potential* is a very crude measure of market *access*. Indeed, accessibility depends, in addition to distance, on trade policy and cultural relationships, among other determinants. A better approach consists in looking not only at the *potential*, but rather at the *actual* accessibility to countries' markets.

A measure based on such an approach has been proposed in the new economic geography literature, which has revived the concept of proximity to markets and formalised the role of economic geography in determining income. Using the methodology proposed by Redding and Venables (2004) and described in Box 1, measures of market and supplier access have been derived from bilateral trade equations estimated over the period 1970 and 2005 for the 32 countries/areas covering 98.5% of world trade flows in goods (see Boulhol and de Serres, 2008, for details).

Comparison of the different measures

The various measures of centrality discussed in the previous sub-section have been computed for most OECD countries and Table 2 reports the computed values for 2005, plus the average of the country ranking over the different measures. To facilitate the comparison, each of these measures is scaled such that the average across countries is 100 for each year. The cross-country pattern is reasonably close across indicators. Linear correlation is especially high, at around 95%, between market potential, market access and supplier access (and the average ranking). Ranking the countries enables to distinguish five

Box 1. Construction of market access and supplier access measures

Market and supplier access measures are derived from the estimation of a gravity-like relationship. As is common in the literature, trade costs in the bilateral trade specification are assumed to depend on three variables: bilateral distance, common border and common language. Noting X_{i-j} as the export from country i to country j and d_{ij} the bilateral distance, the following equation is estimated for each year t:

$$Log\ X_{i\rightarrow j,t} = s_{it} + a_t.Log\ d_{ij} + b_t.Border + c_t.Language + m_{jt} + v_{ijt}$$

where the so-called freeness of trade (ϕ), which is inversely related to trade costs, is given by $Log\ \phi_{ijt} = a_t.Log\ d_{ij} + b_t.Border + c_t.Language$. The estimates of "intra-country" freeness of trade, ϕ_{iit}, are computed based on the same formula applied to internal distance, common border and common language. s_{it} and m_{jt} are unobserved exporter and importer characteristics, respectively. For each year, they are proxied by country fixed effects. According to the model (see Boulhol and de Serres, 2008, for details), these effects capture some characteristics of the countries related to the number of varieties, expenditures on manufactures, price indices, etc. Market and supplier access, respectively MA and SA are then constructed from the estimated parameters of the bilateral equation according to:

$$MA_{it} = \sum_k m_{kt} \cdot \phi_{ikt}\ ;\ SA_{it} = \sum_k s_{kt} \cdot \phi_{ikt}$$

For all the countries, market access (supplier access respectively) is computed as a weighted sum of unobserved importer characteristics m_j (exporter characteristics s_i respectively) of all countries. Only the weights put on each partner change across countries, with these weights being a function of estimated trade costs. If a given country k has a large market capacity m_k, countries having low trade costs with country k, *i.e.* a high freeness of trade, put a high weight on m_k and tend to have a high market access. A similar argument applies to supplier access for countries having low trade costs with partners having a large export capacity. Note that this is the same principle as that applied to market potential, whose computation boils down to weighting all countries' GDP by the inverse of the bilateral distances.

groups, in ascending order and Figure 2 represents this clustering using market potential for illustration purposes:

- The remote and sparsely populated countries: Australia and New Zealand.
- Low-income peripheral countries.
- High-income peripheral countries, Korea and North America.
- Continental Europe, the United Kingdom and Japan.
- The centrally located and dense economies of Belgium and the Netherlands.

As expected, access measures are negatively correlated to the sum of distances and positively correlated to population density, suggesting that market and supplier access encompasses these different geographical dimensions. Besides, population density is an important factor explaining the position of Japan and Korea at or above what could be expected from the pure sum-of-distances measure.[11]

Given the size of its own market, the relative position of the United States in terms of market potential or market access might look surprising. As shown by the first column in Table 2 which gives the simplest measure of proximity, one reason is that the United States is much further from markets than European countries. Another reason is that the size of

Table 2. **Measures of proximity/distance to markets, 2005**

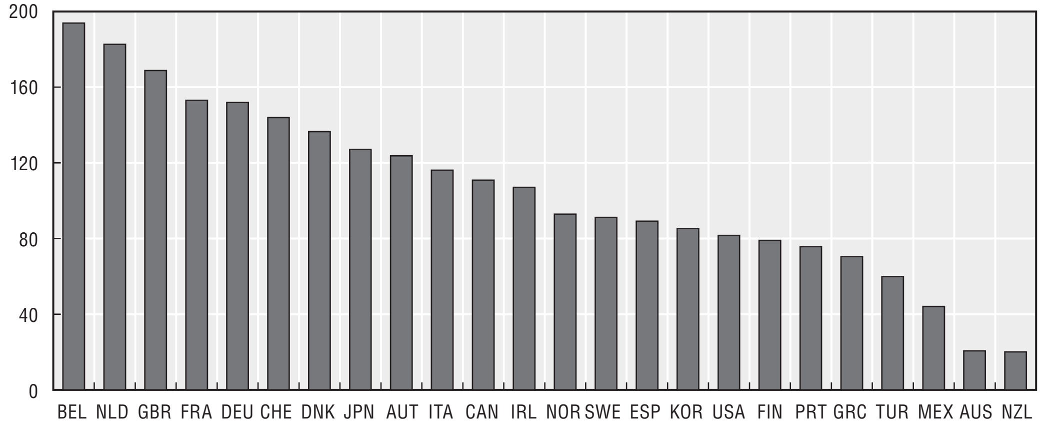
	Average across countries = 100 for each indicator					Average ranking[1]
	Sum of distances (*Distsum*)	Market potential	Market access	Supplier access	Population density	
Australia	214	21	25	23	2	1.4
Austria	69	124	116	123	78	16.2
Belgium	69	194	236	222	113	21.8
Canada	113	111	126	86	3	10.6
Denmark	68	136	119	130	97	18.0
Finland	72	79	66	74	12	8.0
France	70	153	145	137	84	18.2
Germany	68	152	154	172	197	21.6
Greece	76	70	61	55	63	7.2
Ireland	73	107	100	101	46	11.8
Italy	72	116	115	110	150	15.2
Japan	139	127	111	163	266	15.6
Korea	131	85	104	154	406	14.2
Mexico	149	44	44	33	43	4.0
Netherlands	69	183	221	199	308	22.8
New Zealand	234	20	26	25	14	2.2
Norway	70	93	76	80	11	9.8
Portugal	81	76	73	59	90	8.4
Spain	77	89	96	73	67	10.0
Sweden	70	91	75	84	15	10.6
Switzerland	70	144	136	147	143	18.8
Turkey	78	60	52	52	75	6.6
United Kingdom	70	169	158	136	189	19.4
United States	119	82	92	64	27	7.6
	Linear correlation coefficient					
Sum of distances		–0.69	–0.57	–0.52	–0.17	–0.62
Market potential			0.96	0.92	0.50	0.97
Market access				0.93	0.53	0.92
Supplier access					0.71	0.95
Density						0.62

1. All the countries are ranked based on each of the five indicators, 1 standing for the most remote country and 24 for the most central one. The average ranking is the average of these five rankings.

the domestic market is not in itself an adequate indicator of market potential or access to markets. To see this more closely, Table 3 breaks down market potential and market access into their domestic and foreign components, respectively. Looking for example at market potential, it is true that the domestic component represents two thirds of the total for the United States whereas that share is only 22% for the Netherlands and 4.5% for Canada. Still, the domestic market potential for the United States is only 30% greater than that for the Netherlands, even though its GDP is 20 times bigger. This is because the internal distance of the United States is 15 times bigger. What matters is not the size of the total domestic market, captured here by the GDP, but that size relative to internal distance.[12] In any case, these considerations have very limited consequences for the econometric analysis that follows, since they refer essentially to the levels of the proximity measures and most of the regressions include country fixed effects.

Figure 2. **Market potential, 2005**[1]

Average across countries = 100



1. Market potential is defined in equation (4).

Table 3. **Domestic and foreign components of market potential and market access, 2005**

Base: "World" = 100

	Market potential			Market access			Internal distance[1] Km
	Total	Domestic	Foreign	Total	Domestic	Foreign	
Australia	21	4	17	25	9	17	1 043
Austria	124	14	110	116	13	103	109
Belgium	194	27	166	236	69	167	68
Canada	111	5	106	126	7	120	1 188
Denmark	136	17	120	119	16	103	78
Finland	79	4	75	66	6	60	218
France	153	39	114	145	32	113	278
Germany	152	63	89	154	73	81	225
Greece	70	8	62	61	9	52	136
Ireland	107	10	97	100	12	88	100
Italy	116	43	73	115	54	61	206
Japan	127	99	28	111	83	28	231
Korea	85	34	52	104	61	43	119
Mexico	44	7	37	44	10	34	528
Netherlands	183	41	142	221	96	126	77
New Zealand	20	3	17	26	9	18	195
Norway	93	7	86	76	6	70	214
Portugal	76	8	68	73	12	62	114
Spain	89	21	68	96	40	55	268
Sweden	91	7	84	75	8	68	252
Switzerland	144	24	120	136	19	117	76
Turkey	60	6	54	52	6	46	332
United Kingdom	169	60	109	158	65	93	186
United States	82	54	28	92	64	28	1 161

1. The underlying assumption behind the internal distance $d_{ii} = 2/3\sqrt{area_i/\pi}$ is that a country is a disk where all suppliers are located in the centre and consumers are located uniformly over the area.

Empirical analysis: Augmented Solow model and proximity

The impact of access to markets on GDP per capita has been tested in different contexts and all these studies find that proximity has an important impact on GDP per capita.[13] However, none of them has focused on developed countries despite their widely varying access to markets. In a broad sample covering both least and most developed countries, Australia and New Zealand generally appear to have overcome the "tyranny of distance" (Dolman, Parham and Zheng, 2007). However, this inference might be misleading if the data do not enable to account for important country specificities. Focusing on a more homogenous group over a large period using panel techniques should therefore lead to a more reliable estimate.

