# Geography and Economic Growth

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**Abstract**

This paper addresses the complex relationship between geography and macroeconomic growth. It investigates the ways in which geography may matter directly for growth, controlling for economic policies and institutions, as well as the effects of geography on policy choices and institutions. It finds that location and climate have large effects on income levels and income growth through their effects on transport costs, disease burdens, and agricultural productivity, among other channels. Furthermore, geography seems to be a factor in the choice of economic policy itself. When geographical regions that are conducive to modern economic growth are identified, it is found that there is a disjunction between such regions and many areas of the world of high population density and rapid population increase. This is especially true of populations that are located far from coasts and navigable rivers and that thus face large transport costs for international trade, as well as of populations in tropical regions of high disease burden. Much of the population increase in the next 30 years is likely to take place in these geographically disadvantaged regions.

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Two centuries after the start of modern economic growth, a large portion of the world remains mired in poverty. Some benefits of modern development, especially increased life expectancy and reduced infant mortality, have spread to nearly all parts of the world, though huge and tragic discrepancies remain in some regions. In terms of material well-being, however, as measured by gross domestic product (GDP) per capita adjusted for purchasing power parity (PPP), the yawning gaps are stunning and show few signs of amelioration. According to the valuable data assembled by Angus Maddison for the Organization of Economic Cooperation and Development (1996), Western Europe outpaced Africa in average per capita GDP by a factor of around 2.9 in 1820 and a factor of 13.5 by 1992. More stunningly, Maddison puts the African per capita income in 1992 at $1,284 (measured in 1990 PPP adjusted dollars), which is essentially identical to his estimate of the average GDP per capita in Western Europe in 1820 at $1,292. One area of the developing world, Asia, showed significant progress during the past 30 years, with average incomes rising from around $1,275 in 1965 to $3,252 in 1992 on the Maddison data.[1] In Africa, however, the levels of income in the 1990s were about the same as in 1970. (Maddison puts Africa’s average income at $1,289 in 1971 and $1,292 in 1992.) In Latin America and the Caribbean, average income levels in 1992 ($4,820) were only 6.6 percent higher than in 1974 ($4,521).

Figure 1 shows the global map of GNP per capita as of 1995 (using World Bank estimates of PPP-adjusted 1995 dollars). Two geographical correlates of economic development are unmistakable. First, the countries in the geographical tropics (between 23.45 degrees N and S latitudes) are nearly all poor.[2] Almost all high-income countries are in the middle and high latitudes. Second, coastal economies generally have higher income than the landlocked economies. Indeed, among 28 non-European landlocked countries there is not a single high-income country.

Figure 2 shows the distribution of population density, measured as population per square kilometer. Unlike GDP, for which data generally are available only on a national or broad subnational basis, data on the world distribution of population are now available on a geographic information system (GIS) basis, with a resolution of 5 minutes by 5 minutes.[3] We can immediately make three observations about population density. First, there is no simple relationship between population density and income level. We find densely populated regions that are rich (Western Europe) and poor (India, Indonesia, and China), and sparsely populated regions that are both rich (Australia and New Zealand) and poor (the Sahel of Africa). On a cross-country basis there is a weak positive correlation between income density and GNP per capita.[4] Second, the great Eurasian landmass is more densely populated than the rest of the world. (This seems to be as much a function of human history as underlying geophysical and biogeographical conditions, as we show later.) Third, the coastlines and areas connected to the coast by navigable rivers are more densely populated than the hinterlands (a term we use to refer to regions more than 100 kilometers from the coast or an ocean-navigable waterway). Part of our goal is to decipher some sources of population density and its somewhat subtle relationship to income levels.

If we multiply GDP per capita and population density, we can calculate GNP density, measured as GNP per square kilometer, as shown on a country level in figure 3. In line with the first two figures, the coastal, temperate, Northern hemisphere economies have the highest economic densities in the world. Four of these areas—Western Europe, northeast Asia (coastal China, Japan, and Korea), and the Eastern and Western seaboards of the United States and Canada—are the core economic zones of the modern world.[5] These regions are the overwhelming providers of capital goods in global trade, the centers of global finance, and the generators of a large proportion of global production. If we take the regions within the United States, Western Europe, and temperate-zone East Asia that lie within 100 kilometers of the coastline, these areas account for a mere 5 percent of the world's inhabited land area, 15 percent of the world's population, and at least 37 percent of the word's GNP measured at purchasing power parity.[6] If we exclude coastal China from the calculations, which lags far behind the other economies in this group, then the core coastal region has a mere 10 percent of the world's population but produces at least 35 percent of the world GNP. According to recent data of the World Trade Organization, just 11 countries in North America, Western Europe, and East Asia, with 14 percent of the world's population, account for a remarkable 88 percent of global exports of capital goods (machinery and transport equipment).[7]

To take a closer look at these patterns, we examine the per capita GNPs of all 150 countries in the world with population of 1 million or more in 1995. Together these 150 countries had a combined 1995 population of 5.65 billion out of a global population estimated at 5.67

billion. Therefore our universe of observation includes 99.6 percent of the world population. For purposes of discussion we define a tropical country as one in which half or more of the land area is within the geographical tropics. There are 72 tropical countries, with 41 percent of the world's population, and 78 nontropical countries, with 59 percent of the world's population. Among the tropical countries the simple average of 1995 GNP per capita (not weighted by country population) is $3191. Among the nontropical countries the average is $8903, or nearly three times greater. A simple test of the difference of means across the two groups is significant at the P < .001 level. Using GIS-based calculations to allocate populations within countries that are partly tropical and partly nontropical, we calculate that 1.98 billion live in the geographical tropics, or approximately 35 percent of the world's population.

It is convenient to divide the nontropical countries into two subgroups, the temperate-zone economies and the subtropical economies. For our purposes we define subtropical as countries in which half or more of the population lives in tropical or subtropical ecological zones, but in which the country's land area is more than half outside of the geographical tropics.[8] There are 15 subtropical economies, and 63 temperate-zone economies. While the tropical countries have mean income of $3,191, the subtropical countries have mean income of $7,254, and the temperate-zone economies have a mean income of $9,296. If we only consider the economies that were not socialist in the postwar period, the geographical divide is even sharper: nonsocialist tropics, $3,590; nonsocialist subtropics, $7,492; and nonsocialist temperate, $14,825.

Out of the top 30 economies ranked by 1995 PPP-adjusted GNP per capita, only 3 are tropical, and they are tiny: Hong Kong (China), Singapore, and Mauritius. Twenty-seven are temperate-zone and none of these are subtropical. The 3 tropical countries account for a mere 1.1

percent of the combined population of the top 30 economies. Using GIS data, we can also examine the proportion of the population living in the geographical tropics in the top 30 economies, taking into account that we have not counted as tropical 3 of the top 30 economies (Australia, Taiwan [China], and the United Arab Emirates) that have a part of their populations in the tropical region. Making this adjustment, the tropical share of the top-30 population is 2.3 percent.

Nearly all landlocked countries in the world are poor, except for a handful in Western Europe that are deeply integrated into the regional European market and connected by low-cost trade. (Even mountainous Switzerland has the vast bulk of its population in the low-elevation cantons north of the Alps, and these population centers are easily accessible to the North Atlantic by land and river-based traffic.) There are 35 landlocked countries in the world with populations greater than 1 million, of which 28 are outside of Europe. Of the 28 non-European landlocked countries, the richest is 47th-ranked Botswana, which owes it pride of place to well-managed diamond mines. The second richest is Paraguay, ranked 72. The difference in means is striking: the non-European landlocked countries have an average income of $5,691, compared with the non-European coastal countries, which have an average income of $1,673 ($p = .001$). The difference in economic density is even stronger, since the landlocked countries tend to be very sparsely populated (67 people per square kilometer in landlocked countries compared with 202 people per square kilometer in coastal countries).

Of course, geography is not everything. Even geographically favored countries, such as temperate-zone, coastal Democratic People's Republic of Korea or well-located Czechoslovakia, failed to thrive under a socialist economic and political system. Nonetheless, development surely seems to be favored among the temperate-zone economies, especially the subset that (1) is in the Northern Hemisphere; (2) has avoided socialism; and (3) has avoided being ravaged by war. In total, there are 78 nontropical economies, of which 7 are in the Southern Hemisphere: Argentina, Australia, Chile, Lesotho, New Zealand, South Africa, and Uruguay (all in the temperate zone). We classify 33 countries as socialist during the post-war period, of which 31 are in the northern temperate zone, and two are in the northern subtropical zone. We also classify 12 nontropical countries as war-torn. There are 12 nontropical landlocked countries outside of Europe, of which 9 were socialist and 3 were not.

With these definitions, we find the following. There are 24 countries with the most favored combination of geography and politics—Northern Hemisphere, temperate zone, coastal, nonsocialist, and nonwar torn—with an average income of $16,483. In fact, 22 of these countries have an average GDP per capita of above $10,000, with Turkey and Morocco being the only exceptions.[9] Using a multiple regression estimate for the 78 nontropical countries, average incomes per capita are reduced by an estimated $3,969 for being in the subtropics, $4,540 for being in the Southern Hemisphere, $9,267 for being socialist, and $4,954 for being landlocked.

A summary of geographical characteristics by major region is shown in table 1. For each region we show the average GDP per capita, total population and land area, and several key variables that we will find to be closely related to economic development: the extent of land in the geographical tropics, the proportion of the region's population within 100 kilometers of coastline, the percentage of the population that lives in landlocked countries, the average air distance (weighted by country populations) of countries within the region to one of the core economic areas, and the density of human settlement (population per square kilometers) in the coastal region (within 100 kilometers of the coastline) and the interior (further than 100 kilometers from the coastline). Some important characteristics are evident. First, Sub-Saharan Africa, the poorest region, has several characteristic closely associated with low income in general: a very high concentration of land in the tropics, a population heavily concentrated in the interior (only 18.6 percent within 100 kilometers of the coast); more than a quarter of its population in landlocked countries (the highest of any region); a situation quite far from the closest "core" markets in Europe; and low population densities in the coastal and interior regions. By contrast, Europe, the richest region shown, is nontropical, heavily concentrated near coastal areas, and with moderate population density, has almost no population in landlocked regions. South Asia and the transition economies of Eastern Europe and the former Soviet Union are, like Sub-Saharan Africa, also heavily concentrated in the interior rather than the coast. India's great mass of population, for example, lives in the Gangetic valley, often hundreds of kilometers from the coast. South Asia is, of course, partly tropical and densely populated (indeed, it is the most densely populated region in the world), while the transition economies are nontropical and the least densely populated region shown. Latin America is the other highly tropical region, with low population densities and a moderately coastal population. The United States, not shown, has two enormous advantages for development: a temperate-zone landmass and a relatively high proportion of population near the coast (50 percent within 100 kilometers of the coast, if we include the ocean-navigable Saint Lawrence Seaway and Great Lakes in this classification).

