Geography and Economic Development

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Abstract

This paper addresses the complex relationship between geography and macroeconomic growth. We investigate 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. We find 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 we identify geographical regions that are not conducive to modern economic growth, we find that many of these regions have high population density and rapid population increase. This is especially true of populations that are located far from the coast, and thus that face large transport costs for international trade, as well as populations in tropical regions of high disease burden. Furthermore, much of the population increase in the next thirty years is likely to take place in these geographically disadvantaged regions.

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I. Introduction

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 gains in life expectancy and reduced infant mortality, have spread to nearly all parts of the world, though huge and tragic discrepancies remain in even these areas. In material well being, however, as measured by gross domestic product 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 (1995), Western Europe outpaced Africa in average per capita GDP by a factor of around 2.9 in 1820, and by a factor of 13.2 by 1992. More stunningly, Madison puts the African per capita income in 1992 at $1,284 dollars (measured in 1990 PPP adjusted dollars), which is essentially identical to Maddison's estimate of the average GDP per capita in Western Europe in 1820, $1,292. One area of the developing world, Asia, showed significant progress during the past thirty years, with average incomes rising from around $1,212 in 1965 to $3,239 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 $1,284 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 GDP per capita as of 1995 (using PPP-adjusted estimates from World Bank 1997). Two geographical correlates of economic development are unmistakable. First, the countries in the geographical tropics are nearly all poor.[2] Almost all high-income countries are in the mid- and high latitudes. Second, coastal economies are generally higher income than the landlocked economies. Indeed, outside of Europe, there is not a single high-income landlocked country, though there are 29 non-European landlocked countries.

Figure 2 shows the distribution of population density, measured as population per km^2. Unlike GDP, for which data generally are available only on a national or broad sub-national basis, the world distribution of population as of 1994 is 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 population density and GDP per capita.[4] Second, the great Eurasian landmass is more densely populated than the rest of the world. (This seems to be a

[1] These figures refer to the unweighted average of GDP per capita of nine countries: China, Korea, Taiwan, Hong Kong, Singapore, the Philippines, Malaysia, Indonesia, and Thailand.

[2] The geographical tropics refers to the area between the Tropic of Cancer (23.45 N latitude) and the Tropic of Capricorn (23.45 S latitude), the band in which the sun is directly overhead at some point during the year.

[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 population greater than 1 million, the correlation between population density (population per km^2) and GDP per capita in 1995 is 0.32.

function of human history in addition to 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 (we will use this term to refer to regions more than 100 km from the coast or an ocean-navigable waterway). Part of our goal is to decipher some of the sources of population density, and the somewhat subtle relationship of population density to income levels.

If we multiply GDP per capita and population density, we can calculate GDP density, measured as GDP per km^2, shown 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 U.S. 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 world's financial centers, and the generators of a large proportion of global production. If we take the regions within the U.S., Western Europe, and temperate-zone East Asia that lie within 100 km of the coastline, these areas account for a mere 3 percent of the world's inhabited land area, 13 percent of the world's population, and at least 32 percent of the world's GDP 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 9 percent of the world's population but produces at least 30 percent of the world GDP. According to recent data of the World Trade Organization (1995), just 11 countries in North America, Western Europe, and East Asia, with 14 percent of the world's population, account for 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 GDPs of all 150 countries in the world with population of 1 million or more in 1995. In total, these 150 countries had a combined 1995 population of 5.65 billion, out of a global population estimated to be 5.67 billion. Therefore, our universe of observation includes 99.7 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 population, and 78 non-tropical countries, with 59 percent of the world population. Among the tropical countries, the simple average of 1995 GDP per capita (not weighted by country population) is $3,326. Among the non-tropical countries, the average is $9,027, or nearly three times greater. A simple test of the difference of means across the two groups is significant at the p

[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 sub-national 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 countries, in declining order of shares in global exports, are as follows (with shares in parentheses): U.S. (20.0), Japan (20.0), Germany (14.6), France (6.4), U.K. (5.8), Italy (4.9), Canada (4.7), Korea (3.2), Taiwan (2.9), Belgium (2.7), Netherlands (2.5). Other major exporting countries 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 (0.7).

< .001 level.[8] Using GIS based calculations to allocate populations within countries that are partly tropical and partly non-tropical, we calculate that 1,804 million live in the geographical tropics, or approximately 32 percent of the world's population.

It is convenient to divide the non-tropical countries into two sub-groups, the temperate-zone economies and the sub-tropical economies. For our purposes, we define sub-tropical as countries in which half or more of the land area is tropical or sub-tropical ecological zones, but in which the country's land area is more than half outside of the geographical tropics.[9] There are 15 sub-tropical economies, and 63 temperate-zone economies. While the tropical countries have mean income of $3,326, the sub-tropical countries have mean income of $7,874, and the temperate-zone economies have a mean income of $9,302. Among the economies that were not socialist in the postwar period, the geographical divide is even sharper: non-socialist tropics, $3,685; non-socialist sub-tropics, $9,248; and non-socialist temperate, $14,828.

Of the top thirty countries ranked by 1995 PPP-adjusted GDP per capita, only two are tropical, and these two are tiny: Hong Kong and Singapore. Four are subtropical, and 23 are temperate-zone. The two tropical countries account for a mere 1.0 percent of the combined population of the top 30 countries. Using geographic information system data, we can also examine the proportion of the population living in the geographical tropics in the top 30 countries, taking into account that four of the top thirty countries that we have not counted as tropical (Australia, Chile, Taiwan, and the United Arab Emirates) 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 and Central Europe which are deeply integrated into the regional European market, and connected by low-cost trade.[10] (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 population greater than 1 million, of which 29 are outside of Western and Central Europe. Of these 29 countries, the richest is 38th (!), Botswana, which owes it pride of place to well-managed diamond mines. The second richest is 68th, Belarus. The difference in means is striking: the landlocked countries outside of Western and Central Europe have an average income of $1,771, compared with the non-European coastal countries, which have an average income of $5,567 (p = .001). The difference in economic density is even stronger, since the landlocked countries tend to be very sparsely populated (59 people per km^2 in landlocked countries compared with 207 people per km^2 in coastal countries).

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[8] The estimated significance level to the *t*-test is precise only if the errors are normally distributed, the two groups are statistically independent, and they are drawn from a random sample (not the whole population). The small estimated p value nevertheless indicates that the means are far apart. This caveat applies to the p values reported below.

[9] There is, apparently, an inconsistency in our classification, since Tropics is based on land area in the geographical zone, but Subtropics is defined according to ecozone (from Leemans 1990). 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 sub-tropics, so for that category we fall back on an ecozone definition.

[10] The landlocked countries in Western and Central Europe are Austria, the Czech Republic, Hungary, the Former Yugoslav Republic of Macedonia, Slovakia, and Switzerland.

Of course, geography is not everything. Even geographically favored countries, such as temperate-zone, coastal North 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 non-tropical 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 46 countries as socialist during the post-war period, of which 31 are in the North temperate zone, and four are in the North sub-tropical zone. We also classify 12 non-tropical countries are war-torn. There are 12 non-tropical landlocked countries outside of Europe, of which 10 were socialist and 2 were not.

With these definitions, we find the following. There are 23 countries with the most favored combination of geography and politics — Northern Hemisphere, temperate zone, coastal, non-socialist, and non-war torn — with an average income of $18,000. In fact, 22 of these countries have an average GDP per capita above $10,000, with Turkey and Morocco being the only exceptions.[11] Using a multiple regression estimate for the 78 non-tropical countries, average incomes per capita are reduced by an estimated $4,785 for being in the sub-tropics; $3,590 for being in the Southern hemisphere; $10,053 for being socialist; and $5,190 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 km of the coastline or within 100 kilometers of the coastline or ocean-navigable river,[12] the percentage of the population that lives in landlocked countries, the average distance by air (weighted by country populations) of the countries within the region to the closest "core" economic areas, [13] the density of human settlement (population per km^2) in the coastal region (within 100 km of the coastline) and the interior (beyond 100 km from the coastline). Some important characteristics are the following. First, Sub-Saharan Africa, the poorest region, has several characteristics closely associated with low income in general: a very high concentration of land in the tropics, a population heavily

[11] Morocco is just on the borderline of classification as a sub-tropical country, with 48 percent of the population in the tropical and sub-tropical ecozones.

[12] Using geographical information system (GIS) data, we calculate the coastal population in two ways. First, we take all land area within 100 kilometers of the open sea, except for coastline in the arctic and sub-arctic region above the winter extent of sea ice (NGS, 1995), and measure the population within that area. Additionally, we identify river systems that accommodate ocean-going vessels on a regular basis (e.g. the Saint Lawrence Seaway and the Mississippi River), and add land areas within 100 kilometers of such navigable rivers. Since we do not have direct costs of transport for these river systems, there are inevitably difficulties in classification, as some ostensibly ocean-navigable rivers impose very high costs for such transport. Due to the classification difficulties and the greater empirical relevance of coastal access alone, the population and land area near navigable rivers are not used in the rest of the paper. Information on our classification of river systems is available from the authors. Ocean-navigable rivers are displayed in Figure 8.

[13]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, Rotterdam, or Tokyo.

concentrated in the interior (only 19 percent within 100km of the coast); with more than a quarter of the population in landlocked countries (the highest of any region); very far from the closest "core" markets in Europe; and with low population densities in the coastal and interior regions. By contrast, Europe, the richest region shown, is non-tropical; heavily concentrated near coastal areas; with almost no population in landlocked regions; and with moderate population density. 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 the most densely populated in the world), while the transition economies are non-tropical and also the least densely populated region. Latin America is the other highly tropical region, with low population densities, and with a moderately coastal population. The United States, not shown, has two enormous advantages for development: a relatively high proportion of population near the coast (38 percent within 100 km of the coast, and a remarkable 67 percent if we include ocean-navigable river systems), and a temperate-zone landmass.

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 the possibility of 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, alongside the importance of economic and political institutions. From an analytical point of view, we believe that geographical considerations should be re-introduced into the econometric and theoretical studies of cross-country economic growth, which so far have almost completely neglected geographical themes.[14] Our broad conclusions, described below, may be summarized as follows.

- Tropical regions are hindered in development relative 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 relative to the hinterlands.

- Landlocked economies may be particularly disadvantaged by their lack of access to the sea, even when they are no farther than the interior parts of coastal economies, for at least three reasons: (1) cross-border migration of labor is more difficult than internal migration; (2) infrastructure development across national borders is much more difficult to arrange that similar investments within a country; and (3) coastal economies may have military or

[14]The key recent reference on cross-country growth is Barro and Sala-i-Martin (1995). 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 (1996), who note that economic productivity of countries (measured as per capita GDP) increases with the distance from the equator.

economic incentives to impose costs on interior landlocked economies;

- High population density seems to be favorable for economic development in coastal regions with good access to internal, regional and international trade. This may be the result of increasing returns to scale in infrastructure networks, or because of an enhanced division of labor in settings of high population density. On the other hand, population density in the hinterland shows no such advantages, and our results show a net disadvantage.

- Population growth across countries in the recent past 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 between current population densities and a region's potential for modern economic growth, since population densities seem more to have been driven by agricultural productivity rather 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, international division of labor between industry and agriculture, etc.), *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, etc. *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 to disentangle the forces of differential geography and self-organizing agglomeration economies.

The paper is organized as follows. Section II discusses a range of theoretical approaches linking geography and growth. Section III explores these linkages in cross-country empirical models of growth, population density, and income per capita. Section IV looks in more detail at population densities. Section V discusses several implications of these findings for economic policy and for future economic analysis.