This sub-section assesses the impact of the different measures of proximity/distance on GDP per capita when added to the usual explanatory variables in the augmented Solow framework.[14] Table 4 presents a first set of results obtained from the GDP per capita level specification. In order to identify the sum-of-distances and population density measures, country fixed effects have to be removed and, therefore, the first two columns include country effects, whereas the last two do not.[15] This first set of results indicates that the effect of proximity is robust to the various measures. Market potential, the weighted sum of market and supplier access, and the sum of distances are all highly significant with the expected sign, with only population density not having any strong link to GDP per capita.[16] This confirms that, as expected from the previous section, population density is a much weaker indicator of proximity to markets than the other three. Based on the estimates related to the sum of distances (which do not control for country fixed effects), an increase of 10% in the distances to all countries triggers a decrease of 2.1% in GDP per capita.[17]

Table 4. **Basic framework with proximity variables**[1]

Dependant variable GDP per capita	Level AR(1)			
	(1)	(2)	(3)	(4)
Physical capital	0.178***	0.174***	0.178***	0.156***
	(0.020)	*(0.019)*	*(0.020)*	*(0.024)*
Human capital	0.313***	0.317***	0.928***	0.813***
	(0.115)	*(0.122)*	*(0.070)*	*(0.051)*
Population growth[2]	–0.003	–0.005	–0.006	–0.014
	(0.018)	*(0.018)*	*(0.023)*	*(0.028)*
Market potential	0.086***			
	(0.023)			
Weighted sum market and supplier access		*0.056****		
		(0.015)		
Sum of distances			–0.210***	
			(0.023)	
Population density				0.008
				(0.005)
Rho[3]	0.863	0.882	0.946	0.913
Fixed effects				
Country	Yes	Yes	No	No
Year	Yes	Yes	Yes	Yes
Sample size				
Total number of observations	696	696	696	696
Number of countries	21	21	21	21

Note: Standard errors are in brackets. *: significant at 10% level; ** at 5% level; *** at 1% level.

1. The functional form corresponding to the "level" specification is reported earlier in the text. Standard errors are robust to heteroscedasticity and to contemporaneous correlation across panels.
2. The population growth variable is augmented by a constant factor ($g + d$) designed to capture trend growth in technology and capital depreciation. This constant factor is set at 0.05 for all countries.
3. *Rho* is the first-order auto-correlation parameter.

In order to test the robustness of the proximity effects across specifications, the following results focus on the indicator that rests more firmly on sound theoretical grounds, *i.e.* market and supplier access. The first three columns of Table 5 add the weighted sum of market and supplier access to the specifications shown in columns 1 to 3 of Table 1, respectively. Market and supplier access is always highly significant, being robust to the inclusion of country and year dummies, as well as country specific time trends. Moreover, the estimate for the access variable is around 0.06-0.07 in all cases, while the parameters for human and physical capital are mostly unchanged compared with Table 1.[18] This result suggests than the impact of centrality to markets acts on top of these usual determinants. Also, the fact that excluding the country effects does not alter the parameter significantly means that the access effect is identified by the variation through time as well as across countries.

The estimated effect of access is fairly robust to the treatment of physical capital, human capital and the access variables as being potentially endogenous (column 4).[19] Finally, in the last column, the error correction specification is tested using the pooled mean group estimator. Here again, the impact of centrality seems to be orthogonal to the other dimensions, although the level of the parameter is somewhat higher.

Figure 3 presents the contribution of market and supplier access to GDP per capita for the 2000-04 period, based on the estimates in columns 1 and 5, which are representative of the level and error-correction specifications respectively. Unsurprisingly, Australia and New Zealand are the big losers from their geographic position. To a lesser extent, Greece, Portugal and Finland suffer compared with the average country. The beneficiaries are core European countries, especially Belgium and the Netherlands. As noted above, the order of magnitude of the geography effects varies substantially depending on the specifications. For example, market and supplier access is estimated to penalise Australia and New Zealand by around 11% of GDP in the level specification. The effect would be almost three times as large based on the error-correction specification, which is hardly plausible. Conversely, Belgium and the Netherlands benefit by around 6-7% compared with the average country in the level framework and by 16-18% in the error correction one.

Transport costs

In this section, the influence of proximity to large markets on GDP per capita is examined through the working of a direct channel: transportation costs. The cost of transporting goods is obviously closely linked to distance. However, shifts in modes of transport, technological improvements in long-distance shipping and changes in fuel costs have influenced the relationship between geographic distance and economic distance. To some extent, the impact of transport costs was implicitly captured in the measures of market and supplier access derived in the previous section. Nevertheless, the development of indicators of transport costs allows for assessing directly their impact on trade and GDP per capita, separately from other factors affecting market access, such as variations in the degree of openness to trade across various foreign markets as well as over time.

Transport costs constitute only one source of total trade costs, albeit an important one. According to recent estimates, broadly defined trade costs of "representative" goods expressed in *ad valorem* tax-equivalent terms can be as high as 170% in industrialised countries (Anderson and van Wincoop, 2004) with transport costs amounting to 21%, the rest being accounted for by border-related trade barriers (44%) and retail and wholesale

Table 5. **Sensitivity of proximity effects across specifications**[1]

Dependant variable GDP per capita	Level AR(1)	Level AR(1)	Level AR(1)	Level AR(1)	Error correction model
	(1)	(2)	(3)	(4)	(5)
Common parameters					
Physical capital	0.174***	0.166***	0.188***	0.171***	0.307***
	(0.019)	(0.019)	(0.017)	(0.060)	(0.032)
Human capital	0.317***	0.750***	–0.069	0.855***	0.902***
	(0.122)	(0.075)	(0.149)	(0.208)	(0.186)
Population growth[2]	–0.005	–0.008	–0.002	0.005	–0.411***
	(0.018)	(0.022)	(0.018)	(0.019)	(0.067)
Weighted sum of market and supplier access	0.056***	0.066***	0.064***	0.091**	0.131**
	(0.015)	(0.009)	(0.016)	(0.044)	(0.054)
Rho[3]	0.882	0.952	0.820	0.868	
Country-specific parameters					
Lambda[4]					–0.176***
					(0.024)
Time trend	No	No	Yes	No	Yes
Fixed effects					
Country	Yes	No	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	No
Sample size					
Total number of observations	696	696	696	696	695
Number of countries	21	21	21	21	21
First stage regressions[5]					
Hausman test				$\chi^2(4) = 12.4$	
				(*P = 0.015*)	
Hansen J-stat				$\chi^2(29) = 5.87$	
				(*P value = 1.00*)	
Physical capital				Shea $R^2 = 0.059$	
				(*P value = 0.238*)	
Human capital				Shea $R^2 = 0.182$	
				(*P value = 0.000*)	
Weighted sum of market and supplier access				Shea $R^2 = 0.092$	
				(*P value = 0.002*)	

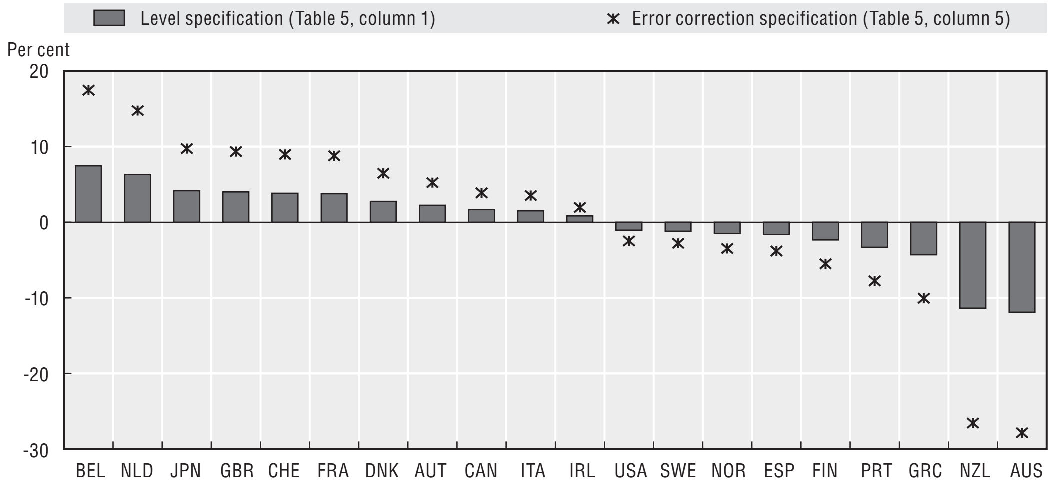
Note: Standard errors are in parentheses. *: significant at 10% level; ** at 5% level; *** at 1% level.

1. The functional forms corresponding to the "level" and "error-correction" specifications are reported earlier in the text. In the level specification, standard errors are robust to heteroscedasticity and to contemporaneous correlation across panels. In the error-correction specification, only long term parameters are reported.
2. The population growth variable is augmented by a constant factor ($g + d$) designed to capture trend growth in technology and capital depreciation. This constant factor is set at 0.05 for all countries.
3. *Rho* is the first-order auto-correlation parameter.
4. The parameter *lambda* is the average of the country-specific speed adjustment parameter, λ_i.
5. The instruments used in column (4) are $Z_{it} = Distsum_i.h_t$ where the h_t are time dummies. The tests reported for the Instrumental Variables estimator read as following. The Hausman test is a joint test of exogeneity of physical capital, human capital and market and supplier access. Exogeneity is rejected and this is due to human capital only (this is seen when including residuals from the first-stage regressions in the main equation). The over-identification test is the Hansen test. It is computed without the AR(1) process for the residuals. For first-stage regressions, Shea partial R^2 (*i.e.* based on the excluded instruments only) are reported for each potentially endogenous regressor, along with the *P-value* of the F-test. These statistics reveal that weak instruments could be an issue for physical capital only.

distribution costs (55%).[20] Excluding distribution, transport costs would on the basis on these estimates account for about one-third of international trade costs. This covers the contribution of both direct (freight charges including insurance) and indirect (holding cost for transit, inventory costs, *etc.*) transport costs. The empirical analysis presented in this section is based on estimates of freight charges for air, maritime and road transportation

Figure 3. **Estimated impact of market and supplier access on GDP per capita**[1]

Deviation from average OECD country in 2000-04



1. Contributions of market and supplier access to GDP per capita are based on Table 5. They are computed as differences to the average country and on average over the period 2000-04. For example, based on the estimate from the level specification, the favourable access to world markets that Belgium benefits from compared with the average country would contribute to as much as 6.7% of its GDP. Because of a break in the series due to the reunification, data for Germany were used only for the period 1970-89. Therefore, Germany is not included in the figure.

of merchandise. Indirect costs, which are usually inferred from trade flow regressions rather than directly observed, are not covered. In addition, the cost of international telecommunications is considered insofar as it affects trade in services and, to a lesser extent, trade in goods *via* its impact on back-office operation, financing, etc.