These patterns prompt the following questions. How much has geography mattered for economic growth once we control for economic policies and institutions? If geography mattered in the past, how much does it still matter today? Are there persistent advantages to early developers through agglomeration effects, learning by doing, and the like, or do latecomers have the advantage of possibly rapid growth through technological diffusion, capital imports, and other forces of convergence?

Based on the evidence in this paper, we believe that geography continues to matter importantly for economic development along with economic and political institutions. From an analytical point of view, we believe that geographical considerations should be reintroduced into econometric and theoretical studies of cross-country economic growth, which so far have almost completely neglected geographical themes.[10] Our broad conclusions, described in more detail below, may be summarized as follows:

- Tropical regions are hindered in development in comparison to temperate regions, probably because of higher disease burdens and limitations on agricultural productivity
- Coastal regions and regions linked to coasts by ocean-navigable waterways are strongly favored in development in comparison to the hinterlands. Since internal migration is easier than international migration and infrastructure development within a country is easier than cross-border infrastructure development, populations in landlocked countries are particularly disadvantaged by their lack of access to the sea.
- Population density is favorable for economic development in coastal regions with good access to internal, regional, and international trade. Population density is unfavorable for economic development in the hinterland.
- Population growth across countries is strongly negatively correlated with their relative potential for economic growth. That is, human populations are growing most rapidly in countries least equipped to experience rapid economic growth. More generally, there is no

strong relationship in history between population growth and a region's potential for modern economic growth, since population densities seem to have been driven more by agricultural productivity than conditions for modern industry and services.

It is worthwhile to mention briefly the relationship of our approach to the recent creative and important work on geography by Paul Krugman, Anthony Venables, and others. The "new geography" follows the "new trade theory" by showing how increasing returns to scale, agglomeration economies, transport costs, and product differentiation can lead to a highly differentiated spatial organization of economic activity (including cities, hubs and spokes, and international division of labor between industry and agriculture), even when the underlying physical geography is undifferentiated. These models illustrate the possibility of "self-organizing" spatial patterns of production based on agglomeration effects, rather than differences in climate, transport costs, ecology, and so on. Our starting point, by contrast, is that the physical geography is in fact highly differentiated, and that these differences have a large effect on economic development. The two approaches can of course be complementary: a city might originally emerge because of cost advantages arising from differentiated geography, but then continue to thrive as a result of agglomeration economies even when the cost advantages have disappeared. Empirical work should aim at disentangling the forces of differential geography and self-organizing agglomeration economies.

## Geography and Models of Economic Growth

While geography has been much neglected in the past decade of formal econometric studies of cross-country performance, economists have long noted the crucial role of geographical factors. Indeed, though Adam Smith is most often remembered for his stress on economic institutions, he also gave deep attention to the geographic correlates of growth.[11] (Smith should also be remembered for his recognition that Europe's first-mover military advantage gave it an ability to impose huge costs on other parts of the world.[12]) Smith saw geography as the crucial accompaniment of economic institutions in determining the division of labor. His logic, of course, was rooted in the notion that productivity depends on specialization and specialization depends on the extent of the market. The extent of the market in turn depends on both the freedom of markets and the costs of transport. And geography is crucial in transport costs:

> As by means of water-carriage a more extensive market is opened to every sort of industry than what land-carriage alone can afford it, so it is upon sea-coast, and along the banks of navigable rivers, that industry of every kind naturally begins to subdivide and improve itself, and it is frequently not till a long time after that those improvements extend themselves to the inland part of the country.

In view of the crucial role of transport costs Smith notes that:

> All the inland parts of Africa, and that part of Asia which lies any considerable way north of the Euxine [Black] and Caspian seas, the ancient Scythia, the modern Tartary and Siberia, seem in all ages of the world to have been in the same barbarous and uncivilized state in which we find them at present. The sea of Tartary is the frozen ocean which admits of no navigation, and though some of the greatest rivers in the world run through that country, they are at too great a distance from one another to carry commerce and communication through the greater part of it. There are in Africa none of those great inlets, such as the Baltic and Adriatic seas in Europe, the Mediterranean and Euxine seas in both Europe and Asia, and the gulphs of Arabia, Persia, India, Bengal, and Siam, in Asia, to carry maritime commerce into the interior parts of that great continent. . . . (p. 25)

Great thinkers such as Fernand Braudel and William McNeil, and important recent historians such as E. L. Jones and William Crosby, have placed the geography and climate of Europe at the center of their explanations of Europe's preeminent success in economic development. Braudel points to the key role of Mediterranean-based and North Atlantic coastal economies as the creative centers of global capitalism after the fifteenth century. MacNeil similarly stresses Europe's great advantages in coastal trade, navigable rivers, temperate climate, and suitable disease patterns as fundamental conditions for European takeoff and eventual domination of the Americas and Australasia. Crosby details the advantages of the temperate zones in climate, disease ecology, and agricultural productivity. Two important essays, one by the Council on Foreign Relations (1953) and another a generation later by Andrew Kamarck

(1976) for the World Bank, synthesized these arguments in excellent surveys on tropical development. These studies have been largely ignored by the formal modelers of economic growth.

One of the most interesting recent attempts to ground very long-term development in geographical and ecological considerations comes from ecologist Jared Diamond (1997), who asks why Eurasians (and peoples of Eurasian origin in the Americas and Australasia) “dominate the modern world in wealth and development” (p. 15). He disposes of racialist explanations not only on moral grounds but on the basis of rigorous findings of the shared genetic inheritance of all human societies. His explanation rests instead on the long-term advantages of Eurasia in agglomeration economies and the diffusion of technologies. Human populations in the Americas and Australasia were cut off by oceans from the vast majority of human populations in Eurasia and Africa. They therefore could not share, through trade and diffusion, in technological advances in agriculture, communications, transport, and the like. Additionally, Diamond argues that technological diffusion naturally works most effectively *within* ecological zones, and therefore in an east-west direction along a common latitude, rather than in a north-south direction, which almost invariably crosses ecological zones. This is because plant species and domesticated animals appropriate to one ecological zone may be completely inappropriate elsewhere. Eurasia, claims Diamond, therefore enjoyed the benefit of its vast east-west axis heavily situated in temperate ecological zones, while Africa was disadvantaged by its north-south axis which cut across the Mediterranean climate in the far north, the Saharan Desert, the equitorial tropics, and the southernmost subtropical regions. Diamond argues that these advantages, in addition to more contingent (or accidental) advantages in indigenous plant and animal species, gave Eurasia a fundamental long-term advantage over the rest of the world.

Historians have also stressed the changing nature of geographical advantage over time in conjunction with technological changes. In early civilizations, when transport and communications were too costly to support much interregional and international (not to mention oceanic) trade, geographical advantage came overwhelmingly from agricultural productivity rather than access to markets. Therefore early civilizations almost invariably emerged in the highly fertile river valleys of the Nile, Indus, Tigris, Euphrates, Yellow, and Yangtze rivers. These civilizations produced high-density populations that in later eras were actually disadvantaged by their remoteness from international trade. Northern Europe could not be densely settled before the discoveries of appropriate technologies (for example, the moldboard plow in the Middle Ages, and tools to fell the great northern forests). Similarly, as the advantages of overland trade and coastal-based trade between Europe and Asia gave way to oceanic commerce in the 16th century, economic advantage shifted from the Middle East and Eastern Mediterranean to the North Atlantic. In the 19th century, the high costs of transport of coal for steam power meant that early industrialization almost invariably depended on proximity to coal fields. This advantage of course disappeared with the discoveries of petroleum refining, oil- and hydro-based electricity production, and the reduced cost of bulk transport. Railroads, automobiles, and air transport, as well as all forms of telecommunications, surely reduced the advantages of the coastline relative to the hinterland, but according to the evidence below the advantages of sea-based trade remain.

To summarize, we can say that leading historians and economists have long recognized geography to be a crucial scaffolding for economic development, even though it has been neglected in most recent empirical studies of comparative growth. Leading thinkers have pointed to four major areas in which geography will play a fundamental *direct* role in economic productivity: transport costs, human health, agricultural productivity (including animal husbandry), and proximity and ownership of natural resources (including water, minerals, hydrocarbon deposits, and so forth). The factors may also have indirect effects, if first-mover advantages or population densities affect subsequent growth dynamics through agglomeration economies or other feedback mechanisms. We now turn to a more formal consideration of these factors.

*Formal Models of Geography and Development*

THE AK MODEL. To establish some formal ideas about the interaction of geography and development, we will start with the simplest model of economic growth, the AK model (known in its earlier incarnation as the Harrod-Domar model), adding transport costs. In the resulting model growth differences across countries depend on several parameters that we will find to be important in later empirical analysis. These factors include: (1) underlying total factor productivity, denoted by $A$, which may differ across countries for fundamental geographical reasons (for example, the differences in productivity of temperate and tropical agriculture or in endemic health conditions among various ecozones); (2) transport costs, reflecting both distances and physical access to trade (such as navigability of rivers or distance from the coastline); and (3) national saving rates and, implicitly, government economic policies.

Suppose that an economy has the aggregate production function:

(1) $$Q = A K$$

The capital stock evolves according to

(2) $$dK / dt = I - \delta K$$

We assume for the moment that population is constant and is normalized to 1, so that $Q$ represents both output and output per capita. Later on we discuss some issues of population growth.

The national saving rate is fixed at $s$ (the alternative assumption of intertemporal optimization would be straightforward as well, but with little gain in realism or insight). The relative price of investment goods to final output is $P_I$. Thus,

(3) $$sQ = P_I I$$

From equations 1, 2, and 3 we immediately derive the growth rate of the economy:

(4) $$\gamma = (1/Q)(dQ/dt) = (1/K)(dK/dt) = sA/P_I - \delta$$

Economic growth is positively dependent on the saving rate, *s*, and the level of total factor productivity, *A*, and negatively dependent on the relative price of capital goods, $P_I$, and the rate of depreciation, $\delta$.

Transport costs affect the relative price of capital goods because some investment goods must be imported from abroad. In many developing countries virtually all equipment investment in imported from abroad. To illustrate some implications of transport costs, we now assume that each country produces a distinct final good and investment, *I*, is a composite of the final goods produced in the various countries. The key assumption is that there are gains from trade, so that transport costs and other barriers to trade reduce growth. We do not directly model the underlying reasons for specialization in production and hence gains from trade. As is well known, specialization in production may result from one or more of the following factors: differing primary factor endowments; economies of scale in production; economies of specialization via learning by doing; or differing technologies across countries because of investments in proprietary research and development.