II. 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 (1776[1976]) is most remembered for his stress on economic institutions, Smith also gave deep attention to the geographic correlates of growth.[15] (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.[16]) Smith saw geography as the crucial accompaniment of economic institutions in determining the division of labor. Smith's logic, of course, started with the notion that productivity depends on specialization, and that specialization depends on the extent of the market. The extent of the market in turn depends both on the freedom of markets as well as 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. (p. 25)

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 antient Sycthia, 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 (1972, 1981-84) and William McNeill (1963, 1974), and important recent historians such as E. L. Jones (1981) and Alfred Crosby (1986), have placed the geography and climate of Europe at the center of their explanations for Europe's pre-eminent success in economic development. Braudel pointed to the key role of the Mediterranean-based and North-Atlantic coastal economies as the creative centers of global capitalism after the fifteenth century. McNeill similarly stressed 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

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[15]Smith does not discuss culture and economic development in any detail in the Wealth of Nations, but it seems clear that Smith, in line with much thinking of the Scottish Enlightment, viewed human nature as universal, and did not view culture as a primary differentiating factor in economic development. After all, Smith saw the "propensity to truck, barter, and exchange one thing for another," to be 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, one of the leading economic historians David Landes (1998) has argued that culture, in addition to geography and institutions, should be given pride of place in explaining the differences in economic performance.

[16]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."

the temperate zones in climate, disease ecology, and agricultural productivity. Two important essays, one by the Council on Foreign Relations (Lee, 1957), and one a generation later by Andrew Kamarck (1976) for the World Bank, synthesized these arguments in excellent surveys on Tropical Development, which 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 just on moral grounds but on 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 equatorial tropics, and the Southernmost sub-tropical regions. Diamond argues that these advantages, in addition to more contingent (i.e. 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, as technology changes. In early civilizations, when transport and communications were too costly to support much inter-regional and inter-national trade (and virtually any oceanic trade), geographical advantage came overwhelmingly from agricultural productivity rather than from access to markets. Therefore, early civilizations almost invariably emerged in highly fertile river valleys such as 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 (e.g. the moldboard plow in the Middle Ages) and tools to fell the great Northern forests (Landes, 1998). Similarly, as the advantages of over-land 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 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 as a crucial scaffolding for economic development, even though geography 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, etc.). 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

To establish some formal ideas about the interaction of geography and development, we start with the simplest model of economic growth, the AK model (known in its earlier incarnation as the Harrod-Domar model), and add 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 (e.g. the differences in productivity of temperate and tropical agriculture; differences in endemic health conditions among various ecozones); (2) transport costs, reflecting both distances and physical access to trade (e.g. navigability of rivers, distance from the coastline); and (3) national saving rates, and implicitly, government economic policies.

Suppose that an economy has the aggregate production function:

$$Q = AK$$

The capital stock evolves according to:

$$dK/dt = I - dK$$

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,

$$sQ = P_I I$$

The growth rate of the economy is then

(1) $$g = (1/Q)(dQ/dt) = (1/K)(dK/dt) = sA/P_I - d$$

Economic growth is positively dependent on the saving rate, s, and the level of productivity, A, and negatively dependent on the relative price of capital goods, P_I, and the rate of depreciation, d.

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 is imported from abroad. To illustrate some implications of transport costs, we now assume that each country produces a distinct final good, and that 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 some 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 R&D.

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

$$I = I(I^d, I^m)$$

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

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

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, i.e. the the price of I^d equal to 1, we have:

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

We denote the (exogenous) world market price of the imported good as P^{m*}, and write the landed (or cif) price in the home economy as $P^m = \tau P^{m*}$, where $\tau > 1$ is the cif factor, i.e. the world price plus cost, insurance, and freight. Then, from equations 1 and 2 we have a modified equation for the growth of the economy:[17]

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[17]Suppose that instead of Cobb-Douglas, the investment function is a constant-elasticity-of-substitution (CES) function of the underlying investment in each country: $I = \left(\sum m_i I_i^{-e}\right)^{-1/e}$. The elasticity of substitution is $s = 1/(1+e)$. In that case, the price index P_I is also a CES of the prices of the individual investment goods, of the form: $P_I = \left[\sum m_j^s (t_j P_j^*)^{(1-s)}\right]^{1/(1-s)}$. Thus, if the investment function has an elasticity of substitution s, the price index has an elasticity of substitution $1/s$. When s equals 1, so that the investment function is Cobb-Douglas, the price index is also Cobb-Douglas, with $P_I = \prod v P_j^{a_j} = \prod v (P_j^*)^{a_j} t_j^{a_j}$, $v = a_1^{a_1} a_2^{a_2} \ldots a_n^{a_n}$. The growth rate of the home country depends on a geometric weighted

$$g = (sA/a)(P^{m*})^{-(1-a)} t^{--(1-a)} - d \qquad (3)$$

The growth rate is now inversely related to the cost of transport, τ. 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 3.

Equation 3 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 τ. 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 (e.g. 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 the distance from the core. Third, protectionist policies that raise the domestic price of imported capital goods, or that limit the exports needed to import the foreign capital goods, are likely to reduce long-term economic growth. We can't overstress the practical 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 (e.g. fabrics, 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:

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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: $P_I = \min\ t_j P_j^* / m_j$. 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, i.e. P_j^* / m_j is the same across all markets, growth would depend on the *minimum distance to one of the capital-goods suppliers*, rather than to 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 U.S., or Western Europe, or Japan — rather than the average distance to the U.S., 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.

$$Q = min[AK, N/m]$$

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

$$(4) \qquad Y = (1 - mP_n)AK$$

Since domestic final output in the home market is numeraire, its price in the foreign market inclusive of transport costs is τ. Similarly, if the intermediate product sells for P_n in the home market, its price in the foreign market is P_n/t. Suppose that at world prices (i.e. in the foreign market) the share of the intermediate good in final output is given by $s = (P_n/t)N/(tQ)$. Then, equation 4 may be re-written as:

$$(4') \qquad Y = [1 - s\,t^2]AK$$

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

$$(5) \qquad g = (sA/a)\,[1 - s\,t^2]\,(P^m)^{-(1-a)} - d$$

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 $s = 0.7$. Now, compare the growth rates of countries with one-way transport costs equal to 5 percent and 10 percent, i.e. $t = 1.05$ versus 1.10. Ignore, for the moment, the transport costs on capital goods, to focus solely on the effect of intermediate products. Let g_1 be the growth rate of the low-transport-cost economy, and g_2 be the growth rate of the high-transport-cost economy. Then, from equation 5:

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

The growth rate in the low-transport-cost economy is 49 percent higher than in the high- transport-cost economy, even though the transport costs differ by only 5 percentage points. The explanation, of course, is that a “mere” 5 percentage point decrease 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 non-competitive. 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 multi-stage 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 so 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.

Divergence, Convergence, and Poverty Traps

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 slower growing countries.

Models like the AK model also highlight another possibility. Suppose that transport costs are important at one stage of history in determining economic location, but then become less important. In the AK model, the early advantage would lead to a boost of economic activity so that the early-favored region would jump ahead of the others. Once the advantage is lost, all economies would grow at the same rate (assuming the same A, s, δ). The early advantage would never be lost in terms of relative income levels, though growth rates would converge. In models with increasing returns to scale rather than the constant returns to scale in the AK model, the early advantage could lead to persistently higher growth rates even if the geographical advantage itself disappears, since growth rates could be a positive function of the *level* of capital, which itself would be raised by the transitory advantage. Thus, one possible interpretation of the introductory observations that temperate, coastal economies have the highest levels of GDP is that such geographical attributes once conferred advantages in the past, even if they no longer do so today.

As is well known, if the foregoing model is recast as a neoclassical growth model with diminishing marginal productivity of capital, so that $Q = AK^b$, with $b < 1$, then the conclusions reached so far have to be re-cast as follows. The same list of parameters (s, A, P^{m*}, t, d) 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:

(6) $$g_i = (1/Q_i)(dQ_i /dt) = l\,[lnQ^{ss}{}_i - lnQ_i\,]$$

Equation 6 holds that the proportionate rate of growth of country i, g_i, depends on the gap between the steady-state level of output and the contemporaneous level of output. We could, in general, derive $\ln Q_i^{SS}$ to be a function of the underlying parameters s, A, etc. Approximating this relationship in log-linear form, $\ln Q_i^{SS} = b'Z_i$, where Z_i is the vector of underlying growth-influencing parameters, and b is a vector of coefficients, we end up with an empirically estimable equation that has been extremely popular in recent years:

$$g_i = l\,b'Z_i - l \ln Q_i$$

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 non-convergence 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 (Romer 1986, 1990; Grossman and Helpman, 1991) — 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'll 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 the following three senses. First, there are vast human populations in regions quite disadvantaged for modern economic growth. In the long course of human history there has been one tendency for human population densities to rise in areas favorable for growth, so that coastal areas are indeed more densely populated than hinterlands. Another force, however, has been for population densities to rise in fertile agricultural areas, for example along inland river systems like the Ganges, Tigris, Euphrates and Nile, that are useful for irrigation and inland trade, but not international trade. The result is high population densities living in subsistence agriculture rather 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, and especially inversely related to mother's education and the market value of mothers' time.[18] Thus, the concentration of populations in problematic regions is growing. This effect is strengthened by the tendency for improvements in public health (e.g. the spread of antibiotics, vaccines, oral rehydration therapy, etc.) to diffuse more readily than economic growth itself, so that population growth has risen sharply since 1950 in some of the poorest regions.

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 as differences in income *levels* continues to increase.

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 past 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.[19]

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[18]Caldwell (1982), 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 (e.g. 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.

[19]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. For the modern sector, 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 $Q = \left(\sum X_i^g\right)^{(1/g)}$, with $0 < g < 1$. 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 $L = \sum L_i$, we have $n(a+bx) = L$, or $n = L/(a+bx)$. Then,

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 will show 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 the level of 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, p, and a purely exogenous component, q: spq/P_I. Suppose as well that $P_I = P_I(t)$, 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 $p = p(T)$. For simplicity, we will use a linear functional form: $p = c - eT$. These taxes might be formal taxes, bribes demanded to clear customs, seizures of property, etc. 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.[20] Expected utility is then:

(7) $$EU = \int e^{-(d+h)t} \log[TQ(t)]dt$$

This is maximized subject to the constraint that $Q(t) = Q_0 e^{gt}$ where $g = sp(T)q/P_I(t)$. 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 7 can be re-written as

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production is $\left(\sum x^{g}\right)^{(1/g)} = n^{(1/g)}x = L^{(1/g)}x(a+bx)^{-(1/g)}$. The result is that production shows increasing returns to labor. Output per labor is therefore a rising function of L.

[20]There is an instantaneous probability h of losing office. The probability distribution for tenure in office is then $f(t) = he^{-ht}$, and the mean time in office is $1/h$.

$EU = [log(T)+log(Q_0)]/(d+h) + [sp(T)q/P_I(t)]/(d+h)^2$. It then remains to calculate the optimal T, by setting $dEU/dT = 0$. We find:

$$(19) \qquad T = P_I(t)(d+h)/sqe \qquad T \leq 1$$

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 trading quick gain for future loss. To the extent that growth is low (because P_I is high or q is low), or the future is heavily discounted (because $d+h$ is high), or is unresponsive to taxation, then the tax rate should be set at a high level. To the extent that underlying growth is rapid or is 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, e.g. 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 one carries 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.

III. Empirical linkages of geography and growth

Geographical correlates of growth

The basic theory points to two broad categories of geographical factors of deep significance: transport costs, measured by the parameter t , and intrinsic productivity, measured by A. Consider first the transport costs. Remarkably, despite the likely importance of transport costs for economic growth, there are no adequate measures of transport costs for a large sample of developed and developing countries. The best that we could obtain for a large number of countries is the IMF estimates of the CIF/FOB margins in international trade. These margins measure the ratio of import costs inclusive of insurance and freight (CIF) relative to import costs exclusive of insurance and freight (FOB). There are several problems with these measures, the most important being that: (1) they are only crudely estimated by the IMF staff; and (2) they depend on the composition of imports, and thus are not standardized across countries.