The rest of the section provides some details on the construction of an index of overall transport costs and its three main components, as well as the cost of international telecommunications, for the 21 OECD countries included in the empirical analysis reported in the previous sections. Given the limited availability of data covering both the time-series and cross-section dimensions in a consistent and comparable fashion, a number of key assumptions are required in order to build a comprehensive dataset. The impact of transport costs on GDP per capita is then examined both *via* its impact on exposure to cross-border trade and directly as an added determinant in the basic framework used in earlier sections.

Evolution of transport and telecommunications cost indices

Methodology and data sources

The construction of an aggregate index of transportation costs covering air, maritime and road components requires information about the costs for shipping goods between bilateral locations for each mode of transport, with the respective costs measured in the same units to allow for aggregation. In addition, the construction of country-specific indices requires that the respective costs be weighted so as to reflect the relative importance of each trading partner as well as of each mode of transport. In principle, trade flow data could be used to construct weights that are consistent with the actual distribution of goods shipped according to the mode of transport and bilateral destinations. Doing so, however, would make the aggregate index endogenous to the individual costs and is therefore avoided. The indicators of transportation costs used in this paper are taken directly from Golub and Tomasik (2008), which provides details regarding raw data availability, sources, assumptions made and results. The main features can be summarised as follows:

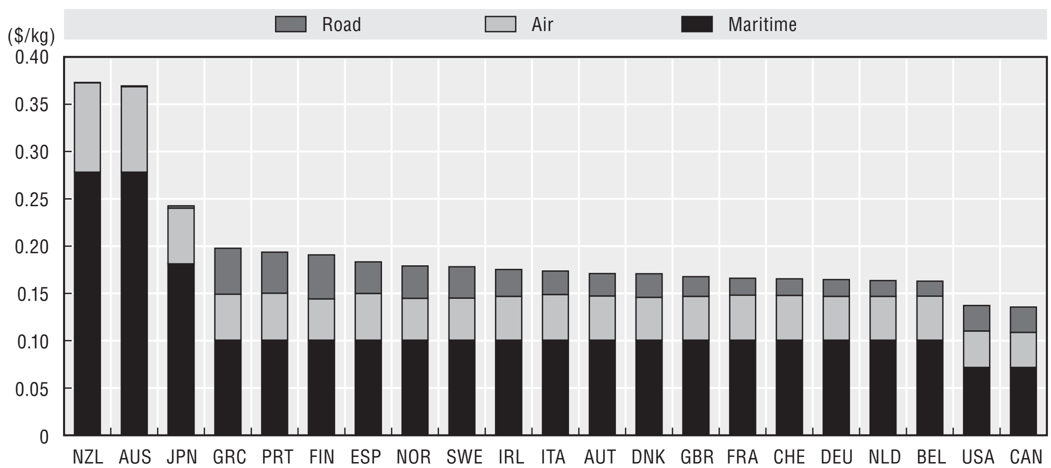
- The basic cost of each mode of transportation between any two locations is measured in US dollars per kilogramme shipped, and the cost of maritime shipping is assumed to be the same for countries within a broad region (*e.g.* for all EU countries *vis-à-vis* other broad regions).
- For each country, the costs of shipping goods to each bilateral destination are aggregated on the basis of GDP weights of partner countries (including a country's own GDP), as was the case for the indicator of market potential discussed in the previous section. The main reason for preferring GDP weights as opposed to actual trade weights is to avoid the endogeneity of trade patterns with respect to trade costs.
- The relative importance of each mode of transport in moving goods across locations is based on a mixture of assumptions and hard data that are available for a few countries. The key assumption made in this context is that all trade between "neighbours" is assumed to take place *via* road transportation.
- The nominal aggregate index of transport cost, expressed in dollars per kilogramme, is deflated using either the US GDP deflator or the US price index of manufacturing goods.

Results

The overall indicator of transport costs over the period 2000-04 is shown in Figure 4 for 21 OECD countries. The figure also provides the contribution of each of the three main sub-components to the overall cost. Individual countries can be regrouped into four blocks on the basis of their overall costs. Not surprisingly, transport cost is highest for Australia and New Zealand with a cost over 2½ times that observed in North America. This is followed by Japan which forms a group on its own, but at a level that is substantially lower than observed for the first group. The indicator shows similar costs for European countries, with only slightly higher values observed in peripheral countries, reflecting higher road transport costs. At the other end, transport costs are lowest in Canada and the United States, owing largely to a lower contribution from maritime freight charges. In fact, the

Figure 4. **Overall transport costs and contribution from three sub-components**

Deflated by US GDP deflator (2000 = 1), average 2000-04

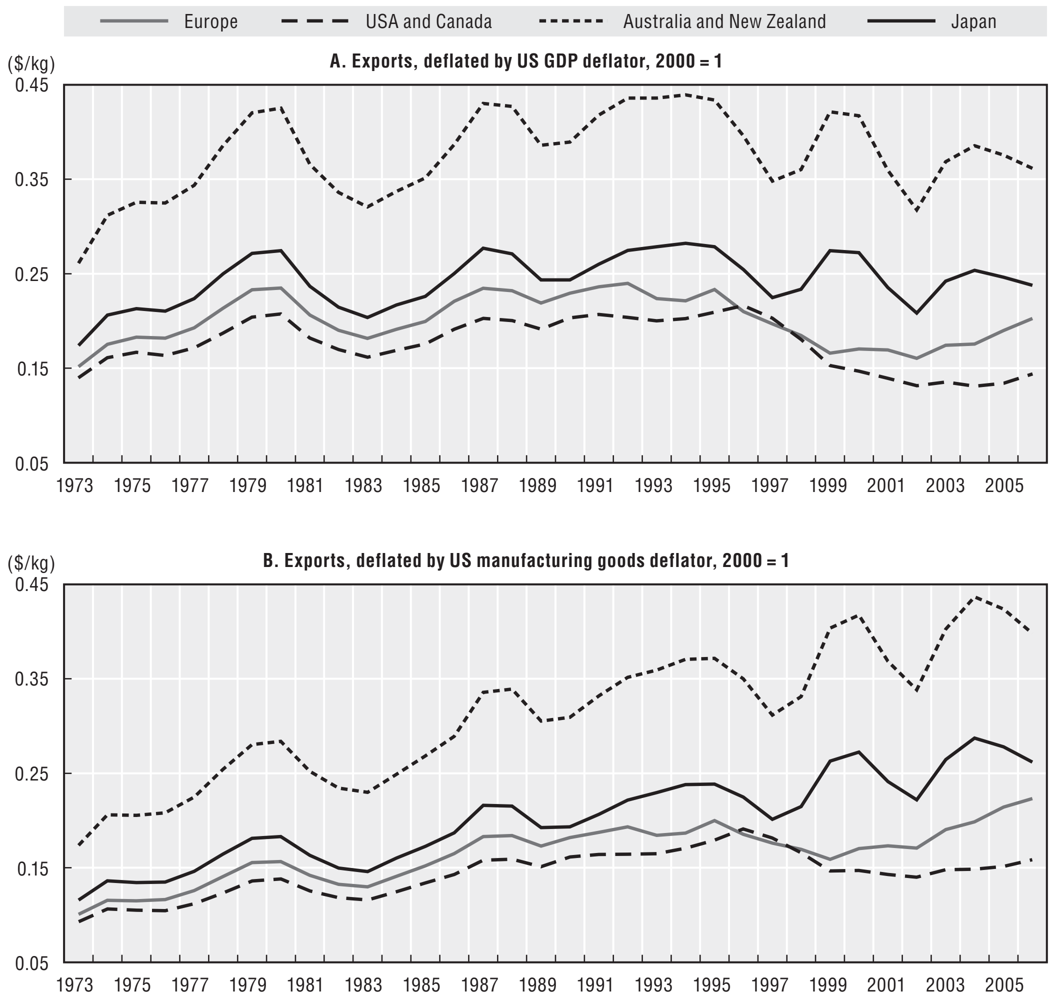


Source: Golub and Tomasik (2008).

maritime component accounts for the largest portion of the variation in the overall costs across the four groups of countries.