Total investment, *I*, depends on investment expenditure on domestic goods, $I^d$, and on imported investment goods, $I^m$:

$$I = I(I^d , I^m) \qquad (5)$$

As a simple illustration, consider the case in which *I* is a Cobb-Douglas function of the underlying domestic and foreign investment goods:

(5') $I = (I^d)^a (I^m)^{(1-a)}$

The true price index of investment goods, then, is a geometric average of the price of domestic investment goods and foreign investment goods. Setting the domestic good as numeraire, or the price of $I^d$ equal to 1, we have:

(6) $P_I = \alpha (P^m)^{(1-a)}$ where $\alpha = a^a (1-a)^{(1-a)}$

We denote the (exogenous) world market price of the imported good as $P^{m*}$, and write the landed (or c.i.f.) price in the home economy as $P^m = \tau P^{m*}$, where $\tau > 1$ is the c.i.f. factor, that is, the world price plus cost, insurance, and freight. So, from equations 4 and 6 we have a modified equation for the growth of the economy:[13]

(7) $\gamma = (sA/\alpha)(P^{m*})^{-(1-a)} \tau^{-(1-a)} - \delta$

The growth rate is now inversely related to the cost of transport, $\tau$. Transport costs in this model reduce growth by raising the cost of the imported capital good, thereby lowering the growth rate. We have seen in earlier empirical studies of economic growth (Barro 1991, for example) that the rate of growth is a decreasing function of the relative cost of investment goods. This is essentially the channel by which the costs of transport and distance enter in equation 7.

Equation 7 suggests three important points even at this very basic and abstract level. First, growth rates will differ according to underlying total factor productivity, *A*. Second, growth rates differ according to transport costs, $\tau$. These in turn are likely to depend on several characteristics. Coastal economies will generally have much lower transport costs than hinterland economies. Countries near to core economies (such as the main capital-goods providers) will generally have lower transport costs than distant economies, so that growth is likely to diminish in direct relation to distance from the core. Third, protectionist policies that raise the domestic prices of imported capital goods or limit the exports needed to import the foreign capital goods are likely to reduce long-term economic growth. We cannot emphasize this point enough: countries require capital goods imports for long-term growth. Protectionist policies raise the price of those imports and thereby slow growth.

A MODEL WITH INTERMEDIATE GOODS. Suppose now that final production requires imported intermediate inputs. This assumption is of enormous empirical importance, since many of the key manufactured exports of developing countries involve the importation of intermediate manufactured goods (such as fabrics or electronic components), which are then assembled domestically with low-cost labor and re-exported to world markets. The transport costs involved in the import of intermediate products and their re-export after domestic processing can be of critical importance in the success or failure of the manufacturing export sector, even if the transport costs for investment goods are minimal.

We must now distinguish between gross output, *Q*, and gross domestic product, *Y*. In particular we set:

(8) $Q = \min[AK, \mu N]$

where $N$ is the intermediate good imported from abroad. The final good in the home market continues to be numeraire (with price 1), and the relative price of the imported intermediate good is $P_n = \tau P_n^*$ . The gross domestic product in units of the final good is given by $Y = AK - P_n N = AK - \mu P_n AK$, or:

(9) $Y = (1 - \mu P_n)AK$

Since domestic final output in the home market is numeraire, its price in the foreign market inclusive of transport costs is $\tau$. Similarly, if the intermediate product sells for $P_n$ in the home market, its price in the foreign market is $P_n/\tau$. Suppose that at world prices (that is, in the foreign market) the share of the intermediate good in final output is given by $\sigma = (P_n/\tau)N/(\tau Q)$. Then equation 9 may be rewritten as:

(9') $Y = [1 - \sigma\tau^2]AK$

All of the model goes through as before, so that the modified growth equation is now:

(10) $\gamma = \alpha\, s\, A\, [1 - \sigma\tau^2]\, (P^m)^{-(1-a)} - \delta$

The key point here is that relatively small transport costs can have huge effects on output and growth when the share of intermediate inputs in final demand is large. For example, suppose $\sigma = 0.7$. Now compare the growth rates of countries with one-way transport costs equal to 5 percent and 10 percent, that is, $\tau = 1.05$ versus 1.10. Ignore for the moment the transport costs on capital goods and focus solely on the effect of intermediate products. Let $\gamma_1$ be the growth rate of the low-transport-cost economy, and $\gamma_2$ be the growth rate of the high-transport-cost economy. Then from equation 10 we have:

$$\gamma_1 / \gamma_2 = [1-.7(1.1025)]/[1-.7(1.21)] = 1.49$$

The growth rate in the low-transport-cost economy is 49 percent higher than in the high-transport economy even though the transport costs differ by only 5 percent. The explanation, of course, is that a "mere" decrease of 5 percent in one-way transport costs on intermediate and final goods implies a whopping increase of 49 percent in domestic value added.

The notion that intermediate inputs represent such a high proportion of the value of gross output may seem unrealistic, but such is the case for many key export sectors in developing countries. In many kinds of labor-intensive industries—such as apparel and electronics assembly—the developing country imports a very high proportion of the value of final output. The intermediate imports are assembled by the domestic workers and then typically re-exported to world markets. The developing country is essentially selling labor services used in assembly operations rather than selling the entire product. For such assembly industries, even small increases in transport costs can render the sector noncompetitive. Thus in Radelet and Sachs (1998) we find that only those developing countries with good transport access to world markets have been able to establish assembly-type industries.

These arguments further underscore the disadvantages of the hinterland relative to the coast in economic development. Almost all modern production depends on the multistage processing of output, with inputs often produced in many specialized enterprises, some abroad and some domestic. The low-cost transport of such intermediate products is crucial, especially in developing countries where many intermediate components are necessarily imported from abroad. Only coastal areas or areas linked to the coastline through navigable waterways or very low-cost land transport have a chance to compete in such activities.

CONVERGENCE. The AK model, of course, has one central feature: the absence of convergence. Because there are no diminishing returns to investment in the production function, there is no tendency for growth to slow down as capital deepening occurs. For this reason, countries that have underlying advantages in saving rates, efficiency, transport costs, or rates of depreciation will display permanently higher growth rates and a widening proportionate gap with more slowly growing countries.

As is well known, if the foregoing model is recast as a neoclassical growth model with diminishing marginal productivity of capital, so that $Q = A K^{\beta}$, with $\beta < 1$, then the conclusions reached so far have to be recast as follows. The same list of parameters ($s$, $A$, $P^{m*}$, $\tau$, $\delta$) now all affect the steady-state level of $Q$, denoted $Q^{ss}$, and the steady-state capital stock, $K^{ss}$, but not the long-term growth rate. Because the capital stock converges gradually to its steady state, so too does the level of output. In this case, we can write the growth equation as follows:

(11) $$\gamma_i = (1/Q_i)(dQ_i\,/dt) = \lambda[\ln Q^{ss}_i - \ln Q_i\,]$$

Equation 11 holds that the proportionate rate of growth depends on the gap between the steady-state level of output and the contemporaneous level of output. We could, in general, derive $\ln Q^{ss}_i$ to be a function of the underlying parameters *s*, *A*, and so forth. Approximating this relationship in log-linear form, $\ln Q^{ss}_i = \beta' Z_i$ , where $Z_i$ is the vector of underlying growth-influencing parameters, and $\beta$ is a vector of coefficients, we end up with an empirically estimable equation that has been extremely popular in recent years:

(12) $$\gamma_i = \lambda\, \beta' Z_{\mathrm{i}} - \lambda \ln Q_i$$

In this formulation growth depends positively on the parameters in question and negatively on the initial income variable. The empirical presence of the term $-\lambda \ln Q_i$ has been used to examine whether or not there is a tendency towards convergence as in the neoclassical model, or continuing divergence, as in the AK model, in which the *level* of income is not a determinant of the rate of growth.

As is well understood, the issue of convergence versus nonconvergence depends heavily on the underlying structure of production. In an environment of increasing returns to scale at the firm level as well as gains from a greater diversity of products—as in the popular models of Dixit-Stiglitz imperfect competition—there may well be increasing or at least constant returns to the capital stock at the macroeconomic level. The marginal productivity of capital would then be constant (as in the AK model) or even increasing, as the aggregate capital stock increases. In that setting, the AK model would depict the aggregate production technology better than the neoclassical model with its assumption of declining marginal productivity of capital. Thus, as is well known, to the extent that scale economies and product diversity are critical, we would expect to see little convergence between rich and poor countries and could well see divergence. To the extent that economies of scale and product diversity are limited, we would be more likely to see convergence in income levels, controlling for other factors.

*Geography and Population Dynamics*

It is not easy to integrate population dynamics in a meaningful way into the simple AK model, so we will have to step outside that simple framework to discuss some important issues on the relationship of geography, population dynamics, and growth. We have stressed repeatedly the advantages of coastal regions for economic development. We have not said anything, however, about the distribution of human populations across regions. In fact, the linkages are problematic in three ways.

First, there are vast human populations in regions quite disadvantaged for modern economic growth. In the long course of human history there has been a tendency for human population densities to rise in areas favorable for growth, so that coastal areas are indeed more densely populated than hinterlands. Another tendency, however, has been for population densities to rise in fertile agricultural areas, such as along inland river systems such as the Ganges, Tigris, Euphrates, and Nile, which are useful for irrigation and inland trade but not international trade. The result is high population densities living on subsistence agriculture rather than benefiting from modern economic growth. Second, current population growth tends to be highest in the more remote regions, mainly because population growth is negatively related to per capita income, especially the market value of mothers' time.[14] Thus, the concentration of populations in problematic regions is growing. This effect is strengthened by the general beneficial tendency for improvements in public health (such as the spread of vaccines or oral rehydration therapy) to diffuse more readily than economic growth.

Third, as a result of the mismatch of economic growth and population trends, there is a mass migration of populations from the hinterland to the coast. The vast majority of migratory movements are within poor countries, leading to unprecedented inflows of population into urban areas and the rise of mega-cities in developing countries. The next largest migration, most likely, is across borders of developing countries, including vast flows of population from landlocked countries to coastal economies. And the third largest migration is from poor countries to richer countries. This migration would of course be vastly larger were it not for immigration controls in the richer economies. In any case, the pressures for migration both internal and international will rise sharply in the coming decades.

The effects of population pressures on economic growth are likely to differ markedly in the hinterland and the coast. In the hinterland, where transport costs are extremely high, the division of labor is low and output is most likely characterized by decreasing returns to scale in labor in the face of limited supplies of land. Therefore higher population densities will be associated with falling output per capita, a tendency that we have seen in many African countries in the last 20 years. In the coastal economies, on the other hand, where transport costs are low and the division of labor is high, a rising population may be associated with stable or even increasing incomes per capita, even when the capital-labor ratio declines. This is because higher population densities make possible an increasingly refined division of labor.[15]

We thus see that economies are likely to bifurcate on two pathways. The hinterland will be characterized by decreasing returns to scale in labor and high rates of population growth. The coastline will be characterized by increasing returns to scale and falling rates of population growth as incomes per household rise. The hinterland may therefore show Malthusian dynamics while the coastline shows rising income levels and falling natural population growth rates. The two systems will interact through ever greater pressures on migration from the hinterland to the coast.