Nonetheless, the CIF/FOB margins are informative, and predictive of economic growth. The CIF/FOB margin for 1995 is 3.6 percent for the U.S., 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.[21] We estimate an equation relating the CIF/FOB band to the distance of the country to the "core" areas of the world economy (Distance, measured in thousands of kilometers), and to the accessibility of the country to sea-based trade, by including a dummy variable for non-European landlocked countries (Landlocked):

$$\underset{}{CIF/FOB} = \underset{(84.9)}{1.06} + \underset{(3.0)}{0.010}\ \text{Distance (1,000 km)} + \underset{(2.4)}{0.11}\ \text{Landlocked}$$

$N = 83$, $R^2 = 0.32$[22]

As expected, there is a penalty both for distance from the core economies and for being landlocked. Each 1,000 km raises the CIF/FOB margin by 1.0 percentage points; being landlocked raises the CIF/FOB margin by 11.1 percentage points. We will show later that the CIF/FOB margin is indeed predictive of income levels and economic growth. Incidentally, if we regress CIF/FOB on the proportion of the population within 100 km of the coast (Pop100km), we also find a negative effect, but when we include both Pop100km and Landlocked, Landlocked has more explanatory power. 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 and navigable rivers. 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 in the interior (beyond 100 km of the coast) even in countries with coastlines such as Kenya (coastal population equals 6 percent of the total), Mozambique (40 percent), Sudan (2 percent), and Tanzania (16 percent). 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 (e.g. cataracts, shallows, etc.) 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 km of the coast*.

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

[22] Absolute value of *t* statistics are in parentheses below the coefficients, and N is the number of observations.

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 149 developed and developing countries in 1995 shows that more ocean-accessible regions in the world are indeed also more urbanized, as are economies closer to the economic core regions. In a simple regression we find:

$$\%Urban = \underset{(10.8)}{132.3} + \underset{(3.6)}{17.1}\ Pop100km - \underset{(7.1)}{10.8}\ LDistance \qquad R^2 = 0.29 \quad N = 149$$

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 (WHO,1997a), is almost entirely concentrated in the tropics.[23] This pattern is neither accidental, nor mainly the result of reverse causation in which poor countries are 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 chloroquine and other antimalarial drugs. The geographical extent of malaria is determined mostly by the ecology of the parasites (different species of malaria *Plasmodia*) and the vectors (different species of *Anopheles* mosquitoes). *Malaria was brought under control since 1945 mainly in temperate-zone and sub-tropical environments*, where the foothold of the disease (both in terms of the mosquito population and the parasite endemicity) was more fragile. Figure 5 shows the extent of endemic malaria in 1946, 1966 and 1994, with its gradually retreat to the core tropics. Using data from the World Health Organization, we construct a measure of malaria intensity (seen in Figure 4).[24] 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.

[23] 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.

[24] Because of lack of true malaria incidence or prevalence data for the most severely affected countries, our index is necessarily approximate. We digitized a world map of the extent of malaria in 1994 (shown in Figure 5) from the World Health Organization (WHO 1997), and used GIS to calculate the fraction of a country’s land area subject to malaria, excluding the areas of “limited risk”. To quantify the differing intensity of malaria, we collected WHO (1992) data for 1990 on the percent of malaria cases that are the malignant *falciparum* species of malaria, which, of the four species of malaria, has the most severe symptoms, is the most resistant to drugs, and is responsible for almost all malaria mortality. The malaria index is the product of the percent land area times the percent of *falciparum* cases. As discussed below, *falicparum* malaria is predictive of low economic growth, but non-*falicparum* malaria is not.

Malarial Intensity (scale 0-1) =

-0.01 + 0.3 Wet Tropics + 0.5 Dry Tropics + 0.4 Wet Subtropics + 0.2 Dry Subtropics
(0.7) (2.0) (4.9) (3.9) (1.5)

+ 0.5 Sub-Saharan Africa N = 148 $R^2 = 0.74$
(6.7)

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 mosquitoes (dengue, yellow fever, and lymphatic filariasis in addition to malaria), mollusks (e.g. schistosomiasis), and other arthropods (onchocerciasis, leishmaniasis, trypanosomiasis, Chagas' disease, and visceral filariasis), 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 (Murray and Lopez, 1996), confirms the heavy tropical concentration of infectious disease as a cause of death. This is shown in Figure 6.

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. Our 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 well as possible for factor inputs.

Other more prosaic geographical correlates, such as the 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 (1995a) 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 both in 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 like (6) such that:

(20) $$g_{it} = b'Z_i + m_{it}$$

In any period $T > 0$, $Q_{iT} = exp(g_i\ T)Q_{i0}$. Suppose that in the distant past Q_{i0} is randomly distributed across countries, with $\ln Q_{i0} = \ln Q_0 + z_i$, and with z_i independent of the Z_i. Then, we can estimate a cross-country *level* equation of the form:[25]

$$(21) \qquad \ln(Q_{iT}) = \ln(Q_0) + Tb'Z_i + e_i$$

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, not merely the relative level of income, of country i. 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 for measures of key institutional determinants of growth (e.g. openness of markets, protection of property rights, etc.) 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 100km of the coastline; and (3) LDistance, the minimum log-distance of the country to one of the three core regions, measured specifically as the minimum log-distance to New York, Rotterdam, or Tokyo. We estimate this relationship three times: for Maddison's GDP estimates for 1950 and 1990, and for the World Bank's PPP GDP estimates for 1995 on the subset of countries for which Maddison's data are available. In all three regression estimates, reported in Table 2 output is a positive function of Pop100km, and a negative function of Tropicar and LDistance. The magnitude of the effects tends to increase over time, as expected. In 1950, the "penalty" for Tropicar was -0.69, signifying that tropical areas were only 50 percent (= exp(-0.69)) of per capita income of the non-tropical areas controlling for the other factors. By 1995, the effect has risen to -0.99 (or 37 percent of the non-tropical 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 GDP 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.

In regression (4) of Table 2, we limit Z to a parsimonious set of four variables closely linked to geography: the prevalence of malaria; transport costs as measured by the CIF/FOB margin; the proportion of the country's population near the coastline; and the endowment of hydrocarbons per capita. These four variables alone account for 69 percent of the cross-country variation in per capita income, and are all with the expected sign and statistically significant

[25]The random term e_i is of course a function of the initial error term $?_i$ as well as the intervening sequence of disturbances $m_{it}\ {}_{t=0,..,T}$. OLS estimation would require that the error terms are independent of the Z_i.

(hydrocarbons only at the 10% level). 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 re-run 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 left out variables (e.g. 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 to a reduction of transport costs.

In regression (6), we include a vector of variables related to political and economic institutions: Socialism, which is a dummy variable for socialist economic institutions; New 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 are highly correlated with the level of income. The socialist variable is not significant, probably because of the strong collinearity with Open and because of 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 also do not have signficantly lower income levels. If the malaria index is not included, the new state variable is highly significant, which suggests the possibility that the heavy burden of disease in tropical Africa and Asia made these regions more susceptible to colonization. We find, importantly, that *both policy and geography variables* are strongly correlated with 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 PPP-adjusted 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 (1995), in which average annual growth between 1965 and 1990[26] 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 log of life expectancy at birth in 1965; the openness of the economy to international trade; and the quality of public administration (regression 1 of table 3). 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. In regression 2 of table 3 we add Tropicar, Pop100km and LDistance. Tropicar and Pop100km are highly significant and of the expected sign. All other things equal, annual growth is 0.9 percentage points lower in tropical countries than in nontropical countries. Landlocked countries (Pop100km = 0) experienced 1.0 percentage points slower growth than coastal economies. Interestingly, the LDistance 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 and have better public institutions during the period. If we drop those two variables, then LDistance has the expected negative sign with statistical significance (not shown).

In regression (3) of Table 4, we drop LDistance and add a measure of malaria at the beginning of the period.[27] Initial malaria incidence has a dramatic correlation with poor economic performance. Countries that had severe malaria in 1966 grew 1.2 percentage points per year slower than countries without *falciparum* malaria, even after controlling for life expectancy. The estimated effect of being in the tropics becomes smaller than it was without the malaria variable, and insignificant. Clearly, the malaria variable is picking up the explanatory power of the tropics variable. The effect of initial life expectancy is also reduced, though still large and significant.

The effect of malaria is accentuated if we also account for changes in malaria over the period. Countries that had severe malaria, but reduced its prevalence, grew more rapidly than countries that were not able to control malaria. We use the malaria index for 1994, and calculate the change in malaria in the intervening period, dMal6694. In regression (4), countries with severe malaria and no change in malaria are estimated to have grown 2.0 percentage points more slowly than countries free of *falciparum* malaria, other things being equal. Countries that had severe malaria in 1966 but got rid it of during 1966-1994 period are estimated to have grown 2.5 percent faster than countries with malaria, or slightly (0.5 percent) faster than countries without malaria.

In fact, none of the countries in the sample with 100 percent of their land area subject to *falciparum* malaria were able to eradicate it completely over this period. The reductions in malaria were largest in the countries with the least malaria in 1966. Table 4 shows malaria

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[26]Growth is measured as $(1/25)\cdot(\ln GDP_{1990} - \ln GDP_{1965})\cdot 100$.

[24]The malaria index at the start of the growth period 1965-1990 is constructed in a similar manner to the malaria index for 1994, used above. We digitized a malaria map for 1966 (shown in Figure 5) from the World Health Organization (WHO, 1967) to calculate the fraction of a country's land area subject to malaria. The malaria index is the product of the percent land area times the percent of *falciparum* cases in 1990. The *mix* of *falciparum* versus *vivax* and other species of malaria in a given ecozone is not likely to depend very much on vector control or public health measures, nor is it likely to change over time. For instance, Sub-Saharan Africa has always had almost 100 percent of the malignant *falciparum*, while the temperate regions that once had malaria had almost no *falciparum*.

reductions specific to different ecozones (Table 4).[28] The temperate ecozones were effectively free of *falciparum* malaria in 1966. The reductions in malaria occurred in the desert (non-temperate) regions, and the subtropics. There was a small *increase* in the malaria index for countries in tropical ecozones.

The change in malaria incidence could be partly *due* to economic growth if growth provided countries with the economic resources and institutional wherewithal to carry out effective control programs. To account for the possible impact of economic growth on malaria reduction, we instrument the malaria change with four subtropical ecozone variables and two desert tropical ecozone variables.[29] Regression (5) shows that the estimated impact of malaria on growth *increases* when change in malaria is instrumented. There is no indication that faster growth is the cause of malaria reduction. Some of the countries that have had the largest increases in malaria, like India and Sri Lanka, have had steady, if unspectacular, economic growth over this period. Likewise some countries with dramatic decreases in malaria, like Namibia, had almost no economic growth. It is only after controlling for other relevant variables that the effect of malaria reduction on growth becomes apparent.

The index of malaria, and malaria change, may be more than just a measure of malaria. It may be picking up the incidence of other tropical diseases not well indicated by the average life expectancy and tropical area. Among tropical diseases, malaria is widely recognized to be the most important, but the malaria index may also be a proxy for scourges like onchocerciasis, filariasis, and trypanosomiasis.

Malaria occurs throughout the tropics, but severe malaria is heavily concentrated in sub-Saharan Africa, as shown in Figure 4. Africa currently has 90% of the estimated cases of malaria each year (WHO 1997a), and it is the only region of the world where *falciparum* malaria predominates. When sub-Saharan Africa is left out of regression (5) (not shown), the size of the malaria coefficients fall to about half their size in the full sample, and the estimates lose statistical significance (although change in malaria 1966-94 is significant at the 7% level). With the loss of fifteen sub-Saharan countries from the sample, it is not possible to obtain accurate estimates of the effect of the tropics and the effect of malaria separately. When Tropicar is left out of the non-African regression, both initial malaria and change in malaria are significant at the 5% level.

In regression (6) 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 km^2 within the economy in the initial year, 1965. We separate GDP per km^2 on the coast and GDP per km^2 in the interior, for reasons discussed earlier: population density on the coast is likely

[28] Countries in Table 4 are classified by their predominant ecozone from the following groupings: Temperate (temperate, boreal and polar ecozones), Desert (tropical and subtropical deserts), Subtropical (non-desert subtropical), and Tropical (non-desert tropical).

[29] The first stage regression of ecozones on the change of malaria is:

dMal6694 = 0.01 (0.63)
- 0.19 (0.99) Subtropical Thorn Woodland + 0.12 (1.38) Subtropical Dry Forest
- 0.24 (3.29) Subtropical Moist Forest - 1.79 (1.37) Subtropical Rain Forest
- 0.55 (1.33) Tropical Desert + 0.46 (0.35) Tropical Desert Scrub

N = 75, R^2 = 0.19.