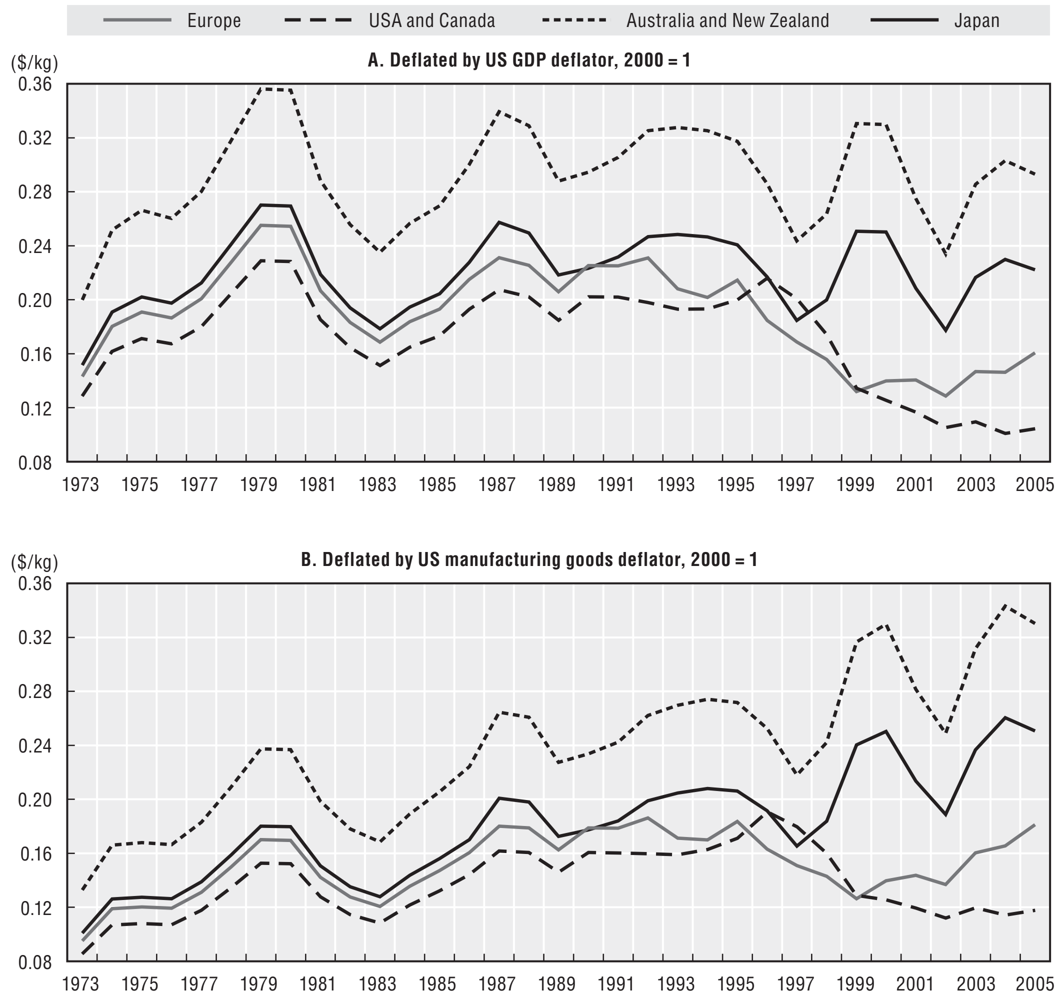
As regards the evolution of overall transport costs over time, a different picture emerges depending on whether the series are deflated by the US GDP deflator or by the US price index of manufacturing goods. On the latter basis, there is a clear upward trend in the four groups of countries throughout the sample period – though with somewhat different slopes – whereas no clear trend appears for the series based on the broader deflator, at least not since the 1970s (Figure 5). In both cases, the profile reflects to a large extent the contribution from maritime shipping costs (Figure 6). Looking more closely at the profile of maritime transport costs what stands out is the widening discrepancy since the mid-1990s between the cost for shipping goods from Asia, which have gone up in real terms, and those for goods shipped from Europe or North America, which have fallen. The break from the earlier pattern which saw the costs in the three zones moving roughly together coincides with the emergence of large trade imbalances. The sharp rise in exports from East Asia has led to capacity bottlenecks in the major ports of that region while containers are returned to Asia half empty.

Figure 5. **Total average transport cost**



Source: Golub and Tomasik (2008).

Figure 6. **Average maritime transport cost**



Source: Golub and Tomasik (2008).

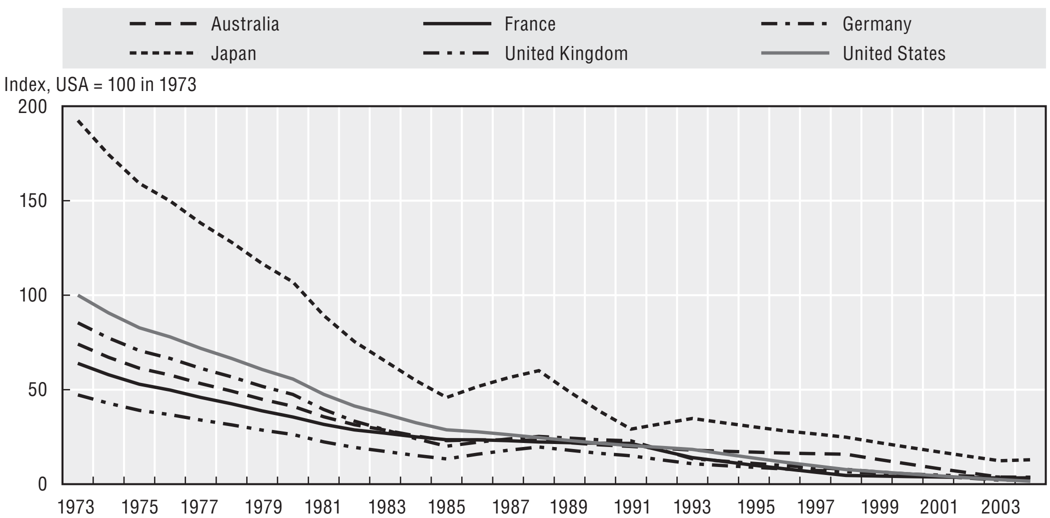
To summarise, the perception that the relative influence of costs related to distance is fast diminishing is not supported, at least not by recent trends in international shipping costs.[21] This apparent puzzle was already noted in earlier studies (in particular Hummels, 2006). In the case of maritime transport, special factors such as rising fuel prices and port charges may have played a role in offsetting the gains from technological improvements. Moreover, studies based on micro data (Blonigen and Wilson, 2006) that compare prices for shipping similar goods and similar maritime routes but *via* different modes (*i.e.* using containers or not), suggest that the benefit from containerisation may not be as large as presumed (all else being equal).

In any case, firm conclusions in this area need to be qualified due to limitations of data availability and measurement. It is not clear how data on road transport, for instance, reflect the gains in quality terms such as those from the use of global positioning systems which allows for precise tracking of the material in transit. In a similar vein, measured price indices for ocean shipping may not adequately reflect improvement in the service provided, for instance time savings brought about by containerisation. And, the importance of time as a trade barrier has been stressed in earlier studies (Hummels, 2001; Nordås, 2006; Nordås *et al.*, 2006). More generally, all transportation modes have benefited from progress in information and communication technology as well as from a better integration *via* intermodal systems. Taken at face value, the absence of a decline in the weight-based measures of real cost of transport (*i.e.* nominal costs deflated by the manufacturing price index) suggests that there may have been less technological progress in transportation than in manufacturing. However, due to innovations outside the transport sector, the composition of traded goods has changed significantly over the past decades, and many valuable goods are now relatively light, *e.g.* electronic chips. Consequently, transport costs may well have fallen relative to the value of transported goods.[22]

One area where the presumed death of distance does not seem to be at all exaggerated is international telecommunications since costs in this area have fallen in all countries to the point where they are no longer significant anywhere (Figure 7). In fact, historical data indicate that the substantial cross-country variations that still prevailed in the early 1970s had largely disappeared by the late 1980s, and since then the downward trend has continued, bringing costs to basically zero during the early 2000s. It should be noted, however, that this indicator only captures one type of telecommunications and therefore the treatment of this aspect of distance is covered too narrowly for firm conclusions to be drawn.[23] Nonetheless, this result would suggest that countries that are particularly affected by their distance to market may wish to ensure that their ICT networks are particularly well developed – not least by getting their regulatory frameworks right – so as to fully exploit the benefits from trading in the types of services where physical distance matters little.

Figure 7. **Real cost of one minute international telephone call from selected origin countries**

Deflated by US GDP deflator



Source: Golub and Tomasik (2008).

Impact of transport costs on openness to trade and GDP per capita

The impact of transport costs on GDP per capita is assessed both indirectly *via* their effects on individual countries' exposure to international trade and more directly as an additional determinant in the basic growth equation. The first set of regressions examines the impact of transportation costs through their effect on international trade openness (Table 6). This approach is based on the presumption that transportation costs matter for

Table 6. **Basic framework with openness to trade**[1]

Costs of transport and international communications used as an instrument for trade openness

Dependant variable GDP per capita	Level AR(1)	Level AR(1)	Level AR(1)	Level AR(1)	Level AR(1)	Level AR(1)
		IV		IV		IV
	(1)	(2)	(3)	(4)	(5)	(6)
Physical capital	0.175***	0.171***	0.164***	0.218***	0.208***	0.196***
	(0.020)	(0.022)	(0.023)	(0.030)	(0.021)	(0.022)
Human capital	0.234*	–0.273	0.740***	0.724***	0.210*	0.221**
	(0.122)	(0.324)	(0.058)	(0.068)	(0.112)	(0.112)
Population growth[2]	–0.016	–0.018	–0.038	–0.033	–0.028	–0.044*
	(0.023)	(0.025)	(0.031)	(0.029)	(0.025)	(0.026)
Trade openness	0.035*	0.029	0.048***	0.107***	0.068***	0.106***
	(0.020)	(0.061)	(0.017)	(0.040)	(0.020)	(0.039)
Rho[3]	0.886	0.890	0.941	0.954	0.844	0.855
Time trend	No	No	No	No	Yes	Yes
Fixed effects						
Country	Yes	Yes	No	No	Yes	Yes
Year	Yes	Yes	Yes	Yes	No	No
Sample size						
Total number of observations	633	633	633	633	633	633
Number of countries	21	21	21	21	21	21
	First stage regressions for the Trade openness variable[4]					
Excluded instruments						
Overall transport costs		–0.473**		–0.683***		–0.144**
		(0.233)		*(0.065)*		*(0.062)*
Costs of international communications		0.023		–0.148***		–0.009
		(0.024)		*(0.030)*		*(0.027)*
Sum of distances (average through time)		–0.018***		–0.004**		–0.027***
		(0.004)		*(0.002)*		*(0.002)*
Statistical tests						
Hausman test		?^{2}(1) = 2.76		?^{2}(1) = 3.57		?^{2}(1) = 5.10
		(P = 0.096)		*(P = 0.059)*		*(P = 0.024)*
Hansen J-stat		?^{2}(31) = 23.8		?^{2}(31) = 10.3		?^{2}(31) = 31.2
		(P value = 0.820)		*(P value = 1.000)*		*(P value = 0.458)*
Partial R^2		Shea R^2 = 0.062		Shea R^2 = 0.152		Shea R^1 = 0.190
		(P value = 0.917)		*(P value = 0.000)*		*(P value = 0.000)*

Note: Standard errors are in parentheses. *: significant at 10% level; ** at 5% level; *** at 1% level.