*Geography and Policy Choices*

So far we have stressed that geography may influence growth directly through total factor productivity and transport costs. Geography can have another potent effect by affecting the choice of economic policies. Countries that are proximate to markets, for example, may choose more open trade policies than countries that are distant from markets. We offer a motivation for such a possibility.

Suppose that growth is given by $sA/P_I$ , and that $A$ itself can be decomposed into a multiplicative policy component and a purely exogenous component: $s\pi\alpha/P_I$. Suppose as well that $P_I = P_I(\tau)$, that is, the price of investment goods, is an increasing function of transport costs. At this abstract level we can say that the policy component of growth is a decreasing function of the ad valorem tax rate levied by the government on the private economy, $\pi = \pi(\mathrm{T})$. For simplicity we will use a linear functional form: $\pi = d - eT$. These taxes might be formal taxes, bribes demanded to clear customs, seizures of property, and so forth. The basic idea is that the government gains revenues but at the expense of a worsening policy environment.

Suppose that $T$ is chosen once and for all to maximize the expected utility of government officials. To keep matters very simple in this abstract framework we assume that the policy maker has an intertemporal log utility function, a pure discount rate of $d$, and a hazard rate $h$ of losing office.[16] Expected utility is then:

$$\text{(13)} \qquad \mathrm{EU} = \int \exp[-(d+h)t]\log[TQ(t)]dt$$

This is maximized subject to the constraint that $Q(t) = Q(0)\exp(\gamma t)$ where $\gamma = s\pi(T)\alpha/P_I(\tau)$. What we have, essentially, is an "optimal tax" calculation on the part of the sovereign. Higher taxation yields more immediate revenue, but at the cost of slower future growth and hence lower future revenues. Simple manipulations show that equation 13 can be rewritten as $\mathrm{EU} = [\log(T)+\log(Q_0)]/(d+h) + [s\pi(T)\alpha/P_I(\tau)]/(d+h)^2$ . It then remains to calculate the optimal $T$, by setting $d\mathrm{EU}/dT = 0$. We find:

(14) $T = P_I(\tau)(d+h)/s\alpha e \qquad T \leq 1$

This is an insightful expression. The optimal tax is an increasing function of transport costs, discount rate, and probability of losing office and a decreasing function of total factor productivity and the responsiveness of growth to the tax rate. Basically, the sovereign is translating quick gain versus future loss. To the extent that growth is low (because $P_I$ is high or $\alpha$ is low) or the future is heavily discounted (because $d+h$ is high) or unresponsive to taxation, then the tax rate should be set at a high level. To the extent that underlying growth is rapid or highly responsive to taxation, then $T$ should be set at a lower rate.

The implications for geography are as follows. First, good policy and good geography may have a tendency to go together. When growth is inherently low because of adverse geographical factors and also unresponsive to policy (perhaps for the same reasons), the revenue-maximizing sovereign will impose high rates of taxation, for example, protectionist policies. When the economy is inherently productive and responsive to good economic policies, the sovereign will have the incentive to impose low rates of taxation. The result is that natural differences in growth potential tend to be amplified by the choice of economic policies.

Second, the correlation of favorable underlying growth conditions and good policies leads to an important identification problem in estimating the effects of economic policy on economic performance. Suppose that we were to carry out a regression estimation of growth on taxation and finds a strong negative relationship. This is usually interpreted as a demonstration that policy matters for growth. We have just seen, however, that it might also reflect the fact that growth matters for policy. It is crucial to specify structural growth relationships that include both policy and underlying geography in order to disentangle these alternatives.

## Empirical Linkages of Geography and Growth

### *Geographical Correlates of Growth*

The basic theory points to two broad categories of deeply significant geographical factors: transport costs, measured by the parameter $\tau$ , and intrinsic productivity, measured by *A*. Let us first consider transport costs. Remarkably, despite the likely importance of transport costs for economic growth, there are no adequate measures of them for a large sample of industrial and developing countries. The best we could obtain for a large number of countries is the International Monetary Fund estimates of the c.i.f./f.o.b. margins in international trade. These margins measure the ratio of import costs inclusive of insurance and freight (c.i.f.) relative to import costs exclusive of insurance and freight (f.o.b.). There are several problems with these measures, the most important that they are only crudely estimated by the IMF staff, and they depend on the composition of imports and thus are not standardized across countries.

Nonetheless, the c.i.f./f.o.b. margins are informative and predictive of economic growth. The c.i.f./f.o.b. margin for 1995 is 3.6 percent for the United States, 4.9 percent for Western Europe, 9.8 percent for East Asia, 10.6 percent for Latin America, and a whopping 19.5 percent for Sub-Saharan Africa.[17] We estimate an equation relating the c.i.f./f.o.b. band both to the distance of the country to the “core” areas of the world economy (Distance, measured in thousands of kilometers[18]) and to the accessibility of the country to sea-based trade, by including a dummy variable for non-European landlocked countries (LL):

$$\text{c.i.f./f.o.b.} = \underset{(59.5)}{1.06} + \underset{(2.6)}{0.009}\ \text{Distance (1,000 kilometers)} + \underset{(4.3)}{0.11}\ \text{LL}$$

N = 83, $R^2 = 0.32$

As expected, there is a penalty both for distance from the core economies and for being landlocked. Each 1,000 kilometers raises the c.i.f./f.o.b. margin by 0.90 percentage points, while being landlocked raises the c.i.f./f.o.b. margin by 11.1 percentage points. We will show later that the c.i.f./f.o.b. margin is indeed predictive of income levels and economic growth. Incidentally, if we regress c.i.f./f.o.b. on the proportion of the population within 100 kilometers of the coast (Pop100km), we also find a negative effect, but when we include both Pop100km and LL, the regression estimate prefers LL to Pop100 kilometers. The coefficient on Pop100km remains negative, as expected, but drops in magnitude and is statistically insignificant.

We have seen in table 1 that the various regions in the world differ markedly in locations of their populations relative to the seacoast. African populations especially are far from the coastline, while Europe is overwhelmingly coastal. Indeed, Africa has the highest proportion of landlocked population of any continent in the world, and especially in East Africa the populations are heavily concentrated in the interior, even in countries with coastlines such as Kenya (Pop100km = 0.06), Mozambique (0.40), Sudan (0.02), and Tanzania (0.16). The situation is made worse by the fact that Africa's interior regions are not accessible by ocean-navigable vessels, since the river systems in Africa almost all face impassable barriers (such as cataracts or shallows) that prevent the entry of ocean-going vessels into the interior of the continent.

The notion that the coastal access has a large effect on trade and growth is plausible given what we know about the growth patterns of the most successful developing countries in the period after 1965. Almost without exception, fast-growing developing countries have based their rapid growth on labor-intensive manufacturing exports. And almost without exception, such activities have expanded in port cities or export zones close to ports. As shown in Radelet and Sachs (1998), almost all countries with macroeconomic success in labor-intensive manufacturing exports have populations almost totally within 100 kilometers of the coast.

The geographical determinants of the efficiency parameter *A* are potentially much more varied. First, we can surmise that coastal access will matter for internal trade and productivity as well as for international trade. Cities are engines of growth, and most large cities other than garrison towns or administrative capitals typically grow up on coastlines or ocean-navigable rivers. Therefore countries with neither coastlines nor navigable rivers tend to have less urbanization and less growth. A simple regression estimate for 128 developed and developing countries shows that more ocean-accessible regions in the world are indeed also more urbanized, as are economies closer to the economic core regions. We define Pop100cr as the proportion of a country's economy that is within 100 kilometers of either the coastline or a river navigable by ocean-going vessels. In a simple regression we find

$$\%\text{Urbanization (1994)} = 108.5 + 0.18\ \text{Pop100cr} - 8.23\ \ln(\text{Distance}) \quad R^2 = 0.28$$

(5.8) (3.3) (3.9) N = 128

A second major dimension of productivity linked to geography is the prevalence of infectious disease. As shown in figure 4, malaria, with an estimated incidence of between 200 and 500 million cases per year, is almost entirely concentrated in the tropics.[19] This pattern is not accidental nor mainly the result of reverse causation, with poor countries unable to eradicate a disease under control in rich countries. There is no effective prophylaxis or vector control for malaria in the areas of high endemicity, especially Sub-Saharan Africa. Earlier methods of vector control are losing their effectiveness because of increased resistance of the mosquitoes to insecticides. Standard treatments are also losing effectiveness because of the spread of resistance to cloroquine and mefloquine. The geographical extent of malaria is affected mostly by the ecology of the disease vector (the anopheles mosquitoes) and the inherited endemicity of the disease. Malaria was brought under control between 1945 and 1995 mainly in temperate-zone and subtropical environments, where the foothold of the disease (both in terms of the mosquito population and the endemicity) was more fragile. A simple regression of malarial intensity on ecological zones shows that it is most intense in the tropics and somewhat less in the subtropics (relative to all other ecozones). There is also a strong “Sub-Saharan Africa” effect.

Malarial prevalence (scale 0-3) =

0.03 + 1.3 wet tropics + 1.8 dry tropics + 1.60 wet subtropics + 0.71 dry subtropics

(0.3) (3.6) (7.7) (8.3) (3.8)

+ 1.21 Sub-Saharan Africa N = 150 $R^2$ = 0.74 (8.75)

The pattern for malaria is common for a range of infectious diseases whose vectors of transmission depend on the tropical climate. Many diseases that are carried by mosquitos (dengue and yellow fever in addition to malaria), mollusks (schistosomiasis), other arthropods (onchocerciasis, leishmaniasis), or flies (trypanosomiasis) are endemic in the tropical ecological zones and nearly absent elsewhere. While data on disease burdens by country are generally not available, the recent massive study by Murray and associates on the burden of disease confirms the heavy tropical concentration of infectious disease as a cause of death. This is shown in figure 4a.

A third major correlate of geography and productivity is the link of climate and agricultural output. Our own estimates of agricultural productivity suggest a strong adverse effect of tropical ecozones on the market value of agricultural output, after controlling for inputs such as labor, tractors, fertilizer, irrigation, and other inputs. Estimates in Gallup (1998) suggest that tropical agriculture suffers a productivity decrement of between 30 and 50 percent compared with temperate-zone agriculture, after controlling as best as possible for factor inputs.

Other, more prosaic geographical correlates, such as endowments of high-value natural resources (hydrocarbons, minerals, precious gems), also affect cross-country income per capita at a point in time. We do not have comprehensive measures of the international market value of such resource endowments, so we settle for a rough measure of one key resource: deposits of petroleum and natural gas. Countries rich in hydrocarbon deposits per capita indeed display higher levels of per capita income in 1995, though not necessarily higher economic growth.