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 km^2) = ln(GDP per capita) + ln(Population per km^2), 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 100km of the coast, we put the interior population density at zero. For countries in which the entire population is farther than 100km 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. 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. We now find that higher *coastal population* density is associated with faster growth, while higher *interior population* density is associated with lower growth. Thus, there appear to be economies of agglomeration at play in the coastal regions, though these economies of agglomeration are not powerful enough to overcome the other tendencies towards conditional convergence in income levels. Large populations appear to be a net disadvantage for inland economies which must rely more on their natural base, and have few opportunities for absorbing population through manufacturing and international trade based in cities.

With separate inland and coastal agglomeration effects in regression (6), the estimated effect of malaria becomes less precise, slipping to a 7% significance level. On the other hand, if initial malaria and malaria change are included as in regression (7), they are both strongly significant, but the diminishing returns of interior population density loses statistical significance. We are pushing the limits of the degrees of freedom in our data, but the results suggest that both malaria prevalence and inland population concentrations are detrimental to growth.

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 effect of that disease, or more likely, 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 adverse.

If we summarize the implications on a region by region basis, we conclude the following. Africa is especially hindered by its tropical location; by its high prevalence of malaria; by its low proportion of the population near the coast; and by the low population density near the coast. Europe, North America, and East Asia, the core regions, by contrast, are 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, many of which are landlocked, are burdened by a very low proportion of the population near the coast and very low population density 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. Also, Latin America has a moderate exposure to the problems of tropics, including the prevalence of malaria.

In Table 5 we present a decomposition of the growth rates of these regions using regression (7) in Table 3. We make a statistical accounting of the deviation of each region's growth from that of East Asia during the period. In the case of Africa, health and geography factors are estimated to reduce growth by 3.0 percentage points per year, more than the policy and educational factors. 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 of the shortfall in growth relative to East Asia. As we suggest in the next sub-section, 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 the 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 (Pop100km >= 0.5) and hinterland (Pop100km < 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, Openness, malaria in 1966, the change in malaria between 1966 and 1995, and the log of life expectancy in 1965. The results for the Open coefficient are as follows (robust *t*-statistics in parentheses): All economies (N=92), $b = 2.6$ (6.8); coastal economies (N=46), $b = 3.3$ (6.5); hinterland economies (N=46), $b = 1.4$ (2.5). We see that the growth responsiveness to trade seems to be more than twice as high in coastal economies.

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 - 1990 on the proportion of land within 100 km of the coast (Land100km), Tropicar, and the initial income level:

$$\text{Open6590} = -1.12 + 0.23\ \text{Land100km} - 0.18\ \text{Tropicar} + 0.19\ \text{lnGDP}_{1965}$$

(3.2)   (2.1)   (2.0)   (4.5)

N = 106, $R^2 = 0.44$

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, Thailand, all opened the economy to trade early in the 1960s, much before the other developing countries.

IV. Population Distribution and Economic Activity

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 7. 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 grains). 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 population was heavily influenced by demographic trends well before the period of modern economic growth. We see from Figure 8, for example, that the high population density regions of 1800 are virtually the same as those of 1994 (see Figure 2). Broadly speaking, we can say that the agricultural suitability is more imprinted on global population patterns than the suitability for modern economic growth. 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 economic growth. In particular, 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 reduced fertility, making 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:

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

where P_{i1} 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

$$r_i = g \ln P_{i0} + g \ \ln X_i$$

where *g* and *g* are parameters, and X_i is a vector of geographical characteristics. Taking logs of equation 8 and adding an error term e_i,

(9) $$\ln P_{i1} = (1 + gT)\ln P_{i0} + gT \ln X_i + e_i$$

We can regress the current population density on an initial population density (say in 1800) and geographical characteristics, all in logs, using equation 9. 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 two hundred 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

(10) $$\ln P_{i1} = g' T' \ln X_i + e_i \, .$$

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

The Results

Equations 9 and 10 are estimated using the following geographical features: accessibility to the coast and rivers, elevation, malaria, soil qualities and water availability, and ecozones.[30] The results are reported in Table 6. 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.

[30] The data sources are explained in the appendix.

- 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 non-navigable inland rivers, and less on the coast or near navigable rivers, is directly contrary to 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 in 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 USSR, Western Europe, and East Asia all have *lower* population densities near the coast, conditional on 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 9 uses GIS 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 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, though. Looking at regions separately, the population densities are significantly lower in malarial areas in all regions but Africa, where population is much denser in malarial areas (not shown). Since Africans in malarial areas may have built up partial immunities to malaria, they may not seek to avoid infection by moving to non-malarial areas which may have other disadvantages (e.g. lack of water). Given the strong negative correlation of malaria with income levels, though, the higher population density in malarial areas is of course extremely worrisome.

There may be very long-term geographical arguments for Eurasia's high population densities in comparison with Africa and the lands of new settlement's lower densities. Diamond (1997) argues that Eurasia's East-West axis which runs along, rather than across, ecozones, has allowed the movement of crop varieties, ideas, and goods, as mentioned above. Eurasia had the best selection of native plants and animals, and the lands of new settlement had the least conducive flora and fauna for original domestication, Diamond has speculated. In any event the new lands were physically isolated from the rest of the world until the modern era, and therefore not part of the diffusion of technology, ideas, and trade that gradually permeated Eurasia. Africa, too, suffered from isolation and a North-South axis that hindered the diffusion of Eurasian innovations and crop varieties.

Population in the lands of new settlement heavily reflects the equilibrium between the economic productivity of these regions and the income levels in the European sending countries. Much of the indigenous population was exterminated by conquest and disease soon after first contact with Europeans, and since then incomes of the settlers have generally been somewhat higher than income levels of the strata of Europeans considering migration to distant lands. Although income levels in North America, Australia, and New Zealand have remained on a par with Western Europe, the costs of distance means that the population densities are much lower than Europe (the Eastern U.S. is the closest to an exception). Africa, on the other hand, resisted European conquest until the end of the 19th Century, largely due to devastating mortality from malaria and tropical diseases for would-be European explorers and conquerors, despite Africa's meager military and political defenses.[31] With the application of quinine as a malaria prophylaxis, Europe subjugated most of Africa, but few Europeans settled with the exception of the temperate southern and northern extremes. Thus the low productivity of the land in Africa was reflected in low population densities *and* low incomes.

The mismatch between the geographical suitability for high population densities and geographical suitability for modern economic growth delineates the regions of mass poverty in the world. The most intractable poverty is found in the concentrations of poor far from the coast in Asia and Africa. The numbers of poor are much greater in Asia due to higher population densities on more fertile land. The lands of new settlement have mostly avoided mass poverty since Europeans chose to leave them sparsely settled unless they had the promise of high incomes. Poverty is typical among the surviving native populations, and pockets of dense population that have not had close ties to a wealthier Europe, such as Haiti, but the numbers are dwarfed by the poor of Asia and Africa.

V. Future Research Directions and Some Policy Implications

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, what was gained in seventh-grade geography is lost somewhere on the way to graduate school. The vast majority of papers on economic development and growth 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. In considerable writing on Africa, for

[31] Curtin's (1989) *Death by Migration* tallies the deadliness of Africa for outsiders in the 18th and 19th centuries.

example, many socioeconomic variables have been tested 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 implications of low population densities in coastal areas. Third, the policy implications of these findings, if the findings are true, are staggering. Aid programs should be re-thought, and the critical issue of population migration should be put into much sharper focus.

The research agenda needs to be re-shaped 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 costs of malaria in terms of economic development, we barely know the quantitative extent of the disease. Cause-of-death data are not available for most developing countries, and still worse are the data on morbidity. We lack basic data on transport costs that are comparable across countries, and even more important, within countries, between the hinterland and the urban areas. By neglecting geography variables, we may well tend to *overstate* the role of policy variables in economic growth, and to neglect some deeper obstacles.[32]

The following four research questions relating to geography bear much-heightened scrutiny:

- How do transport costs differ across countries? How much of these differences are related to policy (e.g. port management, poor road maintenance), market structure (e.g. pricing by shipping cartels), or physical geography (e.g. inland versus coastal versus oceanic trade)? How are transport costs likely to change as a result of new information technologies, improved inter-modal 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, etc.? To what extent is the differential burden of disease a result of policy (e.g. the organization of public health services), resources 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 (e.g. 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 as result of: (1) low population densities in rural Africa; (2) limitations of non-agricultural activities in the hinterland; (3) policy decisions or limitations (e.g. lack of adequate family planning); or (4) institutional arrangements, such as communal land tenure which may lead to externalities in family size?

[32] 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.

Of course, having a better grasp of these issues will only lead to a next step of 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 straightforward issue of transport and communications costs. It might be supposed that falling transport costs would 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 setup in equation 3. Suppose that there are two economies with differential transport costs. Suppose, for example that $t_i = \exp(d_i\, m)$ where d_i is the distance of economy i from the core economy, m 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 m is very high, both economies have zero growth. When m is zero, both have equal and high growth. It is when m 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 a 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 which 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 $1,673. 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 transports Rwandan as well as 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 borders, 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 Burkinabés are living in Ghana, Ivory Coast, and elsewhere. In general throughout Southern Africa, there are large relatively uncontrolled population movements across national boundaries. While this is a long-standing pattern of the region, the consequences are becoming increasingly complex and often deleterious, such as 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 10. 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) =

$$\underset{(3.34)}{-2.1} + \underset{(6.42)}{0.91}\ \text{Tropicar} + \underset{(5.31)}{0.41}\ \text{Ln(Distance)} - \underset{(4.63)}{0.74}\ \text{Pop100km}$$

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 non-tropical 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 questionable 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 most likely untrue for the geographically distressed regions where the population increases will be most dramatic.

Fourth, the policy community should re-examine the balance of aid between policy-based lending to individual governments, which is the currently 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 just, 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 for controlling malaria would do more to improve the economic environment — and incidentally, improve policy by improving the incentives for good policies that the sovereign faces. 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 the means of any individual government. The coordinated agricultural research aid effort is seriously underfunded; the situation in tropical public health is even more desperate.

Data Appendix

<u>Variables used in the Cross-Country Regression Analysis</u>

I. <u>Dependent Variables</u>

GDP per capita:

PPP-adjusted GDP per capita, in 1950 and 1990 from Maddison (1995, Tables D1 and F4).

PPP-adjusted GDP per capita, in 1995 from World Bank (1998). For countries missing 1995 World Bank data, the data are from CIA (1996) (or from CIA, 1997, as noted): Afghanistan; Albania; Bosnia and Herzogovina (CIA 1997); Bhutan (CIA 1997); Brunei (CIA 1997); Cambodia; Cuba; Djibouti (CIA 1997); Equitorial Guinea (CIA 1997); Eritrea; French Guiana (CIA 1997); Iraq; Korea Dem.People's Rep.; Kuwait; Liberia; Libya Arab Jamahiriy; Myanmar (CIA 1997); Somalia; Sudan; Taiwan (CIA 1997); Tanzania; The former Yug. Rep. of Macedonia; Yugoslavia (Serbia/Montenegro). Data for additional countries shown in Figure 1 are from CIA (1997).

GDP growth:

Instantaneous growth rate of PPP-adjusted GDP per capita from 1965 to 1990 from the Penn World Tables 5.6 (Summers and Heston, 1994).

II. <u>Transport Cost and Market Proximity Measures</u>

Lt100km:

The proportion of a country's total land area within 100 km. of the ocean coastline, excluding coastline in the arctic and sub-arctic region above the winter extent of sea ice (NGS, 1995). Calculated from digital coastlines in ArcWorld Supplement (ESRI, 1996a).

Lt100cr:

The proportion of a country's total land area within 100 km. of the ocean or ocean-navigable river, excluding coastline above the winter extent of sea ice and the rivers that flow to this coastline. Rivers were classified as ocean-navigable mainly according to descriptions in Rand McNally (1980), Brittanica Online (1998), and Encyclopedia Encarta (1998). Precise information on our classification of river systems is available from the authors. Ocean-navigable rivers are displayed in Figure 9. Calculated from digital coastlines in ArcWorld Supplement database (ESRI, 1996a) and rivers in the ArcAtlas database (ESRI 1996b).