1. The functional form corresponding to the "level" specification is reported earlier in the text. Standard errors are robust to heteroscedasticity and to contemporaneous correlation across panels.
2. The population growth variable is augmented by a constant factor ($g + d$) designed to capture trend growth in technology and capital depreciation. This constant factor is set at 0.05 for all countries.
3. *rho* is the first-order auto-correlation parameter.
4. The instruments used in columns 2, 4 and 6 are overall transport costs, costs of international communications and $Z_{it} = Distsum_i.h_t$ where the h_t are time dummies. The tests reported for the Instrumental Variables estimator read as following. The Hausman test is a test of exogeneity of the trade variable. The over-identification test is the Hansen test. It is computed without the AR(1) process for the residuals. For first-stage regressions, Shea partial R^2 (*i.e.* based on the excluded instruments only) is reported for the potentially endogenous regressor, along with the *P-value* of the F-test.

GDP per capita only insofar as they matter for openness and that trade contributes to GDP. In order to assess the contribution of international trade to GDP per capita, a measure of exposure to international trade (trade openness) is first added as a determinant in the augmented-Solow model.[24]

The results appear in columns 1, 3 and 5 of Table 6, where the specifications vary only according to the combination of fixed-effects and/or time trend included. The coefficient on trade openness is positive and significant in all three cases – albeit only at the 10% level in the first case – and varies from 0.035 when both year and country fixed-effects are included (column 1) to twice that size when a time trend is included instead of year fixed-effects (column 5). The coefficients on the other variables do not vary much across specifications, except in the case of human capital, where the coefficient shows the same sensitivity to the treatment of fixed effects as reported in previous sections. A comparison of Table 6 with the first three columns of Table 1 also shows that adding the trade variable does not have much impact on the parameter values of physical and human capital.

Taken at face value, these results provide evidence that greater openness to trade leads to higher GDP per capita. However, it has long been recognised that given the uncertainties as regards the direction of causality, the introduction of trade as an additional determinant in the Solow model cannot be used as conclusive evidence of a positive influence on GDP per capita, regardless of the apparent size and statistical significance of the estimated parameter.

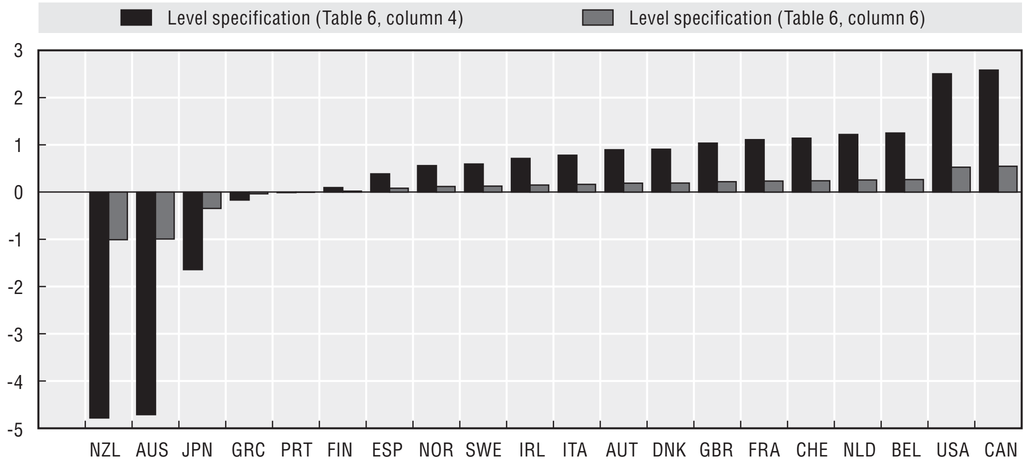
To address the endogeneity problem, an instrumental variable (IV) procedure is adopted, allowing for the indicator of overall transport costs and the cost of international telecommunications to be used as instruments for the measure of openness to international trade in the augmented Solow model. The sum of distance, defined in the previous section, is also used as an instrument.[25] The procedure is similar to that used in the third section and the results are reported in columns 2, 4 and 6 of Table 6. The estimated effect of (instrumented) trade openness on GDP per capita (second stage reported in the top panel) is significant in two of the three specifications (columns 4 and 6), and the estimated coefficient is in these cases higher than when actual trade openness is used (columns 3 and 5). However, this result no longer holds if one controls for both country and year fixed effects, where the coefficient on trade openness is not significant (column 2).[26] As for the results from the first-stage regression (bottom panel), they show that overall transport costs have a significant (negative) impact on trade openness in all three IV specifications, although with large variations in the parameter estimates.

Overall, these results indicate that transportation costs contribute to reduce the exposure to international trade and that in turn the latter appears to have a significant impact on GDP per capita. In contrast, the effect of international telecommunications on trade openness is significant only when country fixed effects are not included, and therefore the evidence is much weaker. The results from the IV procedure provides some evidence that trade openness may have a causal influence on GDP per capita, consistent with earlier findings (*e.g.* Frankel and Romer, 1999).

Against this background, the contribution of transport costs to GDP per capita is reported in Figure 8. In order to provide a range of estimates, the contribution is calculated on the basis of coefficients obtained from two specifications based on Table 6 (columns 4 and 6, respectively). On this basis, high transport costs relative to the OECD average are found to reduce GDP per capita by between 1.0% and 4.5% in Australia and New Zealand, where the effect is largest. At the other end, the lower transport costs for Canada and the United States contribute to raise GDP per capita by between 0.5% and 2.5%.

Figure 8. **Estimated impact of transportation costs on GDP per capita**[1]

Deviation from average OECD country in 2000-04



1. Contributions of market and supplier access to GDP per capita are based on Table 6. They are computed as differences to the average country and on average over the period 2000-04. Because of a break in the series due to the reunification, data for Germany were used only for the period 1970-89. Therefore, Germany is not included in the figure.

Overall economic impact and policy implications

Overall impact

In order to summarise the contribution of proximity to markets to GDP per capita over the whole period, Table 7 uses the parameters estimated from the preferred specification, *i.e.* column 1 of Table 5. In each case, the contribution is measured relative to the average country, and is reported both as an average over the period 2000-04 and as a change since 1970.

Three main results emerge from these calculations. First, as mentioned earlier, the order of magnitude of the impact of remoteness is important, ranging from around –11% of GDP for Australia and New Zealand to +6% for Belgium and the Netherlands. Second, these effects have not changed much over the period, reflecting that geographic factors are generally stable over time. Nevertheless, it seems that the unfavourable position of Oceanic countries has deteriorated somewhat over time, while economic integration has moved Spain, Portugal and Canada closer to central markets.

An alternative way to assess the explanatory power of the geography variables is to compare the standard deviation of the fixed effects before and after the inclusion of these variables. In the augmented Solow model, these country fixed effects account for 72% of the cross-country variance in GDP per capita (Table 8).[27] When geography variables are included, the variance explained by the fixed effects is reduced from 72% to 60%.

The country fixed effects may in this regard be interpreted as the estimated difference in productivity levels relative to the average country and on average over the whole period of estimation. Based on the standard augmented-Solow model (*i.e.* ignoring geography), the estimated country fixed effects put Australia slightly above the average country, while New Zealand lags by 25%. Once geography is controlled for, Australia moves 13% ahead, suggesting that it has managed to overcome the effect of its unfavorable location, whereas New Zealand remains behind the average country, but only by 14%. Taking geography determinants into account does not change the relative position of the United States, which lies 15% ahead of the

Table 7. **Impact of market and supplier access on GDP per capita**[1]

In per cent

	Market and supplier access	
	Difference to average country in 2000-04	Change since 1970
Parameter	*(0.056)*	*(0.056)*
Australia	–11.8	–1.6
Austria	2.1	–0.5
Belgium	7.5	0.2
Canada	2.4	1.3
Denmark	2.5	0.6
Finland	–2.7	–0.7
France	3.8	0.2
Greece	–4.1	0.1
Ireland	0.7	–0.6
Italy	1.4	0.0
Japan	3.3	1.1
Netherlands	6.3	1.0
New Zealand	–11.3	–1.1
Norway	–1.7	–0.2
Portugal	–3.0	1.3
Spain	–1.4	1.5
Sweden	–1.5	–0.8
Switzerland	3.6	–1.2
United Kingdom	4.2	–1.1
United States	–0.3	0.5
Minimum	*–11.8*	*–1.6*
Maximum	*7.5*	*1.5*
Average	*0.0*	*0.0*

1. In order to evaluate the impact of access to markets on GDP per capita, the parameters used are those obtained from Table 5, column 1. Based on these estimates, and taking Australia as an example, the table should be read as follows: compared with the average country in the sample, the distance to markets of Australia contributes to lowering its GDP per capita by 11.8% on average over the 2000-04 period. This is an addition of 1.6 points relative to the same contribution calculated for 1970. Because of a break in the series due to the reunification, data for Germany were used only for the period 1970-89. Therefore, Germany is not included in the table.

average country. Also, the estimated favorable fixed effects for Belgium and Netherlands in the augmented-Solow framework appear to be almost entirely due to centrality.[28]

Policy implications

The economic-geography effects discussed above imply that GDP-per-capita or productivity gaps cannot on their own be used as a measure of unfinished business of policy. Adopting best practice policy across all policy areas will not allow some countries to attain best performance because they are penalised by their location; others may be able to attain very high levels of performance without aligning their policies on best practice. This section briefly reviews some of the policy issues linked to unfavourable geographical location: how best to minimise the costs due to distance and whether the effectiveness of some structural policies are affected by remoteness.