Indeed, Sachs and Warner (1998) have suggested that higher natural resource exports as of 1970 (measured as a percent of GDP) are negatively related to subsequent growth.

*Geography and Levels of Per Capita Income*

We examine the linkage of output to geography in both levels and rates of change of GDP. Suppose that countries differ in their growth rates according to a vector of characteristics $Z$, including determinants of transport costs and total factor productivity. We write a linear approximation of a growth equation such as equation 7 such that:

(15) $$\gamma_{i\,t} = \beta' Z_i + \mu_{i\,t}$$

In any period $T > 0$, $Q_{it} = \exp(\gamma_i \mathrm{T}) Q_{i0}$. Suppose that in the distant past $Q_{i\,0}$ is randomly distributed across countries, with $\ln Q_{i0} = \ln Q_0 + \zeta_i$, and with $\zeta_i$ independent of the $Z_i$. Then we can estimate a cross-country *level* equation of the form:[20]

(16) $$\ln(Q_{iT}) = \ln(Q_0) + T\beta' Z_i + \varepsilon_i$$

Note that the effects of the parameters $Z_i$ on the *level* of $Q_{iT}$ will tend to grow over time in proportion to $T$, since $Z$ affects the growth rate and not merely the relative level of income of country $i$. Note also that if the $Z$ variables are time dependent, then $Q_{iT}$ is a function of the entire time path of $Z_i$. In general, for most variables of interest we have snapshots of $Z$ rather than a time series. One objective of empirical development studies should be the creation of time series measures of key institutional determinants of growth (for example, openness of markets or protection of property rights) in order to strengthen our empirical tests.

We start with the simplest specification, writing the log level of per capita income as a function of three underlying geographical variables: (1) Tropicar, the percentage of land in the geographical tropics; (2) Pop100km, the proportion of the population within 100 kilometers of the coastline; and (3) Ldist, the minimum log-distance of the country to one of the three core regions, measured specifically as the minimum log-distance to New York, Amsterdam, or Tokyo. We estimate this relationship three times: for Maddison's GDP estimates for 1950 and 1990 and for the World Bank's GNP estimates for 1995 on the subset of countries for which Maddison's data are available. In the first three regression estimates (reported in table 2) output is a positive function of Pop100km and a negative function of Tropicar and Ldist. The magnitude of the effects tends to increase over time, as expected. In 1950 the "penalty" for Tropicar was -0.67, signifying that tropical areas were only 51 percent (= exp(-.67)) of per capita income of the nontropical areas controlling for the other factors. By 1992 the effect has risen to -0.97 and by 1996 to -1.01 (or 36 percent of the nontropical areas). Similarly, the benefit of a coastal population rose from 0.73 in 1950 to 1.17 in 1995. The suggestion is that being tropical, landlocked, and distant was bad already in 1950 and adverse for growth between 1950 and 1995.

We now turn in more detail to the 1995 data, for which we have a wider range of possible explanatory variables. We start by estimating this simple level equation for GNP per capita on a PPP basis in 1995 for the 150 countries with population greater than 1 million, and then turn to growth equations for the period 1965-90. We group the explanatory variables *Z* into three broad categories: (1) variables related to transport costs and proximity to markets; (2) variables related to ecological zone; and (3) variables related to economic and political institutions. The list of possible variables is extensive, as we show in table 3.

In regression 4 we limit *Z* to a parsimonious set of four variables closely linked to geography: the prevalence of malaria; transport costs as measured by the c.i.f./f.o.b. margin; the proportion of the country's population near the coastline; and the endowment of hydrocarbons per capita. These four variables alone account for 75 percent of the cross-country variation in per capita income and are all with the expected sign and statistically significant. High levels of GDP per capita are associated with the absence of malaria; low transport costs, a coastal population, and a large endowment of hydrocarbons per capita. The strong correlation of malaria with income levels is not simply an "Africa proxy." When we rerun the equation for the sample of countries outside of Sub-Saharan Africa in regression 5, we find very similar results. When we enter *both* Malaria and Tropicar into the regression (not shown), the effect of the Malaria variable is far more important, suggesting that the negative effect of the Tropicar variable is largely subsumed by the geographic distribution of Malaria. Of course, these associations are hardly a proof of causality. Not only might the explanatory variables be proxies for omitted variables (for example, malaria may be proxying for a range of tropical diseases or other liabilities), but there could also be reverse causation, in which high incomes lead to the control of malaria or a reduction of transport costs.

We can control to some extent for reverse causation by using instrumental variables estimation, with instruments based on exogenous geographical characteristics. For example, malarial prevalence is positively associated with the proportion of land area in the tropics and subtropics. Transport costs are higher for countries that are farther away from the main capital-goods suppliers and are landlocked. The proportion of population within 100 kilometers of the coastline is positively correlated with the proportion of the country's land area within 100 kilometers of the coastline. In regression 6, therefore, we re-estimate the equation with the instruments just suggested, specifically the variables Tropic, Subtropic, ln(Distance), LL, and L100km. The original variables—malaria, transport costs, coastal population, and hydrocarbon endowments per capita—all retain their signs and all but the hydrocarbons variable their statistical significance. The TSLS equation continues to explain around 71 percent of the total cross-country variation.

In regression 7 we include a vector of variables related to political and economic institutions: Socialism, which is a dummy variable for socialist economic institutions; State, which measures the proportion of time under colonial rule; Public, which measures the quality of governmental institutions; and Open, which measures the proportion of time between 1965 and 1990 that the country is open to international trade. We find, in line with many recent studies, that openness and quality of public institutions is highly correlated with the level of income. The socialist variable is not significant, probably because of the strong collinearity with Open and a few of the other variables and the smaller data set once we include the Public variable (since that variable is not available for most of the socialist economies). Newly independent countries have a lower income level (around 11 percent). This could be a legacy of colonial rule or a reflection of the difficulties of state formation in the early years of independence. We did not pursue that issue further. In regression 8, we re-estimate the equation dropping Socialism. We find, importantly, that *both policy and geography variables* are important in explaining the level of 1995 per capita GDP. Remember that geography may be even more important than suggested by this equation, since there are reasons to believe that favorable geography plays a role in inducing growth-promoting institutions such as open trade and an efficient public bureaucracy. We examine this linkage briefly below.

*Geography and Growth of Per Capita Income*

We now examine the forces of convergence and divergence by estimating a cross-country growth equation that allows for the possibility of catching-up effects. Thus we estimate a model of average annual growth during 1965-90 conditional on per capita income levels in 1965. (The dates are determined by data availability. For the purposes of the growth equations we use the Penn World Tables for our measures of GDP per capita.) We test whether growth is affected by the initial income level (negatively in the case of convergence, positively in the case of divergence), as well as by geographical variables holding constant the initial income and other policy and institutional variables.

We start with a baseline equation similar to those in Barro and Sala-i-Martin, in which average annual growth between 1965 and 1990[21] is a function of initial income in 1965, the initial level of education in 1965 (measured by average years of secondary school in the population), the ln life expectancy at birth in 1965, the average ratio of investment to GDP (1970 to 1989), the openness of the economy to international trade, Open, and the quality of public administration, Public. This is shown in regression 1 of table 4. We find evidence for conditional convergence and standard results for the other variables: output is an increasing function of education, life expectancy, openness, and the quality of public administration, though the last variable is not statistically significant. In regression 2 we add Tropicar (the share of land in the geographical tropics), Pop100km and ln(Distance). Tropicar and Pop100km are highly significant and of the expected sign. Tropical countries, all other things equal, experienced 0.7 percentage points per year slower growth. Landlocked countries (Pop100km = 0) experienced 0.9 percentage points slower growth than coastal economies. Interestingly, the ln(Distance) variable is not significant. This suggests that distance to the core may be subsumed by some other variables. Indeed, countries closer to the core economies tended to be more open, with better public institutions, and with higher investment rates during the period. If we drop those three variables, then ln(Distance) has the expected negative sign with statistical significance (not shown).

In regression 3 we drop ln(Distance) and add a measure of the change in malaria incidence during the period. Using data from the World Health Organization from 1946 and the U.S. Centers for Disease Control in 1995, we construct a measure of malaria prevalence (scale from 0 to 3) for 1946 and 1995.[22] We measure the apparent change in prevalence as Dmal4695 = malar95 - malar46. We see that countries that experience a significant drop in malaria (Dmal4695 < 0) have a higher growth rate during the period, even after controlling for initial life expectancy. The direct growth benefit starting with high endemicity (malar46 = 3) and achieving full eradication (malar95 = 0) is estimated to be 3 x 0.65 = 1.95 percentage points per year. Table 5 shows the eradication experience of countries in our sample that started with highly endemic malaria (malar46 = 3). The main successes are temperate-zone economies (Tropicar = 0), such as

Spain and Yugoslavia. On average the temperate-zone endemic economies reduced their malaria rating by 2.9 points on our 3-point scale, while the tropical countries on average reduced their malaria score by only 0.6 points.[23]

In regression 4 we test for agglomeration effects. The basic idea is to see how economic growth depends on the scope of the market. A plausible measure of scope of the market is GDP per square kilometer within the economy in the initial year, 1965. We separate GDP per square kilometer on the coast and GDP per square kilometer in the interior for reasons discussed earlier: population density on the coast is likely to be associated with an increased division of labor and increasing returns, while population density in the interior is likely to be associated with diminishing returns. Note that ln(GDP density) = ln(GDP per square kilometer) = ln(GDP per capita) + ln(Population per square kilometer), and since ln(GDP per capita) is already a regressor, we can enter population density or GDP density interchangeably into the regression. For countries in which the entire population is within 100 kilometers of the coast, we put the interior population density at zero. For countries in which the entire population is farther than 100 kilometers from the coast, we put the coastal population density at zero. We also drop Pop100km as a separate regressor, since Pop100km is highly collinear with the two population density variables. Note that we use the 1994 measures of Pop100km and the 1965 population levels for the country as a whole to calculate the population densities in the coastal and interior regions.

The regression estimate is revealing. As before, we find that education, the investment rate, and openness are powerful explanatory variables. The malaria effects are, again, found to be highly detrimental to growth. We also once again find that higher initial GDP is associated with *lower* growth, in line with the hypothesis of conditional convergence of per capita income levels.

We now find that higher coastal population density is associated with faster growth, while higher interior population density is (weakly) associated with lower growth. Thus there appear to be economies of agglomeration at play in the coastal regions, though they are not powerful enough to overcome the other tendencies towards conditional convergence in income levels.

Our general conclusions from the growth equations are as follows. First, both policy and geography variables matter. There is no simple “geographic determinism” nor a world in which only good policy matters. The tropics are adverse for growth, while coastal populations are good for growth. We did not find strong evidence that distance per se from the core markets is an important determinant of growth. The tropical effect seems to be strongly related to the prevalence of malaria. This could be the true direct and indirect effects of that disease or, more probably, a proxy for a range of tropical maladies geographically associated with malaria. The access to coast seems to matter not just in lowering transport costs but in allowing for some sort of agglomeration economies. A dense coastal population is actually seen to be favorable to economic growth during 1965-90, while a dense interior population is either neutral or adverse.