Pop100km:

The proportion of the population in 1994 within 100 km. of the coastline (as defined for Lt100km). The data for population distribution in 1994 come from the first detailed world GIS population dataset (seen in Figure 2) described in Tobler, et al. (1995).

Pop100cr:

The proportion of the population in 1994 within 100 km. of the coastline or ocean-navigable river (as defined for Lt100cr). The population data are as for Pop100km.

CoastDensity:

Coastal Population/Coastal km^2 = (Population * Pop100km)/(Land Area * Lt100km). Units: persons per square kilometer.

InteriorDensity:

Interior Population/Interior = (Population * (1-Pop100km))/(Land Area * (1-Lt100km)). Units: persons per square kilometer.

Landlocked, not in Europe:

Indicator for landlocked country, excluding countries in Western and Central Europe (Austria, the Czech Republic, Hungary, the Former Yugoslav Republic of Macedonia, Slovakia, and Switzerland). Includes Eastern European countries of Belarus and Moldova.

LDistance:

The log of the minimum Great-Circle (air) distance in kilometers to one of the three capital-goods-supplying regions: the U.S., Western Europe, and Japan, specifically measured as distance from the country's capital city to New York, Rotterdam, or Tokyo.

CIF/FOB shipping cost margin:

The ratio of CIF import prices to FOB import prices as a measure of transport costs from IMF data (Radelet and Sachs, 1998).

III. Other Geographical Variables

Tropicar:

The proportion of the country's land area within the geographical tropics. Calculated from ArcWorld Supplement database (ESRI, 1996a).

Malaria Index in 1966:

Index of malaria prevalence based on a global map of extent of malaria in 1966 (WHO, 1967), and the fraction of *falciparum* malaria. The fraction of each country's land area subject of malaria was calculated from digitized 1967 map shown in Figure 5 ("limited risk" areas excluded). The intensity of malaria is captured by the fraction of malaria cases that are the malignant *P. falciparum* species of malaria in 1990 (WHO, 1992). For African countries without 1990 *falciparum* data, we used the WHO (1997b) data (in which almost all African countries with malaria are described as "predominantly" *falciparum*, which we classified as 100%). The index is the product of the fraction of land area subject to malaria times the fraction of *falciparum* malaria cases.

Malaria Index in 1994:

Constructed in the same way as the malaria index for 1966, based on a global malaria map for 1994 (WHO, 1997a), and fraction of *falciparum* malaria in 1990.

Hydrocarbons:

Hydrocarbon deposits are the log of total BTUs per person of proven crude oil and natural gas reserves in 1993 from WRI (1996).

Southern Hemisphere:

Indicator for countries wholly below the equator, as well as Brazil, Democratic Republic of the Congo (Zaire), Republic of the Congo, Ecuador, Gabon, Indonesia, and Kenya.

Land Area:

Area in square kilometers from World Bank (1997), except for Taiwan and Mexico from CIA (1997), with submerged land subtracted out.

IV. Other Economic, Social, and Political Variables

Openness:

The proportion of years that a country is open to trade during 1965-90, by the criteria in Sachs and Warner (1995b). A country is considered to be open if it meets minimum criteria on four aspects of trade policy: average tariffs must be lower than 40 percent, quotas and licensing must cover less than 40 percent of total imports, the black market premium must be less than 20 percent, and export taxes should be moderate.

Public Institutions:

The quality of public institutions is based on an index created by Knack and Keefer (1995), which is itself an average of five indicators of the quality of public institutions, including (a) the perceived efficiency of the government bureaucracy, (b) the extent of government corruption, (c) efficacy of the rule of law, (d) the presence or abscence of expropriation risk, and (e) the perceived risk of repudiation of contracts by the goverment. Each country is scored on these five dimensions on the basis of surveys of business attitudes within the countries. The subindexes on the five measures are then summed to produce a single, overall index that is scaled between 0 and 10.

New 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) from CIA (1996).

Socialism:

A variable equal to 1 if the country was under socialist rule for a considerable period during 1950 – 1995 based on Kornai (1992).

Life expectancy at birth, 1965:

Data from United Nations (1996).

Years of secondary schooling, 1965:

Data from Barro and Lee (1993).

Urbanization:

% of population living in urban areas, 1995, from World Bank (1998).

War-torn:

Indicator for countries that participated in at least one external war over the period, 1960-85, from Barro and Lee (1994), with additional countries classified by authors.

Population:

Total population in millions from World Bank (1997).

<u>One degree by one degree population database:</u>

The data for population in 1994 come from the first detailed world GIS population dataset (seen in Figure 2) described in Tobler, et al. 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 for each 1° cell was digitized from a WHO (1997a) map for 1994. Distance of each 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 as in Lt100km above. Ocean navigable rivers leading to the sea were classified as in Lt100cr as above. Inland rivers are rivers classified as navigable by ArcAtlas (ESRI, 1996b), but with no outlet to the sea, as well as rivers navigable to the sea, but not navigable by oceangoing vessels. Elevation data are derived from the ETOPO world elevation database (NOAA, 1988). Land used from rice-growing was derived from the ArcAtlas database on agriculture (ESRI 1996b). Soil depth and stream density (a count of the streams in each 1° cell from satellite data) come from NASA (Sellers, et al., 1997). Soil suitability for rainfed crops was derived from Digital Soils Map of the World (FAO, 1995). A classification of land areas into thirty-seven ecozones comes from the UNEP (Leemans, 1990).

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Table 1. Geographical Characteristics of Selected Regions

	Continent GDP/PC	Total Population	Total Land Area (million km^2)	Land in Tropics (%)	Population w/100km of Coast (%)	Population w/100km of Coast or River (%)	Landlocked Population (%)	Distance to Core Market (km)	Coastal Density (pers/ km^2)	Interior Density (pers/ km^2)
Sub-Saharan Africa	1,865	580	24	91	19	21	28	6,237	40	22
Western Europe	19,230	383	3	0	53	89	4	922	109	125
East Asia	10,655	1,819	14	30	43	60	0	3,396	381	91
South Asia	1,471	1,219	4	40	23	41	2	5,744	387	287
Transition Economies	3,902	400	24	0	9	55	21	2,439	32	16
Latin America	5,163	472	20	73	42	45	3	4,651	52	18

Table 2. Level of GDP

	(1) lgdp50	(2) lgdp90	(3) lgdp95	(4) lgdp95	(5) lgdp95 (non-Africa)	(6) lgdp95
Tropical Area (%)	-0.69 (4.13)	-0.99 (5.78)	-0.99 (5.10)			
Pop 100 km (%)	0.71 (4.02)	1.00 (5.43)	1.09 (5.27)	0.85 (3.63)	1.21 (4.17)	0.36 (2.53)
Ldistance	-0.22 (2.56)	-0.39 (4.39)	-0.34 (3.41)			0.03 (0.55)
Shipping Cost (CIF/FOB)				-2.28 (2.32)	-13.50 (4.66)	
Malaria index 1994 (0-1)				-1.55 (6.60)	-1.26 (2.69)	-1.15 (7.65)
Log hydrocarbons per person				0.01 (1.84)	0.01 (1.75)	0.01 (1.85)
Socialism						-0.05 (0.31)
New State (0-3)						-0.06 (0.98)
Trade Openness (0-1)						0.23 (7.38)
Public Institutions (0-10)						0.55 (3.17)
Constant	9.07 (13.58)	11.19 (16.26)	10.98 (14.10)	10.84 (9.82)	22.64 (7.42)	6.71 (11.06)
Observations	129	129	129	83	52	97
R^2	0.38	0.58	0.50	0.69	0.56	0.88

Absolute value of *t*-statistics in parentheses

Table 3. GDP Growth

	(1) gr6590	(2) gr6590	(3) gr6590	(4) gr6590	(5) gr6590 (TSLS)	(6) gr6590	(7) gr6590
GDP p.c. 1965	-2.3	-2.4	-2.5	-2.6	-2.7	-2.3	-2.4
	(7.70)	(8.02)	(8.06)	(7.87)	(7.60)	(7.41)	(7.09)
Years of secondary schooling	0.3	0.2	0.2	0.2	0.2	0.1	0.1
	(1.75)	(1.77)	(1.32)	(1.34)	(1.15)	(0.81)	(0.89)
Log life expectancy 1965	6.6	5.5	4.3	3.3	2.4	4.1	3.4
	(7.23)	(6.21)	(4.45)	(3.60)	(1.79)	(4.53)	(3.89)
Trade Openness 1965-90 (0-1)	1.9	1.9	1.7	1.7	1.7	1.8	1.8
	(5.49)	(4.79)	(4.79)	(4.70)	(4.39)	(4.79)	(4.66)
Public Institutions (0-10)	0.3	0.3	0.3	0.4	0.5	0.3	0.4
	(3.08)	(2.63)	(3.32)	(3.92)	(3.66)	(3.20)	(3.47)
Ldistance		0.0					
		(0.24)					
Pop100km (%)		1.0	0.9	0.8	0.6		
		(3.07)	(3.01)	(2.64)	(1.91)		
Tropical area (%)		-0.9	-0.6	-0.5	-0.4	-0.7	-0.5
		(2.28)	(1.35)	(1.09)	(0.82)	(1.89)	(1.44)
Malaria index 1966			-1.2	-2.0	-2.6	-0.9	-1.6
			(2.15)	(3.60)	(3.87)	(1.86)	(2.89)
dMal6694				-2.5	-4.5		-1.9
				(3.93)	(2.12)		(2.94)
Log coastal density						0.3	0.2
						(4.91)	(4.34)
Log inland density						-0.1	-0.1
						(2.26)	(1.60)
Constant	-8.9	-4.1	1.3	5.9	9.8	0.7	4.1
	(2.90)	(1.17)	(0.34)	(1.57)	(1.76)	(0.19)	(1.08)
Observations	75	75	75	75	75	75	75
R^2	0.71	0.75	0.77	0.80	0.78	0.80	0.82

Absolute value of robust *t*-statistics in parentheses

Table 4. Level and Changes in Malarial Prevalence between 1966 and 1994 by Ecozone

Predominant Ecozone	Malaria Index 1966 (0-100)	Average Change 1966-1994
Temperate (N=57)	0.2	-0.2
Desert (N=23)	27.8	-8.8
Subtropical (N=42)	61.7	-5.0
Tropical (N=21)	64.9	0.5

Note: Countries are classified by their predominant ecozone from the following groupings: Temperate (temperate, boreal and polar ecozones), Desert (tropical and subtropical deserts), Subtropical (non-desert subtropical), and Tropical (non-desert tropical). The index and average reduction are unweighted averages over countries.

Table 5. Growth Rates in Selected Regions Compared with East Asia

		Sub-Saharan Africa-East Asia	South Asia-East Asia	Latin America-East Asia
Growth		-4.2	-2.8	-3.6
Explained		-3.7	-2.0	-3.0
Initial GDP		1.4	1.0	-1.1
Geography and Health	Total	-3.0	-0.8	-0.2
	Coastal density	-0.7	0.0	-0.5
	Interior density	0.0	-0.3	0.1
	Tropics	-0.1	0.1	-0.1
	Malaria	-1.0	-0.1	0.3
	Life expectancy	-1.2	-0.5	0.0
Policy and Education	Total	-2.1	-2.1	-1.8
	Openness	-1.2	-1.2	-1.0
	Public institutions	-0.7	-0.9	-0.7
	Secondary education	-0.2	-0.1	0.0
Residual		-0.5	-0.8	-0.6

Table 6. The Impact of Geography on log Population Density 1994[a]

	(1)	(2)
log Population density in 1800	0.612	
	(79.63)**	
Eurasian continent		1.136
		(28.15)**
Lands of new settlement		-0.998
		(23.73)**
log Distance (km) to:		
Coast	-0.040	-0.145
	(2.26)*	(8.13)**
Navigable river to the sea	-0.113	-0.188
	(6.28)**	(10.2)**
Inland river	-0.324	-0.235
	(26.48)**	(18.4)**
log Elevation in temperate zone		
Up to 1000 meters	0.018	0.096
	(1.35)	(6.77)**
1000 to 2000 meters	0.859	1.108
	(9.63)**	(11.67)**
Over 2000 meters	-1.361	-0.279
	(12.83)**	(8.47)**
log Elevation in tropics		
Up to 1000 meters	-0.034	0.034
	(6.47)**	(7.28)**
1000 to 2000 meters	1.801	2.133
	(6.04)**	(6.2)**
Over 2000 meters	0.846	1.296
	(3.2)**	(3.15)**
Malaria (fraction of area)	0.109	2.104
	(2.48)*	(4.72)**
Soil and Water		
Rice growing land (fraction of area)	1.064	1.335
	(10.44)**	(13.41)**
Soil suitability (0-100)	0.127	0.134
	(21.47)**	(22.25)**
log Stream density (number per cell)	0.144	0.192
	(17.77)**	(23.42)**
Ecozones (compared to Moist Temperate)[b]		
Polar and Boreal	-2.273	-3.202
	**	**
Desert	-1.224	-1.840
	**	**
Dry Temperate	-0.176	-0.409
	**	**
Very Wet Temperate	-1.204	-1.539
	**	**
Dry Tropical	-0.380	-0.494
	**	**
Wet Tropical	-0.932	-1.257
	**	**
Number of observations	13976	14418
R-squared	0.74	0.73

Absolute values of robust *t* statistics are in parentheses. * Significant at the 5% level. ** Significant at the 1% level.