Minimising the cost of distance

The high cost of distance, up to 10% of GDP, raises the question of whether public subsidies to transportation are warranted to reduce shipping costs for companies and individuals. Indeed, if distance has negative externalities, there would seem to be a

Table 8. **Size of country fixed effects and share of variance explained by fixed effects**[1]

	Average GDP per capita, 1970-2004 (deviation from the OECD average)	Fixed effects Augmented-solow Table 1, column 1	Fixed effects Augmented-Solow + geography Table 5, column 1
Australia	7.9	1.9	13.3
Austria	8.5	5.2	2.8
Belgium	4.0	7.3	–0.5
Canada	12.2	7.2	5.4
Denmark	11.3	10.8	8.1
Finland	–3.5	–4.1	–2.0
France	7.6	9.5	5.3
Greece	–30.8	–26.0	–22.5
Ireland	–20.6	–13.0	–14.2
Italy	0.2	6.9	4.9
Japan	–4.2	–13.2	–16.2
Netherlands	6.5	7.0	0.7
New Zealand	–21.1	–24.6	–13.7
Norway	27.9	22.7	24.0
Portugal	–44.6	–36.3	–33.6
Spain	–21.1	–10.1	–9.0
Sweden	13.7	15.4	16.1
Switzerland	29.1	21.9	17.8
United Kingdom	–0.4	3.0	–2.0
United States	17.5	14.6	15.2
Standard deviation	*0.191*	*0.161*	*0.147*
Variance	*0.036*	*0.026*	*0.022*
Share of variance		*0.716*	*0.599*

1. Because of a break in the series due to the reunification, data for Germany were used only for the period 1970-89. Therefore, Germany is not included in the table.

prima facie case for public intervention to correct such externalities. Budgetary subsidies for urban passenger transportation are common in many OECD countries, but are rare for long-distance, notably cross-border, transportation of goods. However, long-distance transportation already benefits from large implicit subsidies. Most importantly, many transportation activities result in environmental damage, and transportation companies and their clients are not charged for this degradation. This is notably the case for air pollution and greenhouse gas emissions in some modes of transportation where regulations on emissions are lax and fuel use is lightly taxed, air and maritime transportation being prime examples. In most countries, road transportation also benefits from not having to pay for the congestion it causes and free access to the road network. Any decisions to provide additional subsidies to transportation would also have to take into account the cost of raising funds for this purpose, and the risk of failure in managing such subsidies.

The authorities can also ensure that prices of transportation services are not inflated by regulations that reduce efficiency and increase costs. Traditionally, transportation sectors have been heavily regulated and exempted from standard competition legislation with adverse effects on costs. Over the past decades, regulations in domestic markets have been eased substantially, especially in road and air transportation (Conway and Nicoletti, 2006). However, cross-border freight transportation is still subject to extensive regulations. Competition pressures in international air routes often remain fairly weak due to restrictive bilateral air service agreements and limits to ownership of national carriers.

Road transportation on many international routes is hampered by lack of "cabotage" rights. And international scheduled maritime freight services are still operated as price-setting cartels on many key routes, reflecting that this activity is exempted from national competition legislation in many OECD countries. Moreover, port efficiency varies widely across countries and affects shipping costs significantly, in part due to regulatory restrictions hampering competition in port services (Clark, Dollar and Micco, 2004).

Distance and the effectiveness of structural policies

Remoteness can in principle influence the effectiveness of some structural policy measures, with implications for policy choices. A possible interaction between policy and distance is that a given policy change to strengthen competition in domestic product markets may have a weaker influence in remote countries than in countries close to large markets, even if such reforms are arguably more needed in the former group of countries as they have limited alternatives to enhance competition. In countries at a large distance from world markets, there may not be room for many competitors in some sectors if the efficient scale of operation is close to the size of the market. In such circumstances the lifting of statutory entry barriers may not stimulate entry, as the size of the market will *de facto* restrict the number of competitors. On the other hand, if legal entry barriers are the binding constraint on entry as seems more likely in countries close to world markets, then lowering such barriers should stimulate competition. Notwithstanding the intuitive appeal of such arguments, no evidence that distance significantly interacts with a measure of competition-restraining regulations could be found on the basis of an admittedly crude empirical investigation. Indeed, the first three columns of Table 9 show, first, that both product market regulation and access to markets remain significant when they are jointly included in the basic equation and, second, that the interaction between regulation and proximity is not significant.

Another area where the effectiveness of policies might be expected to vary depending on distance is R&D spending.[29] Such activity is likely to involve significant fixed costs and thus be subject to economies of scale. With distance limiting the size of the market, the unit cost of innovation can be expected to be higher in remote countries than in countries close to large markets where fixed costs can be spread more widely. Another related channel is the reduced incentives for large multinational firms to establish a commercial presence in remote markets, due to the limited development possibilities. Since multinational firms are the main carriers of innovation to other markets, the impact of domestic R&D spending on growth in foreign markets is limited by their absence in smaller remote markets. Hence, a given increase in public and/or private R&D spending is likely to have a greater leverage and therefore a greater GDP-per-capita impact in countries with short distance to markets than in more remote countries. Furthermore, insofar as the effectiveness of public and/or private R&D can be influenced by the strength of industry and science linkages or by close interactions between researchers from various institutions, the impact of R&D on GDP per capita may vary according to the extent of urban concentration within a country.

These possibilities are examined *via* the introduction in the estimated equation of two interaction terms, one between private R&D and distance and the other between private R&D and the share of the country population living in cities of more than 1 million inhabitants (urban concentration). A measure of R&D intensity (business R&D as a ratio of GDP) is first introduced as an additional determinant in the augmented Solow model

Table 9. **Geography and the effectiveness of structural policies**[1]

Dependant variable GDP per capita	Level AR(1) (1)	Level AR(1) (2)	Level AR(1) (3)	Level AR(1) (4)	Level AR(1) (5)	Level AR(1) (6)	Level AR(1) (7)	Level AR(1) (8)
Physical capital	0.209***	0.199***	0.199***	0.222***	0.213***	0.221***	0.218***	0.222***
	(0.021)	(0.021)	(0.021)	(0.023)	(0.023)	(0.023)	(0.023)	(0.022)
Human capital	0.240***	0.263***	0.231***	0.203**	0.223**	0.366***	0.469***	0.579***
	(0.087)	(0.086)	(0.088)	(0.090)	(0.095)	(0.115)	(0.118)	(0.134)
Population growth[2]	–0.031	–0.027	–0.028	0.018	0.019	–0.009	–0.012	–0.011
	(0.021)	(0.021)	(0.028)	(0.035)	(0.035)	(0.022)	(0.023)	(0.023)
Weighted sum market and supplier access		0.054***	0.052***		0.041**	0.038**	0.048**	0.041**
		(0.018)	(0.018)		(0.021)	(0.019)	(0.020)	(0.020)
PMR[3]	–0.035*	–0.038*	–0.035*					
	(0.019)	(0.020)	(0.020)					
PMR * Population density		0.007						
		(0.007)						
PMR * Weighted sum market and supplier access			–0.003					
			(0.010)					
Business R&D[4]				0.027*	0.031*			
				(0.015)	(0.016)			
Business R&D * Urban concentration					0.114**			
					(0.056)			
Business R&D * Weighted sum market and supplier access					0.007			
					(0.009)			
Human capital * Urban concentration[5]						0.927***		1.341***
						(0.193)		(0.251)
Human capital * Population density[6]							–0.129***	–0.219***
							(0.035)	(0.047)
Time trend	0.017***	0.017***	0.017***	0.020***	0.020***	0.018***	0.017***	0.017***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Rho[7]	0.843	0.844	0.861	0.857	0.853	0.831	0.827	0.846
Fixed effects								
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample size								
Total number of observations	595	595	595	344	344	696	696	696
Number of countries	21	21	21	21	21	21	21	21

Note: Standard errors are in parentheses. *: significant at 10% level; ** at 5% level; *** at 1% level.

1. The functional form corresponding to the "level" specification is reported earlier in the text. Standard errors are robust to heteroscedasticity and to contemporaneous correlation across panels. All interaction variables are constructed from the demeaned respective variables. That way, the estimated parameters on the non-interacted variables still measure the average effect of these variables.
2. The population growth variable is augmented by a constant factor ($g + d$) designed to capture trend growth in technology and capital depreciation. This constant factor is set at 0.05 for all countries.
3. PMR is the product market regulation index which is built in a 0-6 scale. It is introduced in logs.
4. Due to limitations in data, the sample for regressions involving R&D spending is substantially reduced. This is because data on R&D are generally only available from 1981 to 2003/04, and 6 of the 21 countries do not have sufficiently long series to be included. Note also that private R&D is entered in the regression with one lag.
5. Urban concentration is the share of the country population living in cities of more than 1 million inhabitants.
6. Population density measure is the ratio of population to surface area.
7. *Rho* is the first-order auto-correlation parameter.

(column 4), where it comes out significant (although at the 10% confidence level). The specification with the two interaction terms is then shown in column 5 of Table 9, where the results suggest that the effectiveness of private R&D intensity is significantly influenced by the degree of urban concentration, but not by distance to major markets.[30]

A third policy area where geographic factors might be important is human capital formation. In this case, however, the relevant geographic factor is not distance to world markets but rather economic density, in particular the degree of agglomeration. A hypothetical benefit of agglomeration is that there are strong knowledge spillovers associated with proximity, whereby "tacit" or informal knowledge is transmitted *via* face-to-face contact. To the extent that such kind of knowledge is related to cognitive skills acquired during formal schooling, reforms that strengthen educational performance may have stronger productivity raising effects in densely populated urban centres than in areas where population density is lower. If this were to be the case, countries where the population is concentrated in large urban areas would benefit more from educational reforms than countries where the population settlement is more dispersed. The preliminary empirical evidence, as reported in the last three columns of Table 9, is inconclusive. Taking the estimates at face value, the impact of human capital on GDP per capita seems to be strengthened by urban concentration, whereas the opposite result is obtained when the density measure is the ratio of population to surface area.

Conclusions

This paper examines how much of the dispersion in economic performance across OECD countries can be accounted for by economic geography factors. More specifically, the proximity to areas of dense economic activity has been examined. To do so, various indicators of distance to markets and transportation costs have been added sequentially as determinants in an augmented Solow model, which is used as a benchmark.