If we summarize the implications on a region-by-region basis we conclude that Africa is especially hindered by its tropical location, its high prevalence of malaria, its low proportion of the population near the coast, and low population density near the coast. Europe, North America, and East Asia—the core regions—are by contrast favored on all three counts. South Asia is burdened by a high proportion of the population in the interior, a very high interior population density, and a large proportion of the land area in the tropics. The transition economies of Eastern Europe and the former Soviet Union are burdened by a high proportion of landlocked countries and relatedly a very low proportion of the population near the coast, but these countries are benefited by lack of exposure to tropical disease. Finally, Latin America is moderately coastal, but with relatively low coastal population densities. Moreover, Latin America has a moderate exposure to the problems of tropics, including malaria.

In table 6 we present a decomposition of the growth rates of these regions using regression 5 in table 4. We make a statistical accounting of the deviation of each region's growth from that of East Asia during the period.[24] In the case of Africa health and geography factors are estimated to reduce growth by 2.0 percentage points per year, more than the macroeconomic factors of investment, openness, and the quality of public institutions. In South Asia geography is moderately important (-0.8 percentage points per year), while in Latin America, the geography and health variables explain almost nothing about the shortfall in growth relative to East Asia. As we suggest in the next subsection, this accounting may underplay the real role of geography, since economic policy choices themselves are likely to be a function of geography.

*Geographical Effects on Economic Policy Choices*

We have noted in the theoretical section that geography may affect economic policy choices by altering the tradeoffs facing government. A coastal economy, for example, may face a high elasticity of output response with respect to trade taxes, while an inland economy does not. As a result, a revenue-maximizing inland sovereign may choose to impose harsh trade taxes while a coastal sovereign would not. In this section we briefly explore this idea with the data at hand, focusing on the choice of openness versus closure to trade in the period 1965-90 as affected by geography.

The first step is to check the underlying notion: that the responsiveness of growth to openness actually depends on geography. So far we have entered Open and geography variables in a linear manner, not allowing for interactions. To check the possibility of interactions we estimate the basic regression equation for three sets of countries—all, coastal (Pop100cr >= 0.5), and hinterland (Pop100cr < 0.5)—and check the coefficient on the Open variable. Since we lose degrees of freedom in this exercise, we estimate the barebones growth equation, in which annual average growth between 1965 and 1990 is a function of initial income, Open, Investment, malaria in 1946, the change in malaria between 1946 and 1995, and the ln of life expectancy in 1965. The results for the Open coefficient are as follows (t-statistics in parentheses): All economies (N=68), $\beta = 0.10$ (2.1); coastal economies (N=43), $\beta = 0.017$ (4.6); hinterland economies (N=25), $\beta = -0.007$ (0.5). Indeed, we do see that growth responsiveness to trade seems to be related to the extent of the coastal population.

The next step is to see whether more coastal economies in fact choose more open trade policies. This we do by regressing the extent of openness during 1965-90 on Pop100cr and the initial income level:

$$\underset{}{\text{Open6590}} = \underset{(5.5)}{-1.51} + \underset{(2.2)}{0.23}\ \text{Pop100cr} + \underset{(5.6)}{0.23}\ \ln GDP_{1965}$$

$N = 105$, $R^2 = 0.42$

There does indeed seem to be something to this line of reasoning, though the results are at best suggestive and should be tested more carefully in later work. The early liberalizers, on the whole, were the coastal economies. This is certainly evident in East Asia, where countries such as Korea, Malaysia, Taiwan (China), and Thailand all opened the economy to trade early in the 1960s, much before the other developing countries.

## Population Distribution and Economic Activity

### *Geography and Population Density*

The distribution of population around the world is anything but uniform. Large expanses are virtually uninhabited by humans, while almost all the land in Europe and coastal South and East Asia is tilled or occupied by towns or cities. The dramatic differences in population density at different latitudes are shown in figure 5. The geographical features that support high population densities seem to fall along two main dimensions. First, there are features that favor dense agricultural settlements, such as soil suitability, inland rivers for local transport and irrigation, and climatic and ecological systems conducive to rice cultivation (which supports an especially high labor intensity of production compared to other grasses). Second, there are features that support modern economic growth, such as access to the coastline and thereby to international trade. Since population densities have a very long time dependence, the current distribution of world populations was heavily influenced by demographic trends well before the period of modern economic growth. We see from figure 6, for example, that the high population density regions of 1800 are virtually the same as those of 1995 (which were seen in figure 2). Broadly speaking, we can say that the agricultural dimension of population settlement is more imprinted on global population patterns than the growth dimension. Also, the legacy of low population densities in the New World persists despite several centuries of in-migration from the Old World.

Very importantly, the geographical conditions propitious for dense agrarian populations are often very different from those conducive to modern economic growth. Most importantly, agriculture depends more on access to fresh water than on access to the ocean. This has led throughout history to high concentrations of inland populations that are now substantially cut off from participation in international trade. Moreover, as we noted earlier, the dynamics of population change may exacerbate the biases towards high concentration in inland areas. Rising incomes through successful industrialization has made population growth self-limiting in the richer regions. By contrast, the rural areas with poorer growth prospects have some of the highest population growth rates in the world.

The conjunction of a geography that supports high population densities but not economic growth is the location of the most severe and intractable poverty. Hinterland China, north central India, central Asia, and inland Africa are all far from world trade and dependent on labor-intensive agriculture with significant disadvantages for modern economic growth. Severe endemic disease burdens, especially in Africa, add to the geographical obstacles. The role of geography in shaping the distribution of population can be seen in the simple population growth identity. Current population depends on the population at some point in the past, and the growth rate during the intervening period:

(17) $$P_{i1} = P_{i0} e^{r_i T}$$

where $P_{il}$ is the current population density in location $I$, $P_{i0}$ is past population density, $r_i$ is the instantaneous growth rate, and $T$ is time elapsed between period 0 and period 1. The population growth rate in each location, $r_i$, depends on geography as well as initial population. If $r_i$ is not allowed to depend on the initial population density, then current population is always exactly proportional to past population. The population growth rate is given by

(18) $$r_i = g \ln P_{i0} + \gamma \ln X_i$$

where $g$ and $\gamma$ are parameters, and $X_i$ is a vector of geographical characteristics. Taking logs of equation 1 and adding an error term $\in_i$,

(19) $$\ln P_{i1} = (1 + gT) \ln P_{i0} + \gamma T \ln X_i + \varepsilon_i$$

We can regress the current population density on an initial population density (say, in 1800) and geographical characteristics, all in logs, using equation 19. The first coefficient will tell us the degree of persistence in population density. If the coefficient is less than one, $g$ is negative: higher density regions grow slower. This is a measure of "convergence" of population density across space, similar to convergence in economic growth equations. The second set of coefficients tell us the impact of geography on population density given the initial density; that is, the impact of geography on population growth in the last 200 years. If we take the initial point at the time of the first appearance of humans ($T' \cong 500{,}000$; Diamond 1997, p. 37), then $P'_{i0} = 1$ and

(20) $$\ln P_{i1} = \gamma' T' \ln X_i + \varepsilon_i$$

The coefficient vector estimated from this specification tells us the unconditional impact of geography throughout time on current population densities.

*Results of the Analysis*

Equations 19 and 20 are estimated using the following geographical features: accessibility to the coast and rivers, elevation, malaria, soil qualities and water availability, and ecozones.[25] The results are reported in table 7. There are several clear patterns:

- Being close to inland and navigable rivers is an important predictor of population density and more important than being close to the coast.
- Good soils and water supply are important factors in population density.
- Population densities are highest in the moist temperate ecozone.
- Population density is greater at high altitudes in the tropics, but lower at high altitudes in the temperate zone.
- Malaria has a curious positive correlation with population density.

- There is tremendous persistence in relative population density over the centuries, but there is also some convergence towards a more uniform density. (The coefficient on population density in 1800 is positive and less than one.)
- Eurasia has much higher population densities after taking into account all the geographical factors, and lands of new settlement (the Americas, Australia and New Zealand) have much lower population density.

The tendency for population to cluster near nonnavigable inland rivers and less often on the coast or near navigable rivers is directly contrary to the relative importance of these waterways for high economic output. This pattern, along with the clustering of population in areas of good soil and water (especially the particular conditions suitable for rice cultivation) and the more agriculturally productive ecozones, suggests that suitability for agriculture has been the principle driving force behind the population distribution. The distribution of population near rivers rather than near the coast is striking when the regressions are done by region (not shown). South Asia, the former Soviet Union, Western Europe, and East Asia all have *lower* population densities near the coast, given their distance to rivers. In Western Europe and East Asia, the population had the good fortune to cluster near rivers navigable to the sea, while South Asian populations have very poor access to water-borne trade. Latin America is the only region with a stronger concentration of population on the coast than near rivers.

Figure 7 uses the GIS mapping to identify high population densities that are far from the coast and ocean-navigable rivers. The greatest such densities, we see, are in Central Africa, South Asia (especially the Gangetic Plain), the interior of China (with heavy concentrations in the river valley systems and Manchuria), and Central Asia, including Iran, Iraq, Anatolia, and states near the Caspian Sea.

The much higher population densities at higher altitude in the tropics, unlike in the temperate zone, could be due to a less hostile disease environment, since many tropical disease vectors are altitude and temperature sensitive. This doesn't seem to be consistent with the positive correlation of population density and malaria, however. Looking at regions separately, the population densities are (statistically) significantly lower in malarial areas in all regions but Africa, where population is much denser in malarial areas. Since Africans in malarial areas may have built up partial immunities to malaria, they may not seek to avoid infection by moving to nonmalarial areas that may have other disadvantages (such as a lack of water). Given the strong negative correlation of malaria with income levels, the higher population density in malarial areas is of course extremely worrisome.

There are good geographical arguments for Eurasia's higher population densities and the new settlement lands' lower densities. Diamond (1997) argues that Eurasia's east-west axis along rather than across ecozones has allowed for the movement of crop varieties, ideas, and goods. Eurasia also seems to have had the best selection of native plants and animals for original domestication. The lands of new settlement had the least conducive flora and fauna for domestication, Diamond has speculated, and in any event were physically isolated from the rest of the world until the modern era and therefore not open to the diffusion of technology, ideas, and trade that gradually permeated Eurasia.