[a] The regressions included constants that are not reported.

[b] The regression includes 36 ecozones. Moist Temperate ecozone is the left out category. The reported estimates are the average of ecozone coefficients in each ecozone group. "**" means that all the constituent coefficients were statistically different from zero at the 1% level.

Figure 1.

GDP per capita 1995

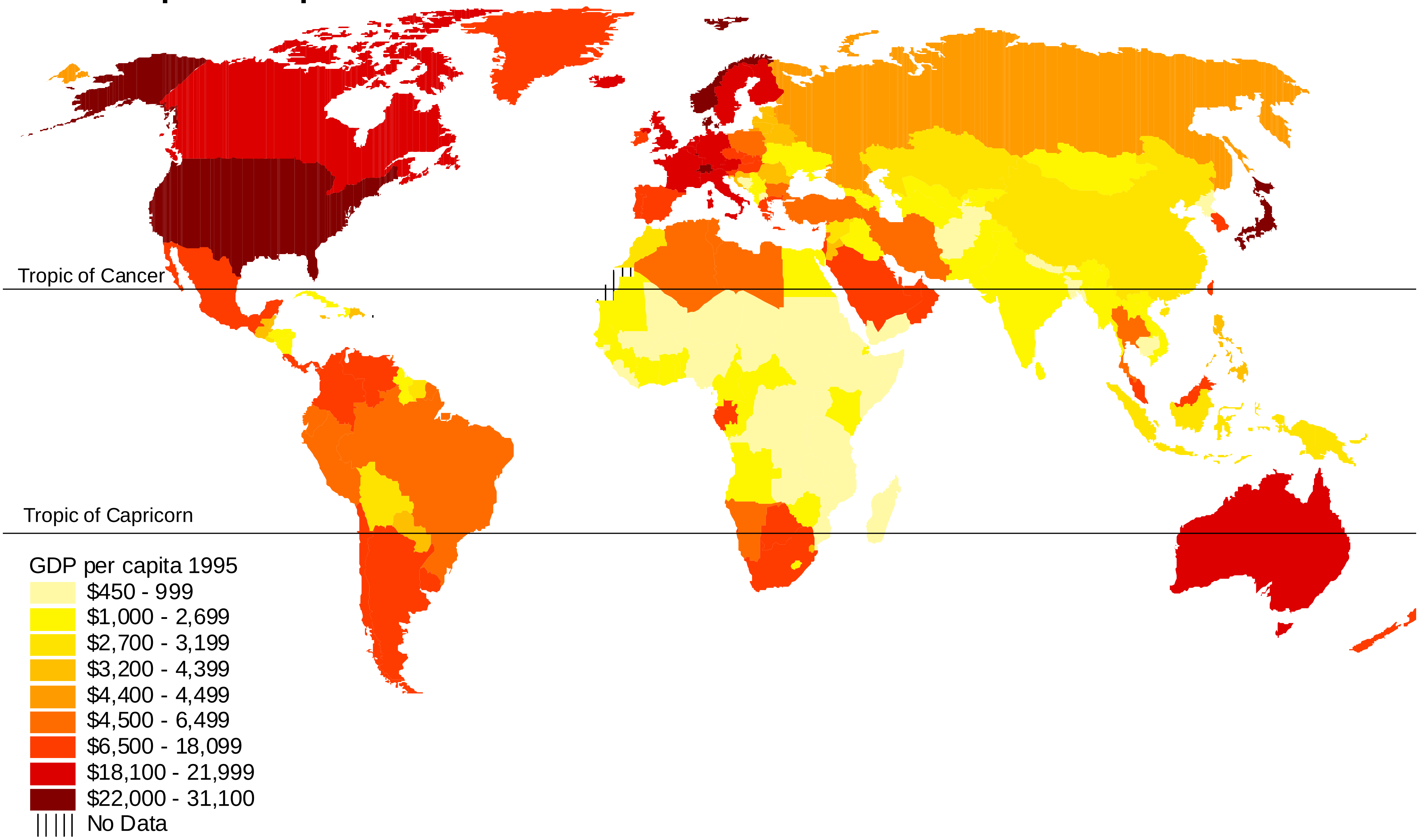


Figure 2.
Population Density

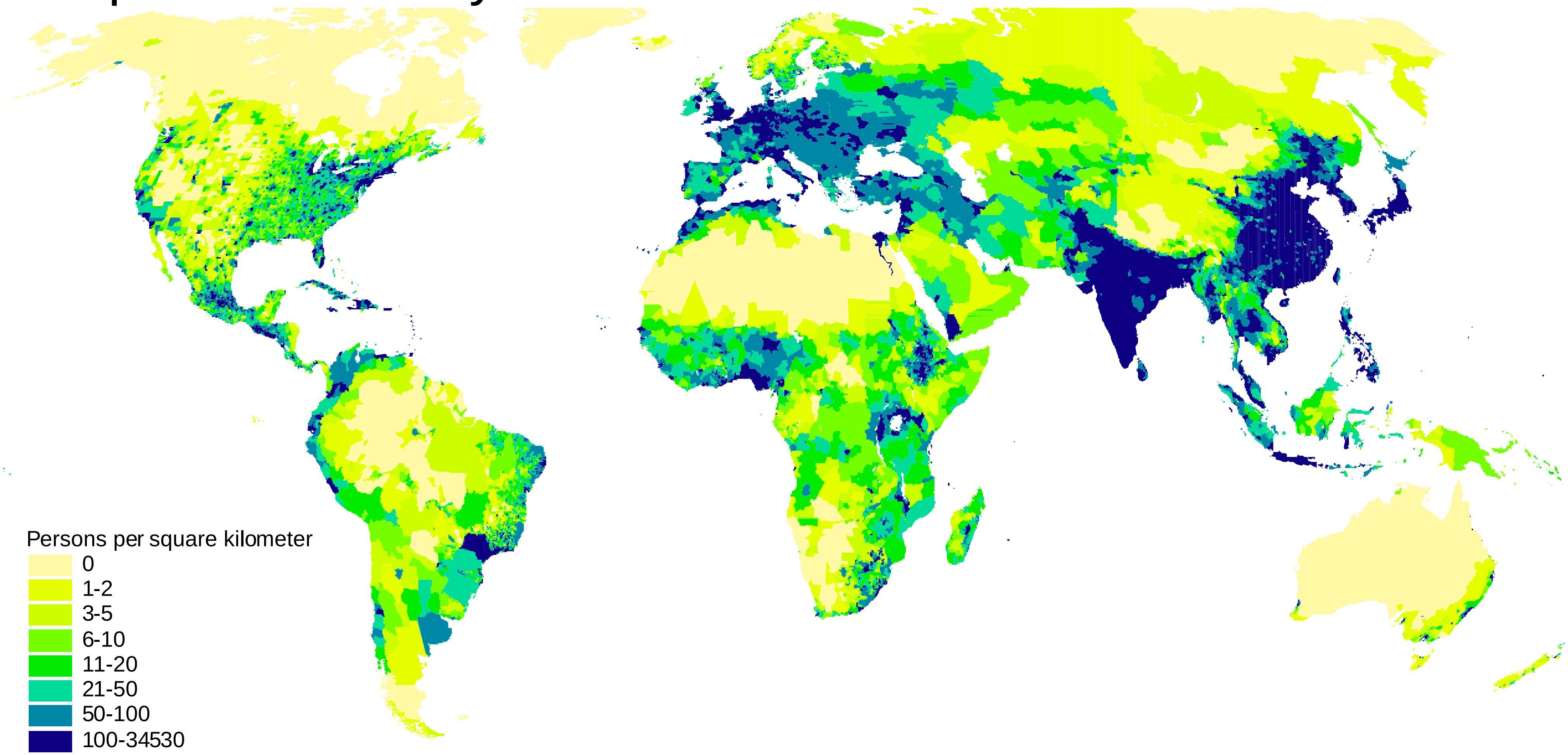


Figure 3.

GDP Density

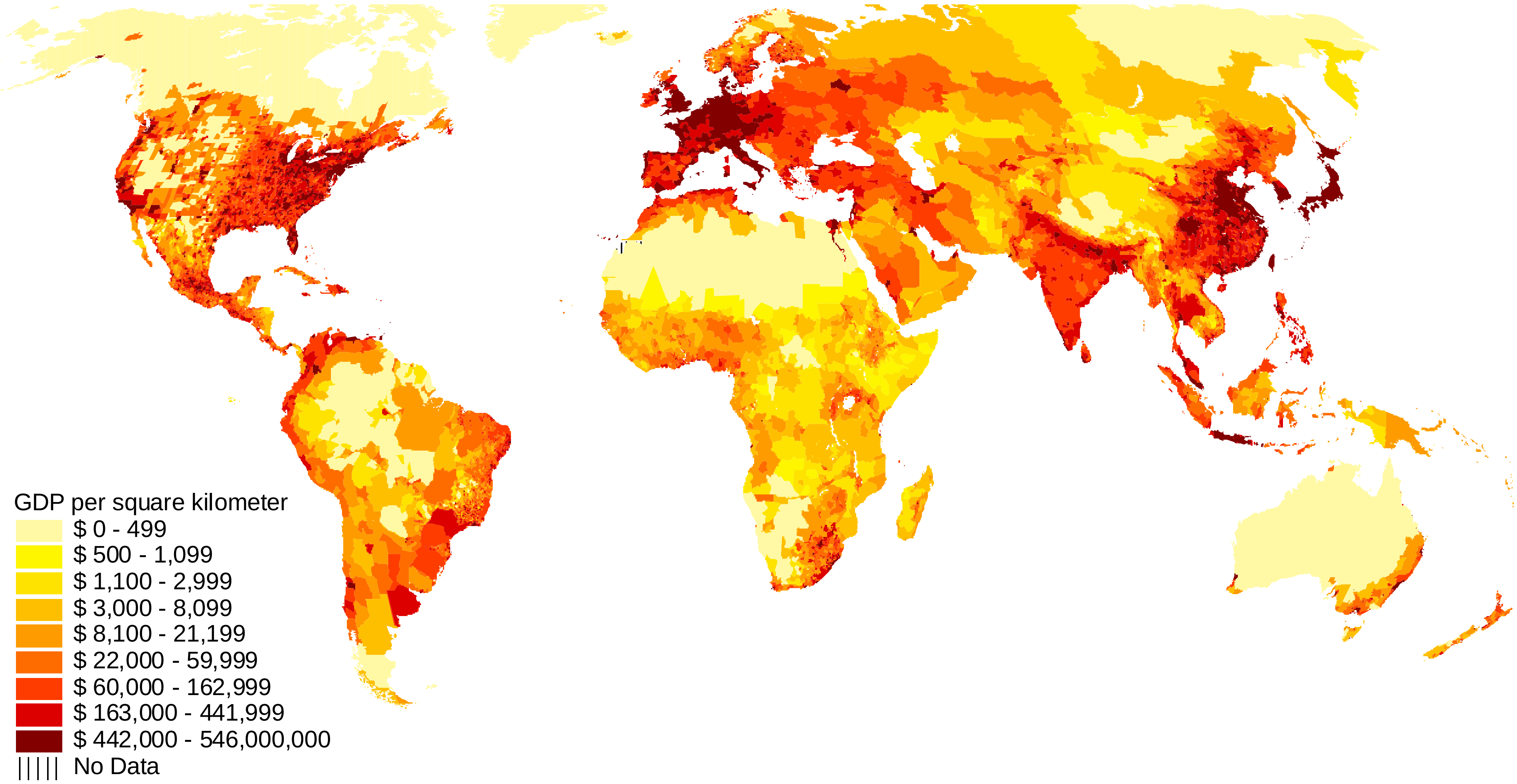


Figure 4.