Three measures of distance to markets are found to have a statistically significant effect on GDP per capita: the sum of bilateral distances, market potential and the weighted sum of market access and supplier access. And the estimated economic impact, which varies somewhat across specifications, is far from negligible. For instance, the lower access to markets relative to the OECD average could contribute negatively to GDP per capita by as much as 11% in Australia and New Zealand. Conversely, the benefit from a favourable location could account for as much as 6-7% of GDP in the case of Belgium and the Netherlands. The impact of transport costs on GDP per capita is also found to be statistically significant, albeit less so in economic terms. For instance, differences in transport costs relative to the OECD average contribute to reduce GDP per capita by between 1.0% and 4.5% in Australia and New Zealand. At the other end, the lower transport costs for Canada and the United States contributes to raise GDP per capita relative to the average OECD country, but only by a small margin varying between 0.5% and. 2.5%. These quantitatively smaller effects are consistent with transportation costs being only one aspect of distance-related costs.

Considering the substantial estimated effect that distance/proximity to major markets has on GDP per capita, one issue is whether there is a role for public authorities to subsidise international transport, at least in the most remote countries, so as to partly compensate for additional trade costs incurred. Against this, it can be argued that transport is already subsidised in many ways, if only because transport industries only partly bear the cost of negative externalities such as pollution and road congestion. Moreover, subsidisation involves well-known issues of government failure. Less controversial, public policies can also contribute to reduce the cost of transportation by strengthening competition in transport industries, which have in the past been heavily regulated. However, considering that since the mid-1980s domestic regulation has been eased to some extent, at least in air and road transport, further gains in this area may come from reductions in regulatory barriers to cross-border freight transport, an area where less progress has been achieved.

Insofar as distance or remoteness may affect the effectiveness of policy, another policy issue is whether the possibility that what constitutes "best practice" in a particular area may differ across countries. Some tentative estimates of these effects have been conducted with respect to product market regulation, human capital and R&D spending. The preliminary results do not provide strong evidence of an impact of remoteness on the effectiveness of policy in these areas. However, there is some evidence that spending on R&D and human capital might have a stronger effect on GDP per capita in countries with higher urban concentration.

Notes

1. The implications of imposing invalid homogeneity restrictions on slope parameters in the context of dynamic panel estimates are discussed in Lee, Pesaran and Smith (1997).
2. The reason is that the number of determinants that can be jointly estimated is limited by available degrees of freedom and risks of multi-collinearity. Hence, the variables can only be tested sequentially with the number of possible permutations rising exponentially with the set of determinants. Sala-i-Martin *et al.*, (2004) have proposed a bayesian method to deal with this standard problem in empirical growth analysis.
3. In principle, a measure of investment in human capital should be used to be consistent with the treatment of physical capital in the basic Solow model. In practice, a proxy for the stock – average number of years of schooling – is used due to the absence of an adequate measure of the flow. However, to ensure consistency with the theoretical model, the measure of stock is introduced both in level and first-difference forms, even in the "level" specification.
4. Following a standard approach in the literature, this constant factor ($g + d$) is set at 0.05 for all countries (Mankiw *et al.*, 1992).
5. Doing so makes it close to a growth rate or error correction model specification, with constraints imposed on the short-term dynamics (see Beck and Katz, 2004, for further details). In that sense, one minus the first-order correlation parameter can be compared with the annual speed of convergence.
6. For a direct comparison, see the results reported in OECD (2003), Table 2.4, second column, on page 81.
7. In fact, the inclusion of specific trend parameters distorts the notion of convergence, since it should then be interpreted as convergence to a different steady-state growth rate across countries (Lee, Pesaran and Smith, 1997, and Islam, 1998). It is therefore not surprising that in such case the estimated speed of convergence of around 19% per annum is higher than when parameter homogeneity is imposed across countries.
8. The sensitivity of human capital to the treatment of the time trend in either level or error-correction specifications can be partly explained by the fact that it is proxied by a variable (average number of years of schooling) that is characterised by a very smooth upward-trend profile over time.
9. In order to minimise the number of determinants shown separately on the graph, the contribution of population growth is lumped with that of physical capital and the contribution of fixed effects cover both year and fixed effects in the top panel and country fixed effects and time trend in the lower panel.
10. The underlying assumption behind the internal distance $d_{ii} = 2/3\sqrt{area_i/\pi}$ is that a country is a disk where all suppliers are located in the center and consumers are located uniformly over the area. An alternative measure consists in using the largest cities in each country both for external and internal distances. This entails some differences depending on the size of the countries. However, the results in this paper proved to be robust to the choice of the distance definition.
11. When variables are compared in yearly changes over the whole panel rather than in levels, the correlation is still very significant, but falls to 50% and 36% between market potential, on the one hand, and market and supplier access, respectively, on the other hand.

12. In that context, the higher calculated total market potential for Canada than for the United States reflects the specific capital-to-capital measure of distance. Whereas the internal distance for the United States is 1 161 km, the capital-to-capital distance between the two countries is 737 km. Hence, this measure of distance gives the US GDP a greater weight for Canada than for the United States itself. This feature disappears when the distance measure takes into account not only the capital but also the biggest cities in each country (see Boulhol and de Serres, 2008).

13. Redding and Venables apply their framework to a cross-section of 101 countries, while Breinlich (2007), highlighting that regional income levels in the European Union display a strong core-periphery gradient, tests the impact of market access using a panel of European regions over 1975-97. Head and Mayer (2007) conduct a similar exercise based on European sectoral data over a shorter period. Concurrently, Hanson (2005) develops a model assuming labour mobility and tests it using data covering US counties. Combes and Overman (2004) present a survey of studies replicating Hanson's approach for various European countries.

14. Based on a cross-section of 148 countries, an earlier study showed that proximity (market potential) explains a significant fraction of the income pattern even after controlling for the usual determinants in Solow-type regressions (Hummels, 1995).

15. As in the second section (Table 1), the human capital parameter is very sensitive to whether country fixed effects are included.

16. Due to the strong correlation between market and supplier access, the specific effect of each indicator cannot be identified. However, the explanatory variable in the model is a weighted sum of the two indicators, the weights being given by structural parameters; see Boulhol and de Serres (2008) for details.

17. This would imply, for example, that the relatively large distance of Australia from world markets compared with the United States accounts for a GDP-per-capita gap of around 12 percentage points (given the values of the sum-of-distances measure reported in Table 3, $0.21.\ln(214/119) \approx 0.12$).

18. These estimates are consistent with those shown in Boulhol and de Serres (2008) based on the pure Redding and Venables model in which market and supplier access are the only determinants of GDP per capita, once time and country fixed effects are controlled for.

19. In order to try to overcome the potential endogeneity bias, the sum of distances variable, *Distsum*, is an ideal instrument. Taking advantage of the panel dimension of the data, the effect of this time-invariant instrument is allowed to vary through time. In other words, a set of instruments, $Z_{it} = distsum_i.h_t$, are used where the h_t are time dummies.

20. The overall cost is computed as $1.21 * 1.44 * 1.55 - 1 = 1.7$. Border-related costs include policy barriers (tariffs and non-tariffs), information and enforcement costs, as well as costs due to the use of different currencies, rules and legal frameworks.

21. A clear downward trend in the relative price of merchandise transportation appears in the case of air transport, but only if the series is deflated by the GDP deflator rather than the narrower index of manufacturing goods prices.

22. According to Hummels (2007), the weight/value ratio of traded goods has fallen especially for the United States, since the early 1990s: $1 (in real terms) of traded merchandise weighs much less today than in the 1970s. Hummels reports that the real value of trade grew 1.5% per year faster than its weight since 1973. Because the measures above refer to the costs in dollar per kg, and have been constructed on the basis of an unchanged weight/value ratio over time, they underestimate relative the decline in *ad valorem* transport costs.

23. For telecommunications, an alternative approach would have been to look at measures of "distance" such as, for instance, the total outbound international network capacity in each country, either in absolute or per inhabitant. Unfortunately, such measures are typically not available before the 1990s.

24. Trade openness is measured as the average of export and import intensities (*i.e.* as a ratio of GDP) and is adjusted for country size. The adjustment is made by regressing the raw trade openness variable on population size and by taking the estimated residual from that panel regression as the measure of trade exposure that is included as an additional determinant in the augmented Solow specification.

25. Even though the variable does not have a time-series dimension, its estimated impact is allowed to vary over time. The value reported in the bottom panel of Table 6, is the average of all parameter estimates.

26. The statistical tests reported at the bottom of Table 6 indicate that when both year and country fixed-effects are included (column 2), the instruments add little information and are therefore considered as weak.

27. The dispersion across countries of the average (log of) real GDP per capita over the period is 0.191, whereas the standard deviation of the country fixed effects in the estimated steady-state (Table 1, column 1) is 0.161 and $(0.161/0.191)^2 = 72\%$.

28. A similar exercise cannot be replicated concerning the impact of the transport costs variables. The reason is that, as shown in the previous section, the effects of transport costs are robust only *via* their impact on international trade. The fixed effects obtained from a specification that includes trade openness as a determinant of GDP per capita could have been reported, but these would be misleading as transport costs are one of the determinants of trade only.

29. R&D spending was left out from the specifications in previous sections because limitations in data availability would have led to a substantial reduction in sample size (from nearly 600 to around 350 observations), and also because the focus of the study is on economic geography determinants.

30. In this specification, the ratio of R&D spending to GDP is used as a proxy for investment in innovation. Although in absence of knowledge depreciation, a decline in the R&D intensity should not lead to a fall in GDP per capita, the specification implies that a switch to a steady-state corresponding to a lower R&D intensity would entail moving to a path with a lower GDP per capita.

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ANNEX

The Augmented Solow Model

The augmented Solow model in empirical analysis

The Solow (1956) model has been widely used as a theoretical framework to explain differences across countries in income levels and growth patterns. The model is based on a simple production function with constant returns-to-scale technology. In the augmented version of the model (Mankiw, Romer and Weil, 1992), output is a function of human and physical capital, as well as labour (working-age population) and the level of technology. Under a number of assumptions about the evolution of factors of production over time, the model can be solved for its long-run (steady-state) equilibrium whereby the path of output per capita is determined by the rates of investment in physical and human capital, the level of technology, and the growth rate of population. In the steady-state, the growth of GDP per capita is driven solely by technology, which is assumed to grow at a (constant) rate set exogenously in the basic model.