**Policy Implications and Future Research Directions**

One skeptical reviewer of an early draft of this work said, “Fine, but we knew all this in seventh-grade geography.” We have three responses. First, it is not really true. Seventh-grade geography did not attempt to quantify the advantages or disadvantages of various parts of the world in a systematic way, holding constant other determinants of economic performance. Second, even if true, whatever was gained in seventh-grade geography was lost somewhere in graduate school. The vast majority of papers on economic development and growth which were written in the past decade using the new cross-country data sets and rigorous hypothesis testing have neglected even the most basic geographical realities in the cross-country work. A large number of writings on Africa, for example, have tested many socioeconomic variables for their effects on growth, without even reflecting on the implications of the high proportion of landlocked countries, the disease environment, the harsh climate and its affects on agriculture, or the low population densities in coastal areas. Third, the policy implications of these findings, if they are true, are staggering. Aid programs should be rethought, and the critical issue of population migration should be put into much sharper focus.

The research agenda needs to be reshaped in light of the importance of geographical variables. We know precious little about the underlying relationships of climate to agricultural productivity, disease vectors, and public health. Not only do we not know the development costs of malaria, but we barely know the quantitative extent of the disease. Cause-of-death data are essentially not available for most developing countries, and even less available are the data on morbidity. We lack basic data on transport costs that are comparable across countries and, even more dramatically, within countries—say, between the hinterland and the urban areas. By neglecting geographical variables we may well tend to overstate the role of policy variables in economic growth and neglect some deeper obstacles.[26]

The following four research questions relating to geography warrant further scrutiny:

- How do transport costs differ across countries? How many of those differences are related to policy (for example, port management or poor road maintenance), market structure (such as pricing by shipping cartels), or physical geography (inland versus coastal versus oceanic trade)? How are transport costs likely to change as a result of new information technologies, improved intermodal transport, and other trends?
- What is the burden of disease on economic development? What are the channels of effects: direct and indirect costs of infant and child mortality, adult morbidity, premature death? What are the main channels of morbidity: direct effects, interactions with other diseases, interactions with nutrition, and so on? To what extent is the differential burden of disease a result of policy (for example, the organization of public health services), resource availability for health expenditures, or intrinsic geographic factors such as the ecology of disease vectors?
- To what extent are observed differences in agricultural productivity a result of policy (such as the taxation of agricultural inputs and outputs), the quality of inputs, the scope and scale of agricultural research, and intrinsic geophysical and biological conditions?
- How are fertility decisions affected by geography? Are the high fertility rates in Sub-Saharan Africa a result of (1) low population densities in rural Africa; (2) limitations of nonagricultural activities in the hinterland; (3) policy decisions or limitations (for example,

lack of adequate family planning); or (4) institutional arrangements, such as communal land tenure, which may lead to externalities in family size?

Of course, having a better grasp of these issues will only lead to further issues for analysis: to what extent do transport costs, disease burdens, agricultural productivity, and population growth and density affect overall economic performance? Consider, for example, the relatively straightfoward issue of transport and communications costs. It might be supposed that falling transport costs will necessarily favor the hinterland, which is now burdened by very high transport costs. Krugman, Venables, and others have shown, to the contrary, that a reduction of transport costs from high to moderate levels can actually disadvantage a high-cost region at the expense of a medium-cost region by giving even greater benefits to the second region. Consider our simple set up in equation 7. Suppose that there are two economies with differential transport costs. Suppose, for example, that $\tau_i = \exp(d_i\, \mu)$ where $d_i$ is the distance of economy, *i*, from the core economy, and $\mu$ is a transport cost parameter that declines over time. Suppose that there is a "near" and a "far" economy, with $d^n < d^f$. When $\mu$ is very high both economies have zero growth. When $\mu$ is zero both have equal and high growth. It is when $\mu$ takes a middle value that growth rates differ, with the near economy growing faster than the far economy. Thus even when we know how transport costs differ and how they are likely to evolve, we must have an accurate spatial model to understand the implications.

The policy implications of these geographical considerations must of course be informed by clearer research results. Even now, however, we can identify several areas of public policy that almost surely should be adjusted. First, we should give heightened scrutiny to the special problems of landlocked countries and hinterland populations within coastal economies. There are 28 landlocked countries outside of Europe, with 295 million people in 1995. These are, for reasons we have been stressing, among the poorest countries in the world, with an average income of $1,633. In a large number of cases the infrastructure connecting these countries to world markets is seriously deficient. The coastal economies harass the interior economies or neglect the road networks that would link them to the coast or impose punitive effective taxation on transit and port charges. In some cases there have been heated political clashes between the interior country and the coastal economies. Chile and Bolivia still lack diplomatic relations 119 years after the War of the Pacific cost Bolivia its coastline. Aid programs to improve transport infrastructure linking landlocked countries to ports almost necessarily require the cooperation of more than one country. For example, crucial infrastructure aid for Rwanda includes the repair and maintenance of the Kenyan road from Nairobi to Mombasa, which also transports Ugandan tea to the Indian Ocean. Such cross-national needs are hard to coordinate and are often neglected by country-based donor efforts. By the same token, but perhaps somewhat easier, policymakers should give heightened scrutiny to transport conditions for hinterlands within national economies, such as Uttar Pradesh in India, where more than 140 million people live several hundred kilometers from the coastline.

Second, policy makers should examine the likelihood and desirability of large-scale future migrations from geographically disadvantaged regions. Suppose that it is true that significant populations face local cost or disease conditions that are simply prohibitive of economic growth. The result is likely to be growing pressures for mass migration, first within countries, then across immediate national border, and finally internationally. We have not yet studied the linkages of geography and migration, though it is painfully evident that the linkage is strong. Landlocked countries such as Bolivia have perhaps 15-20 percent of the population living in neighboring countries, especially Northern Argentina. It is estimated that around one-third of Burkinabes are living in Ghana, Ivory Coast, and elsewhere. In general throughout Southern Africa, there are large relatively uncontrolled populations movements across national boundaries. While this is a long-standing pattern of the region, the consequences are becoming increasingly complex and often deleterious, because of the unintended spread of HIV and other diseases and the inability of the environmental and public health institutions to cope.

Third, to the extent that the arguments in this paper are correct, they shed a dramatic light on current population trends. We have shown that future population increases are likely to be largest precisely in the most geographically distressed economies. Consider the United Nations medium population projections for the year 2030. The projected annual average growth rates between 1995 and 2030 are mapped in figure 8. We see clearly that the highest projected growth rates are for the regions that are least coastal, most tropical, and most distant from the core economies. If we regress the projected population growth on geographical characteristics we find:

Annual population growth, 1995-2030 (projected, in percentage points) =

-2.1 + 0.91 Tropicar + 0.41 Ln(Distance) - 0.74 Pop100km

(3.34) (6.42) (5.31) (4.63)

N = 147

$R^2 = 0.59$

We see, for example, that inland economies (Pop100km = 0) have projected growth rates that are 0.74 percentage points per year higher than coastal economies (Pop100km = 1). Tropical economies have projected growth 0.91 percentage points above nontropical economies.

Population pressures in these difficult locations are likely to intensify the pressures for mass migration. We therefore require a more urgent look at population policy. A certain calm has descended over this policy area on the fallacious grounds that population growth "does not matter for per capita economic growth." We have seen the half-truth of this assessment: it may be true for coastal economies engaged in the international division of labor; it is almost surely untrue for the geographically distressed regions where the population increases will be most dramatic.

Fourth, the policy community should reexamine the balance of aid between policy-based lending to individual governments, which is the current popular form of aid, and greatly enhanced aid for basic science on tropical agriculture and tropical public health. The results in this paper strongly suggest that the tropics are damned not only, or even mainly, by bad policies, but by difficult inherent conditions. If this is the case, the relentless pressures on policy reform may in fact be misguided. Perhaps a more effective approach to malaria would do more to improve the economic environment—and incidentally, improve policy—by improving the incentives for good policies that face the sovereign. There is no doubt that many of the core issues in tropical health and agriculture are prime examples of international public goods that require a concerted scientific and financial commitment far beyond any individual government.

While the coordinated agricultural research aid effort is seriously underfunded, the situation in tropical public health is even more desperate.

**Data Appendix**

One degree by one degree population database

The data for population in 1994 come from the first detailed world population dataset (seen in figure 2) described in Tobler and others (1995). We aggregated the 5′ by 5′ cells to 1° by 1° cells creating approximately 14,000 observations. The world population distribution in 1800 comes from McEvedy and Jones (1978), mostly on a country-wide basis. The geographical data come from a variety of sources. Incidence of malaria was digitized from a WHO (1997) map for 1994. Distance of each 1° population cell from the coast was calculated from the ArcWorld coastal boundaries (ESRI, 1992). These boundaries were edited to remove the coasts north of the winter extent of sea ice in the Arctic Circle. Navigable rivers leading to the sea were taken from the ArcAtlas database (ESRI 1996), compiled by a Russian geographical institute, and then revised by us using descriptions of the navigability of individual rivers (Rand McNally 1996, Britannica Online 1998, and Encyclopedia Encarta 1998). Inland rivers are rivers classified by ArcAtlas as navigable but with no outlet to the sea, as well as navigable to the sea but not navigable by oceangoing vessels. Elevation data are derived from the ETOPO world elevation database (NOAA 1988). Land used for rice growing was derived from the ArcAtlas database on agriculture (ESRI 1996). Soil depth and stream density (a count of the streams in each 1° cell from satellite data) come from NASA (Sellers and others, 1997). Soil suitability for rainfed and irrigated crops was derived from Digital Soils Map of the World (FAO 1995). A classification of land areas into 37 ecozones comes from the UNEP (Leemans 1990)

**Table 3. Variables Used in the Cross-Country Regression Analysis**

**Dependent variables**

*GDP per capita*: GDP, PPP adjusted, per capita, in 1995

*GDP growth rate*: Penn World Tables, 1965 and 1995.