Malaria Index 1994

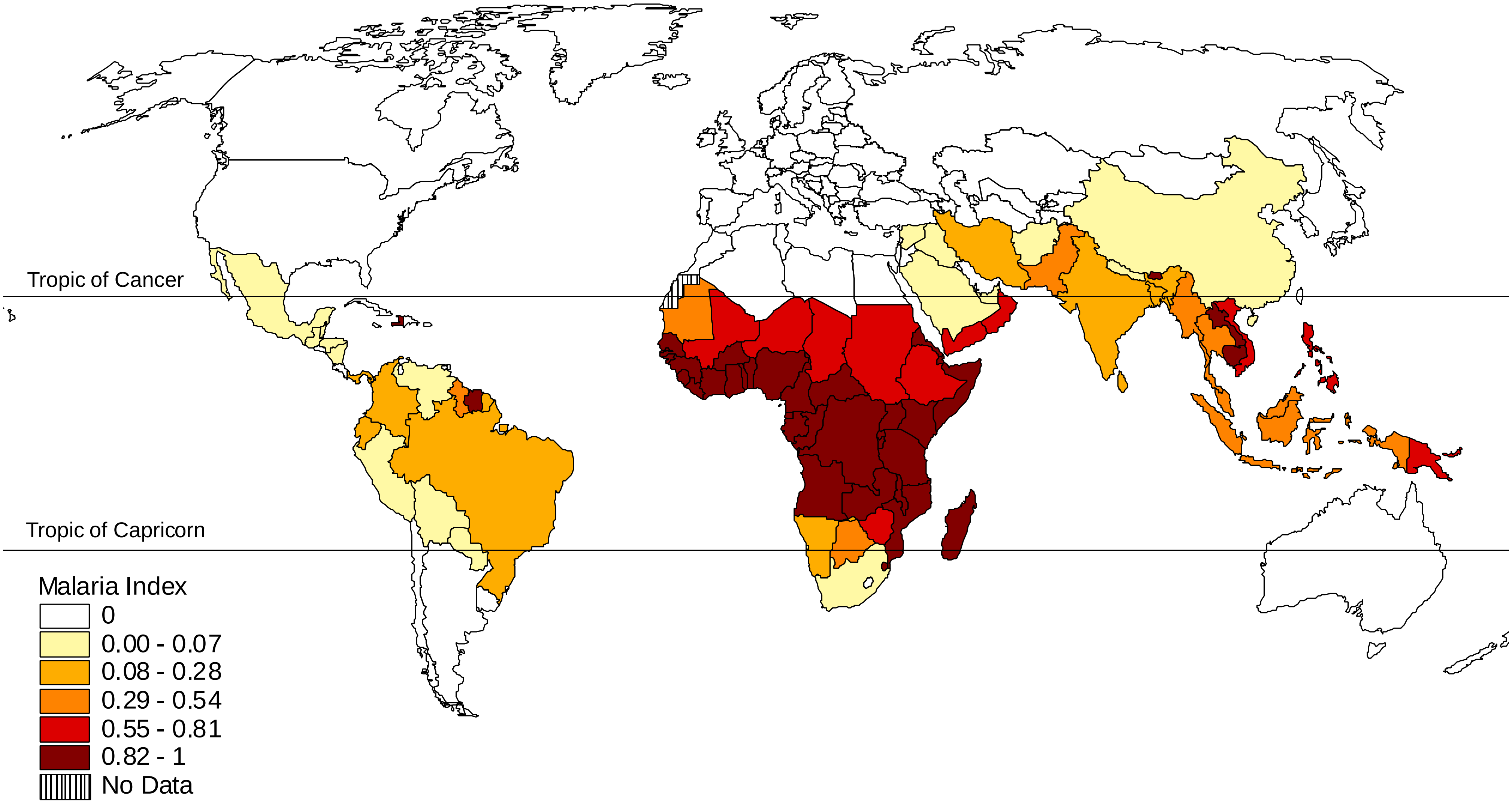


Figure 5.

Malaria risk - 1946, 1966, 1994

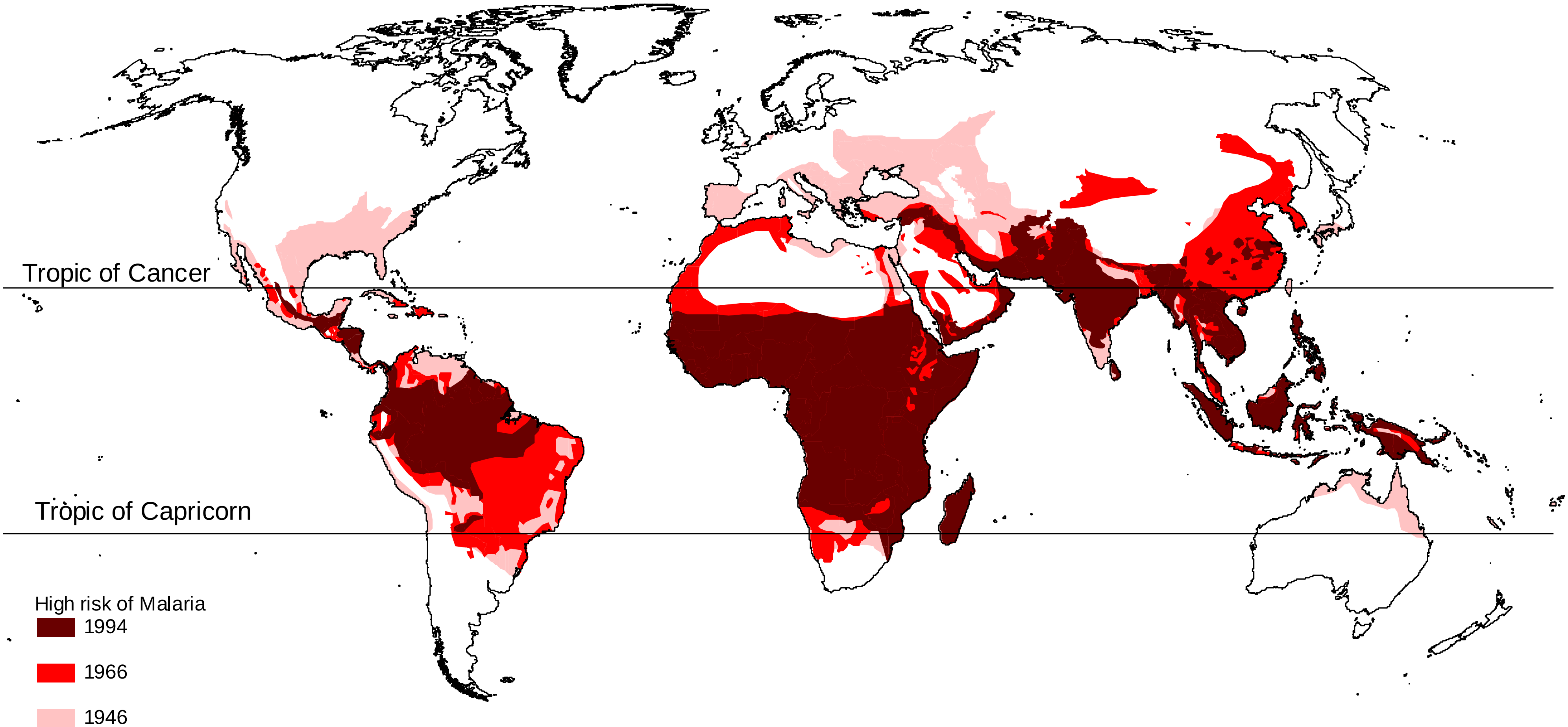


Figure 6.

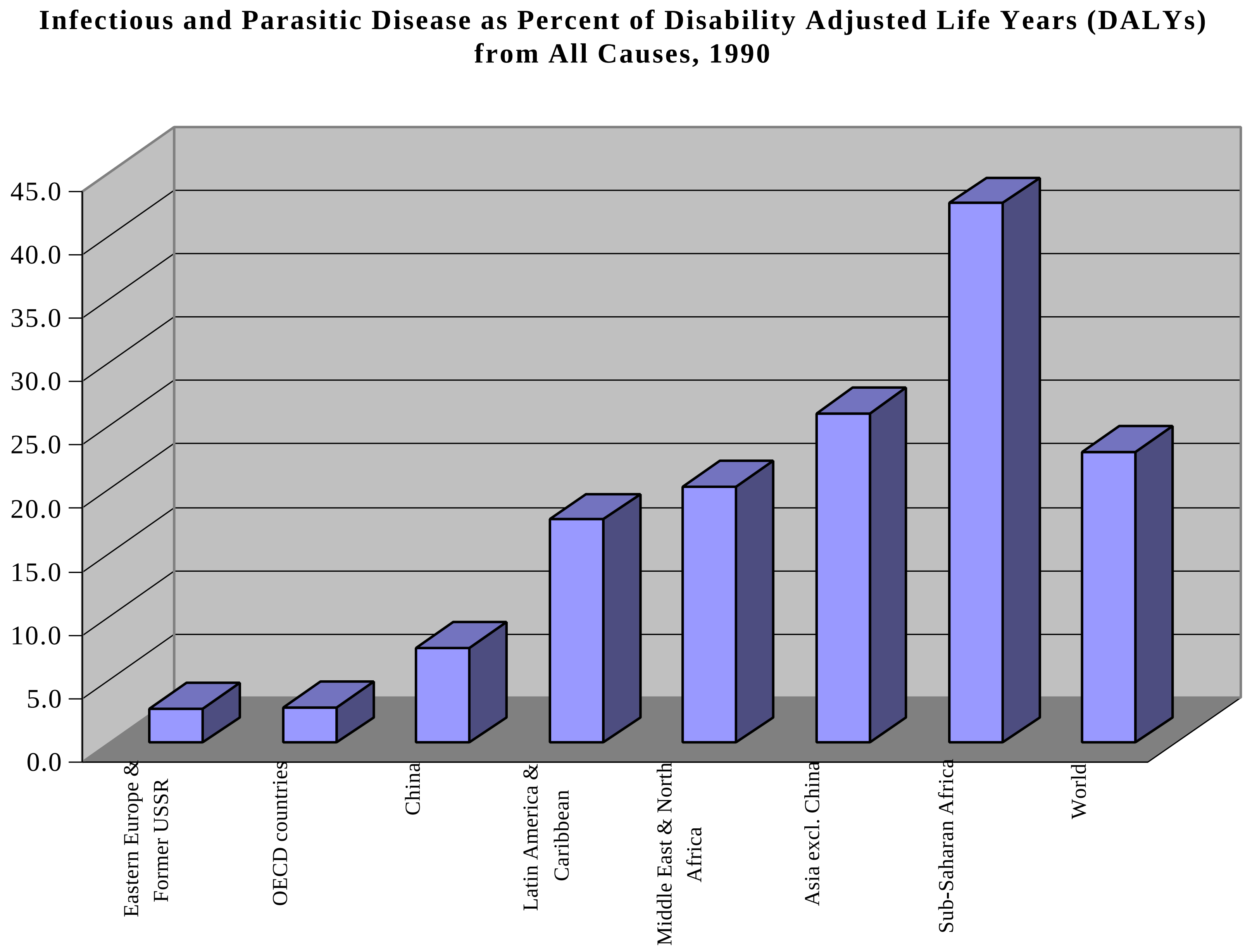

Infectious and Parasitic Disease as Percent of Disability Adjusted Life Years (DALYs) from All Causes, 1990
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Eastern Europe & Former USSR
OECD countries
China
Latin America & Caribbean
Middle East & North Africa
Asia excl. China
Sub-Saharan Africa
World