In an earlier analysis, summarised in OECD (2003), a wide range of variables were added to the basic model as potential determinants. For instance, in the specifications based on economy-wide data, the set of additional variables included measures of inflation, indicators of government size and financing, measures of R&D intensity, as well as proxies for financial development and exposure to international trade. Given the large number of potential determinants, as well as their heterogeneity in terms of country coverage and time-series availability, the additional variables were never introduced all at once but rather by groups through various specifications. However, the three basic determinants of the augmented-Solow model – physical capital, human capital and population growth – were systematically included in all specifications. And, the coefficient estimates on these core variables appeared fairly robust to the sequential inclusion of the additional variables.

The long-run relationship derived from the augmented Solow model can be estimated either directly in its level form, or through a specification that explicitly takes into account the dynamic adjustment to the steady state. Estimates of the long-run relationship in static form have been used in the literature (*e.g.* Mankiw, Romer and Weil, 1992; Hall and Jones, 1999; Bernanke and Gürkaynak, 2001), in particular in studies focusing on income level differentials across countries. However, since the model has often been used in the empirical growth literature to examine issues of convergence, some form of dynamic specification has been more common. The two types of specification – static or dynamic – can be expected to yield similar results if countries are not too far from their steady-states or if deviations from the latter are not too persistent.

In principle, a dynamic specification is preferable, even when the interest is mainly on the identification of long-run determinants. This is because persistent deviations from steady-state are more likely to lead to biased estimates of the long-run parameters in static regressions, especially when the time-series dimension of the sample is relatively short, as is the case for this study (maximum length 1970-2004). In practice, estimating dynamic panel equations is also fraught with econometric problems (Durlauf and Quah, 1999). Furthermore, a major drawback with the most common techniques based on dynamic fixed-effect estimators is that only the intercepts are allowed to vary across countries, implying that all countries converge to their steady-state at the same speed, an assumption unlikely to hold even among developed countries.[1]

To address the latter issue, the previous OECD analysis relied essentially on the Pooled Mean Group (PMG) estimator, which allows for short-run coefficients and the speed of adjustment to vary across countries, while imposing homogeneity on long-run coefficients. However, even though the PMG estimation technique is intuitively appealing and perhaps the most suitable under some conditions, it is not without limitations especially when such conditions are not met. For instance, due to the large number of parameters and the non-linear constraints, the maximum likelihood estimation technique is prone to problems of convergence on local optima. And, experience suggests that parameter estimates can be particularly sensitive in presence of multi-collinearity among regressors, with some parameter values being in such cases too large (and unstable) to be plausible.

Formal presentation of the model[2]

The underlying growth framework is the neoclassical growth model augmented with human capital (Mankiw, Romer and Weil, 1992). The production function is Cobb-Douglas:

$$Y(t) = K(t)^a H(t)^b (A(t)L(t)\ ^{1-a-b}$$

where Y, L, K and H are output, labour, physical and human capital, respectively, and is the level of technology. L and A are assumed to grow exogenously at rates n and g. s_k and s_h being the investment rates in physical and human capital respectively, the dynamics of the reproducible factors are:

$$\dot{k}(t) = s_k(t)A(t)^{1-a-b}\ k(t)^a h(t)^b - (n(t)+d)\,k(t)$$

$$\dot{h}(t) = s_h(t)A(t)^{1-a-b}\ k(t)^a h(t)^b - (n(t)+d)\,h(t)$$

where $k \equiv K/L$ and $h \equiv H/L$ denote the stocks of capital per unit of labour and d is the time-invariant depreciation rate. Under the assumption of decreasing returns to physical and human capital ($a + b < 1$), this growth model generates the following steady states, denoted by *, where $y \equiv Y/L$:

$$Log\ k^*(t) = Log\ A(t) + \frac{1-b}{1-a-b} Log\ s_k(t) + \frac{b}{1-a-b} Log\ s_h(t) - \frac{1}{1-a-b} Log\big(g+d+n(t)\big)$$

$$Log\ h^*(t) = Log\ A(t) + \frac{a}{1-a-b} Log\ s_k(t) + \frac{1-a}{1-a-b} Log\ s_h(t) - \frac{1}{1-a-b} Log\big(g+d+n(t)\big)$$

$$Log\ y^*(t) = Log\ A(t) + \frac{a}{1-a}\Big(Log\ s_k(t) - Log\big(g+d+n(t)\big)\Big) + \frac{b}{1-a} Log\ h^*(t)$$

The steady-state of human capital in the last equation is unobservable, but a log-linearisation leads to:

$$Log\ h^*(t) = Log\ h(t) + \xi.\Delta Log\ h(t)$$

ζ being a function of the technological parameters (*a,b*). Consequently, the income steady-state is given by the following level equation:

$$Log\ y^*(t) = \frac{a}{1-a} Log\ s_k(t) - \frac{a}{1-a} Log\big(g+d+n(t)\big) + \frac{b}{1-a} Log\ h(t) + \frac{b}{1-a}\xi\ \Delta Log\ h(t) + Log\ A(0) + gt$$

(level equation)

The level equation ignores the dynamics to the steady state. A linear approximation of the transitional dynamics can be expressed as follows:

$$Log\ y(t) = (1-\lambda) Log\ y(t-1) + \lambda\ Log\ y^*(t) \quad \Leftrightarrow$$

$$\Delta Log\ y(t) = -\lambda\left[Log\ y(t-1) - \left(\frac{a}{1-a} Log\ s_k(t) - \frac{a}{1-a} Log\big(g+d+n(t)\big) + \frac{b}{1-a} Log\ h(t) + \frac{b}{1-a}\xi\ \Delta Log\ h(t) + g\,t + \psi\right)\right]$$

where $\lambda \equiv (1-a-b)(g+d+\overline{n})$ is the annual speed of convergence and $\psi = Log\ A(0) + g(1-\lambda)/\lambda$ is a constant. In order to obtain the error-correction form, short-run dynamics around the transition path has to be accounted for. Taking the maximum lag as being one, the following is obtained:

$$\Delta Log\ y(t) = -\lambda\left[Log\ y(t-1) - \left(\frac{a}{1-a} Log\ s_k(t) - \frac{a}{1-a} Log\big(g+d+n(t)\big) + \frac{b}{1-a} Log\ h(t) + \frac{b}{1-a}\xi\ \Delta Log\ h(t) + g\,t\right)\right]$$
$$+ a_0 + a_1 \Delta Log\ s_k(t) + a_2 \Delta Log\big(g+d+n(t)\big) + a_3\,\Delta Log\ h(t) + a_4 \Delta^2 Log\ h(t)$$

(error correction equation)

The error correction equation could be estimated by imposing the homogeneity of all the coefficients across countries. Such restrictions are generally not supported by the data. An alternative specification, the Pooled Mean Group, proposed by Pesaran, Shin and Smith (1999) consists in allowing short-run coefficients, the speed of adjustment and error variances to differ across countries, while imposing homogeneity on long-run coefficients. Formally, the following specification is estimated:

$$\Delta Log\ y_i(t) = -\lambda_i\left[Log\ y_i(t-1) - \left(\frac{a}{1-a} Log\ s_k\ (t) - \frac{a}{1-a} Log\big(g+d+n_i(t)\big) + \frac{b}{1-a} Log\ h_i(t) + \frac{b}{1-a}\xi \Delta Log\ h_i(t) + g\,t\right)\right.$$
$$+ a_{0i} + a_{1i} \Delta Log\ s_k\ (t) + a_{2i} \Delta Log\big(g+d+n_i(t)\big) + a_{3i} \Delta Log\ h_i(t) + a_{4i} \Delta^2 Log\ h_i(t) + \varepsilon_i$$

ε_i i.i.d. across i and t , $Var(\varepsilon_i) = \sigma_i^2$

(error correction equation, PMG)

It is common to impose *(g + d)* in *Log[g + d + n(t)]* to be equal to 0.05. Based on the Cobb-Douglas production function, the physical and capital shares are equal to *a* and *b*, respectively. These two parameters should therefore be around 1/3. Consequently, the coefficients that are consistent with the model above should be close to 0.5 for both $Log\ s_k$ and $Log\ s_h$, with a speed of convergence of around $(1-a-b)(g+d+\overline{n}) \approx (1-1/3-1/3).(0.05+0.02) \approx 0.023$.

The empirical framework above is actually fairly general and consistent with various endogenous growth models, but with different interpretation of the parameters (Bernanke and Gürkaynak, 2001). In particular, the Uzawa-Lucas model generates the following steady state (Piras, 1997; Bassanini and Scarpetta, 2001):

$$Log\ y^*(t) = \frac{a}{1-a} Log\ s_k(t) - \frac{a}{1-a} Log\big(\widetilde{g}+d+n(t)\big) + Log\ h(t) + Log\ A(0) + gt$$

where $\widetilde{g} \equiv g + \gamma_{h^*}$ is the steady-state growth rate of GDP per capita, which is the sum of the exogenous growth rate, *g*, and of the equilibrium growth rate of human capital per effective unit of labour, γ_{h^*}. Therefore, one can still assume $\widetilde{g} + d = 0.05$. Thus, the steady-state equation is similar to that obtained in the augmented Solow model, but with the prediction that the coefficient for human capital is equal to one. The transitional dynamics along the stable path is:

$$\Delta Log\ y(t) = -\tilde{\lambda}\left[Log\ y(t-1) - \left(\frac{a}{1-a} Log\ s_k(t) - \frac{a}{1-a} Log\left(\tilde{g} + d + n(t)\right) + Log\ h(t) + \xi\ \Delta Log\ h(t) + g\ t + \psi\right)\right]$$

with the speed of convergence given by: $\tilde{\lambda} \equiv (\tilde{g} + d + \overline{n})(1-a)/a$. There are two differences with the transitional dynamics in the augmented Solow model. First, the human capital coefficient is equal to one in the Uzawa-Lucas model instead of around 0.5 in the augmented Solow specification. Second, the speed of convergence is much faster in the Uzawa-Lucas approach, as a reasonable order of magnitude is $\tilde{\lambda} \approx (1-1/3)/(1/3).(0.05 + 0.02) \approx 0.14$ instead of 0.02 previously.

Notes

1. The implications of imposing invalid homogeneity restrictions on slope parameters in the context of dynamic panel estimates are discussed in Lee, Pesaran and Smith (1997).
2. This section borrows from Bassanini and Scarpetta (2001).