**Transport cost and market proximity measures**

*POP100km:* The proportion of the population within 100 kilometers of the coastline

*LT100km*: The proportion of the country's land area within 100 kilometers of the coastline

*Distc*: The average distance of the population from the coastline

*Distcrv*: The average distance of the population from the coastline or an ocean-navigable river

Density: Population/square kilometer

*CoastDensity*: Coastal population/coastal square kilometer (coast is defined as within 100 kilometers of coast)

*InteriorDensity*: Interior population/interior square kilometer (interior is defined as beyond 100 kilometers of coast)

*LL*: A dummy variable equal to 1 if the country is a non-European landlocked country, and 0 otherwise

*Eurasia:* A dummy variable equal to 1 if the country is on the Eurasian landmass (also islands just off the Eurasian land mass, such as Ireland, United Kingdom, Japan, the Philippines, Indonesia)

*Airdist:* The minimum air-distance to one of the three capital goods supplying regions, the United States, Western Europe, and Japan, specifically measured as distance to New York, Amsterdam, or Tokyo

*CIF/FOB margin:* The ratio of CIF import prices to FOB import prices as a direct measure of transport costs

**Other geographical variables**

*Tropicar:* The proportion of the country's land area within the geographical tropics

*Etropics:* The proportion of the country's land area within the ecological tropics, as measured by a global ecological classification scheme

*MalariaCDC:* Estimate of malaria prevalence in 1995, based on data from the U.S. Centers for Disease Control (1995)

*MalariaWHO:* Estimate of malaria prevalence in 1995 based on a WHO global map

*Hcpc:* Per capita hydrocarbon deposits

*Regional dummy variables:* North America (Nam); South American and Carribean (SAC); Europe and North Africa (Euna); Sub-Saharan Africa (SSA); Asia (A); Australasia (AA)

**Economic and political variables**

*Open:* The proportion of years that a country is open to trade during 1965-90, by the criteria in Sachs and Warner (1995)

*Public:* The overall score on quality of government institutions in 1980, as evaluated by the ICRGE

*CGB7090:* The central government saving rate, as a percent of GDP, between 1970 and 1990

*State:* The timing of national independence (= 0 if before 1914; 1 if between 1914 and 1945; 2 if between 1946 and 1989; and 3 if after 1989)

*Wardum:* A variable between 0 and 1 attempting to proxy for the intensity of war affecting the country during 1950-95, with more recent war given a greater weight

*Social:* A dummy variable equal to 1 if the country was under socialist rule for a considerable period during 1950-95

## Notes

This research leans heavily on the work of a group at the Harvard Institute for International Development, especially Steven Radelet's work on the role of transport costs, and Andrew Warner's work on natural resource abundance. Our progress in exploring the role of geography and the long process of creating new datasets has been shared with these researchers. We thank the organizers of the Annual Bank Conference on Development Economics for the opportunity to present our work in progress.

1. These figures refer to the unweighted average of GDP per capita of nine economies: China, the Republic of Korea, Taiwan (China), Hong Kong (China), Singapore, the Philippines, Malaysia, Indonesia, and Thailand.

2. We will refer alternatively to the geographical and the ecological tropics. The geographical tropics are the area between the Tropic of Cancer (23.45 N latitude) and the Tropic of Capricorn (23.45 S latitude). The ecological tropics refer to climatic conditions. While there are many systems of ecozone classification, the main defining characteristic of the ecological tropics is the absence of any month with an average temperature below $0^0$ C. The absence of freezing, of course, has profound effects on plant and animal ecology, disease vectors, water evaporation, soil formation and regulation, and many other biophysical characteristics of the environment.

3. All data are described in the data appendix. While the population data are presented on a 5 minute by 5 minute refinement, some of the underlying data base is actually less refined, with population interpolated to the 5 minute by 5 minute grid.

4. For the universe of 150 countries with populations greater than 1 million, the correlation between population density (population per square kilometer) and GNP per capita in 1995 is 0.31.

5. For these purposes we include the U.S. and Canadian regions bordering the ocean-navigable Saint Lawrence Seaway and Great Lakes.

6. We have not yet assembled subnational GDP data. Therefore, to make the calculation we assume that GDP per capita is identical in all regions within a country. This understates the size of GDP in the coastal regions, since GDP per capita tends to be higher in coastal regions.

7. These 11 economies, in declining order of shares in global exports, are as follows (with percentage shares in parentheses): the United States (20.0), Japan (20.0), Germany (14.6), France (6.4), the United Kingdom (5.8), Italy (4.9), Canada (4.7), Korea (3.2), Taiwan (China) (2.9), Belgium (2.7), Netherlands (2.5). Other major exporting economies that are closely linked to the core production system include: Singapore (4.3), China (2.7), Mexico (2.3), Malaysia (2.2), and Hong Kong (China) (0.7).

8. There is, apparently, an inconsistency in our classification, since the definition of tropics is based on land area in the geographical zone, but subtropics are defined according to ecozone. We chose to rely on the geographical definition of the tropics both for convenience and because of its empirical relevance in the regression estimates. There is no comparable geographical definition of the subtropics, so for that category we fall back on an ecozone definition.

9. Morocco is just on the borderline of classification as a subtropical country, with 48 percent of the population in the tropical and subtropical ecozones.

10. The key recent reference on cross-country growth is Barro and Sala-i-Martin (1996). This book does not make a single reference to economic geography. Nor do literally hundreds of recent cross-country growth studies. One recent (and nearly lone) exception is Hall and Jones (1997), who note that economic productivity of countries (measured as per capita GDP) increases with the distance from the equator.

11. Smith does not discuss culture and economic development in any detail in *The Wealth of Nations*, but it seems clear that, in line with much thinking of the Scottish Enlightenment, he viewed human nature as universal, and culture as not a primary differentiating factor in economic development. After all, he saw the “propensity to truck, barter, and exchange one thing for another” as universal, not culturally specific. For example, Smith never bemoans the lack of entrepreneurial zeal in one place or another as an explanation for poor economic performance. Later thinkers such as Max Weber put great stress on culture, though the alleged linkages are particularly difficult to document and test. Recently, a leading economic historian, David Landes, has argued that culture, in addition to geography and institutions, should be emphasized in explaining the differences in economic performance.

12. He noted that "all the commercial benefits" to the East and West Indies that might have resulted from increased trade "have been sunk and lost in the dreadful misfortunes" occasioned by European military advantage, which enabled the Europeans "to commit with impunity every sort of injustice in those remote countries."

13. Suppose that instead of Cobb-Douglas, the investment function is a constant elasticity of substitution (CES) function of the underlying investment in each country: $I = (\Sigma\, \mu_j\, I_j^{-\varepsilon})^{-1/\varepsilon}$. The elasticity of substitution is $\sigma = 1/(1+\varepsilon)$. In that case, the price index $P_I$ is also a CES of the prices of the individual investment goods, of the form: $P_I = [\Sigma\, \mu_j^{\sigma}(\tau_j\, P^{*}_{j})^{(1-\sigma)}]^{1/(1-\sigma)}$. Thus if the investment function has an elasticity of substitution $\sigma$, the price index has an elasticity of substitution $1/\sigma$. When $\sigma = 1$, so that the investment function is Cobb-Douglas, the price index is also Cobb-Douglas, with $P_I = \Pi\, \nu\, P_j^{aj} = \Pi\, \nu\, (P_j^{*})^{(aj)}\tau_j^{\,aj}$, $\nu = a_1^{\,a1} a_2^{\,a2} \ldots a_n^{\,an}$.

The growth rate of the home country depends on a geometric weighted average of transport costs from *each* of its capital suppliers, with the weight equal to the share of investment goods from $j$ in the total investment expenditure of the home country. When the elasticity of substitution among investment goods is infinite, the CES price index has zero elasticity and takes the form: $P_I = \min\{\tau_j P^{*}_{j} / \mu_j\}$. What counts in that case is not a weighted average of prices, but rather the lowest price adjusted for the productivity of the various investment goods. The relevance for geography would be as follows: assuming that the efficiency-adjusted price of capital goods is equal in all markets, that is, that $P^{*}_{j}/\mu_j$ is the same across all markets, growth would depend on the minimum distance to one of the capital-goods suppliers, rather than the average distance to all of the suppliers of capital goods. In practice, transport costs would depend on the minimum distance to a major market—the United States, or Western Europe, or Japan—rather than the average distance to the United States, Europe, and Japan. In our empirical work we find that the specification of minimum distance to a major capital goods supplier outperforms the average distance to all major capital goods suppliers.

14. Caldwell in particular has argued that population pressures are likely to remain high in rural areas while falling sharply in urban areas. According to Caldwell, children are net economic assets in peasant rural areas since they can assist in household production from an early age (for example carrying water and firewood), do not generally require high expenditures on education, and can be counted on to care for parents in old age. In an urban setting, however, children are net economic costs: they are likely to attend school rather than contribute to household production, and

because of urban mobility are much less reliable as social security for aged parents. Moreover, the opportunity costs of raising children are much higher, especially if women are part of the urban labor force.

15. The standard model of traditional agriculture is based on a neoclassical production function of the form $Q = Q(L,F)$, where $L$ is labor input and $F$ is a vector of other farm inputs, including land. Output per capita falls as $L$ rises relative to $F$. The increasingly popular model of differentiated production makes $Q$ a function of $n$ intermediate products $X_i$, each produced with labor, $L_i$, so that $Q = (\Sigma X_i^{\gamma})^{(1/\gamma)}$, with $0 < \gamma < 1$. Under conditions of monopolistic competition, free entry, and costless introduction of new product varieties, it is typically shown that $X_i$ is fixed by profit maximizing firms at a given production run $x$, with $L_i = a + bx$. For a total labor force $L = \Sigma L_i$, we have $n(a+bx) = L$, or $n = L/(a+bx)$. Then production is $(\Sigma x^{\gamma})^{(1/\gamma)} = n^{(1/\gamma)} x = L^{(1/\gamma)} x (a+bx)^{-(1/\gamma)}$. The result is that production shows increasing returns to labor. Output per labor is therefore a rising function of $L$.

16. There is an instantanous probability $h$ of losing office. The probability distribution for tenure in office is then $f(t) = h\exp(-ht)$, and the mean time in office is $1/h$.

17. The data refer to unweighted country averages for the respective regions for the countries for which IMF data are available.

18. We experimented with a number of distance measures, all of which produced similar outcomes. We therefore choose the simplest: the smallest distance of the country's capital city to one of the following three cities: New York, Amsterdam, or Tokyo. Adding Los Angeles to this list makes a difference only for Mexico (since all other Latin America economies are closer to the Eastern Seaboard) and no difference to the econometric results.

19. The great range of uncertainty about the number of cases is itself indicative of the lack of concerted study and monitoring of malaria by international organizations in recent years.

20. The random term $\varepsilon_i$ is of course a function of the initial error term $\zeta_i$ as well as the intervening sequence of disturbances $\{\mu_{i\,t}\}_{t\,=\,0\text{ to }T}$. OLS estimation would require that the error terms are independent of the $Z_i$.

21. Growth is measured as (1/25)x(lnGDP1990 - lnGDP1965)x100.

22. Because of lack of suitable data, our index is necessarily approximate. We give a value of 3 if malaria is endemic to the entire country during the entire year. We give a value of 2 if malaria is endemic to the entire rural area, but not

in major cities. We give a value of 1 if malaria endemicity is partial by region and season. We give a value of zero if there is no malaria. Based on our own judgments we refine this scale to include half steps between 0 and 3.

23. The basic regression is (t-statistics in parentheses):

Dmalar4690 = -2.7 + 2.1 Tropicar,

(7.5) (5.4)

N = 57, $R^2$ = 0.35

24. We do not include Hong Kong (China) and Singapore in the East Asia region for purposes of this calculation. These two special cases were also not in the regression estimates because of a lack of some underlying data.

25. The data sources are explained in the appendix.

26. On the other hand, since policy variables are often so poorly measured in cross-country work, there is an inherent downward bias due to measurement errors.

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