Figure 7. Population Density by Latitude, 1994

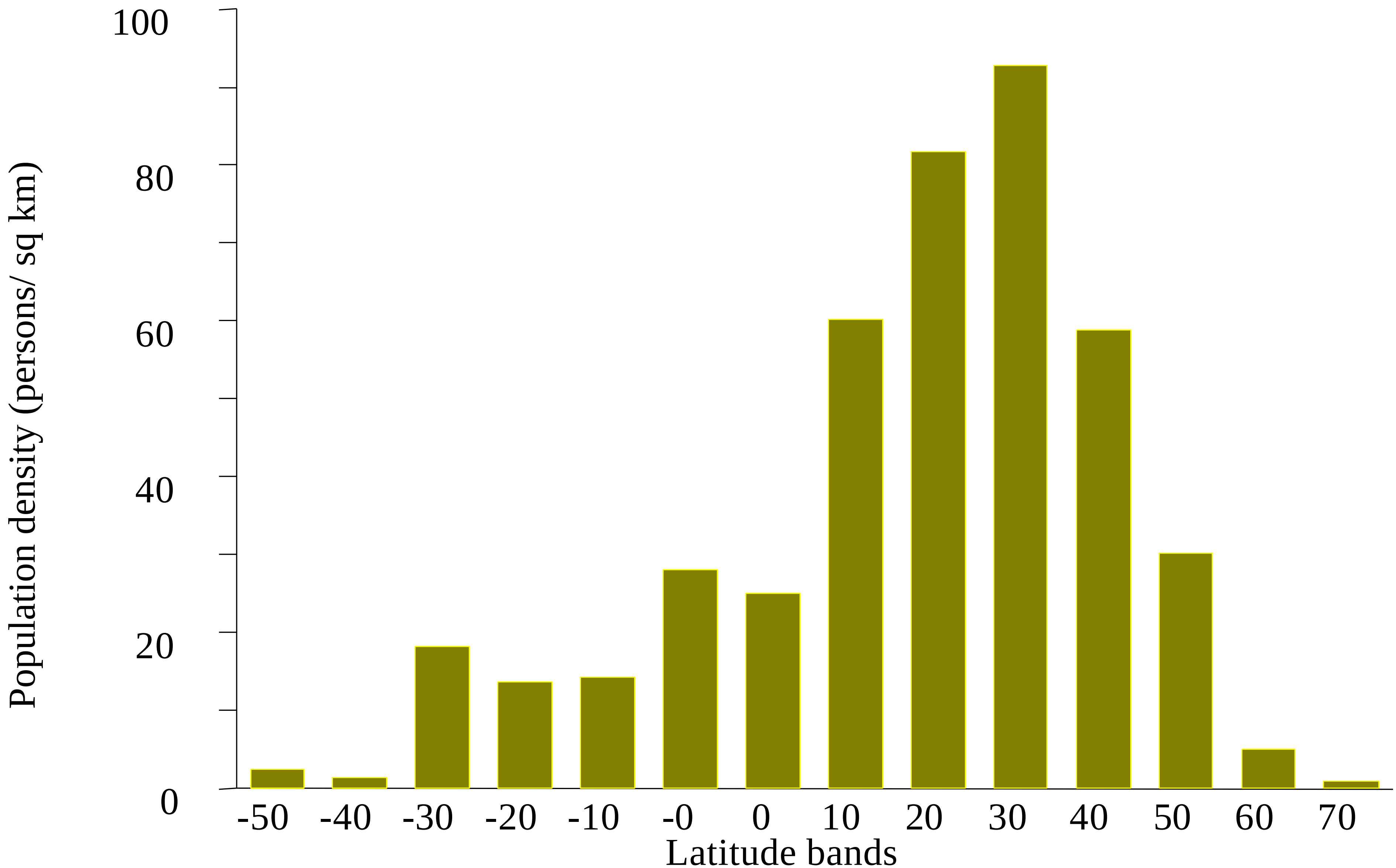


Figure 8.

Population Density in 1800

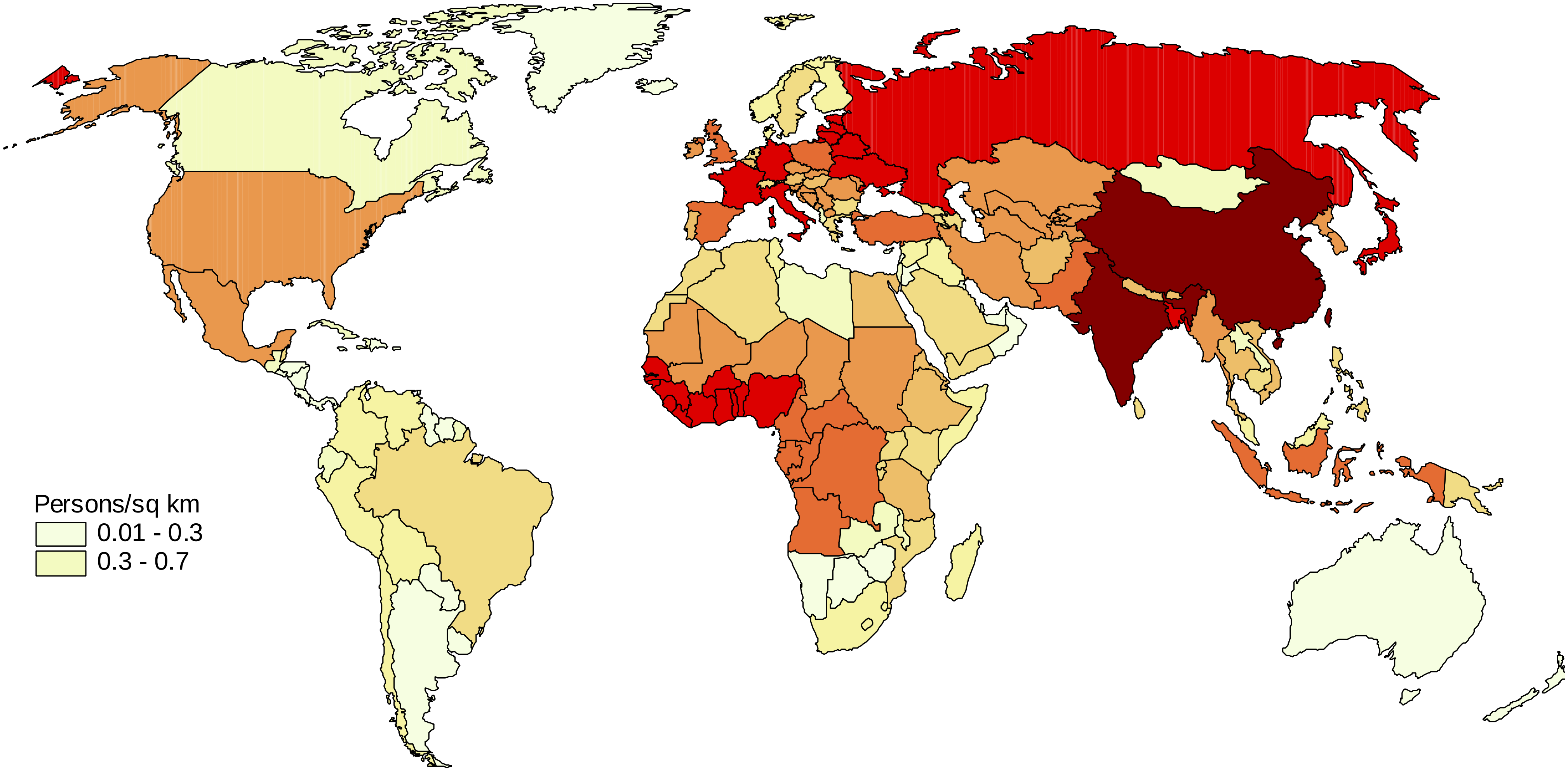


Figure 9.
Populations remote from coastline or major navigable river

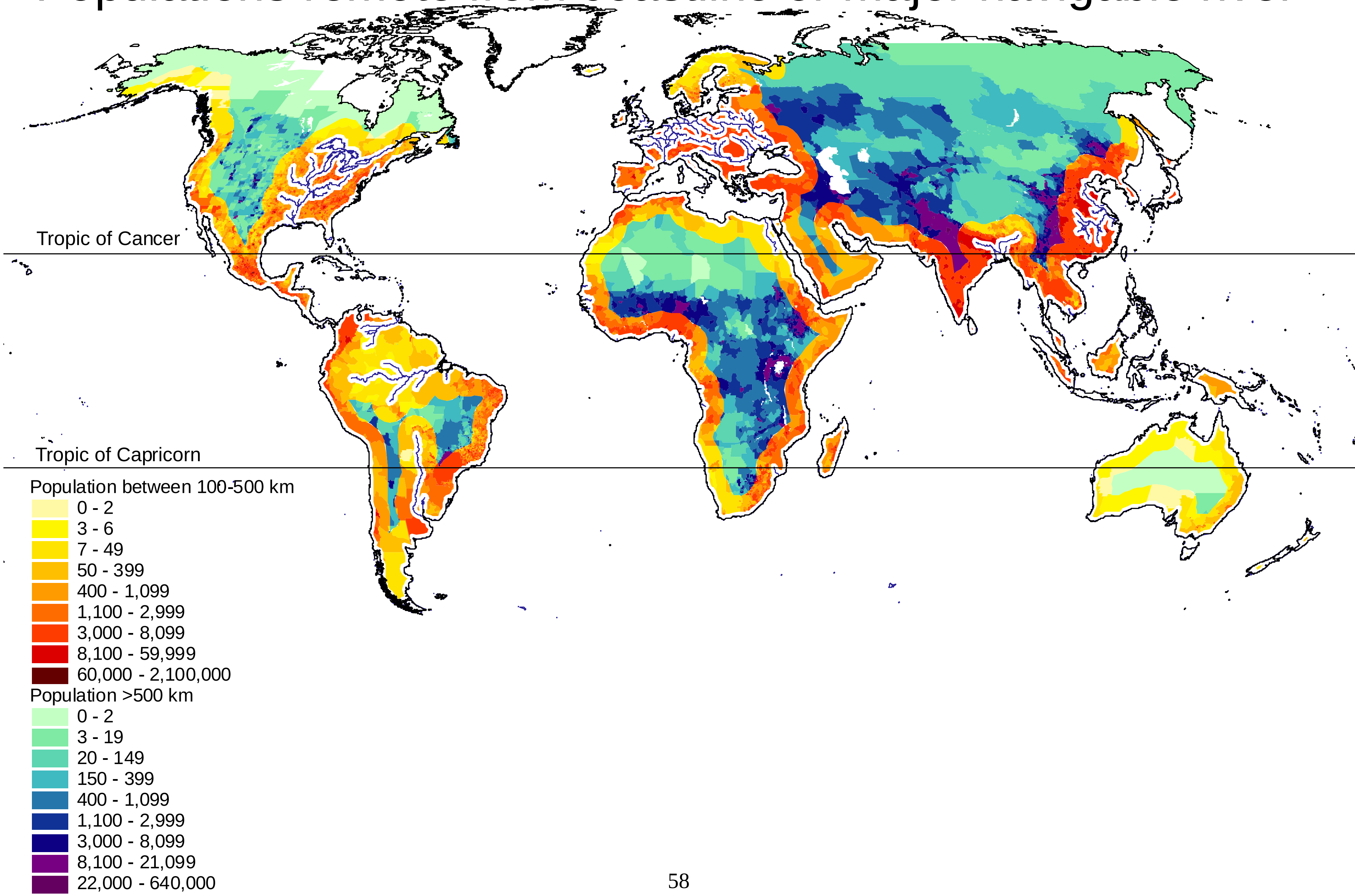
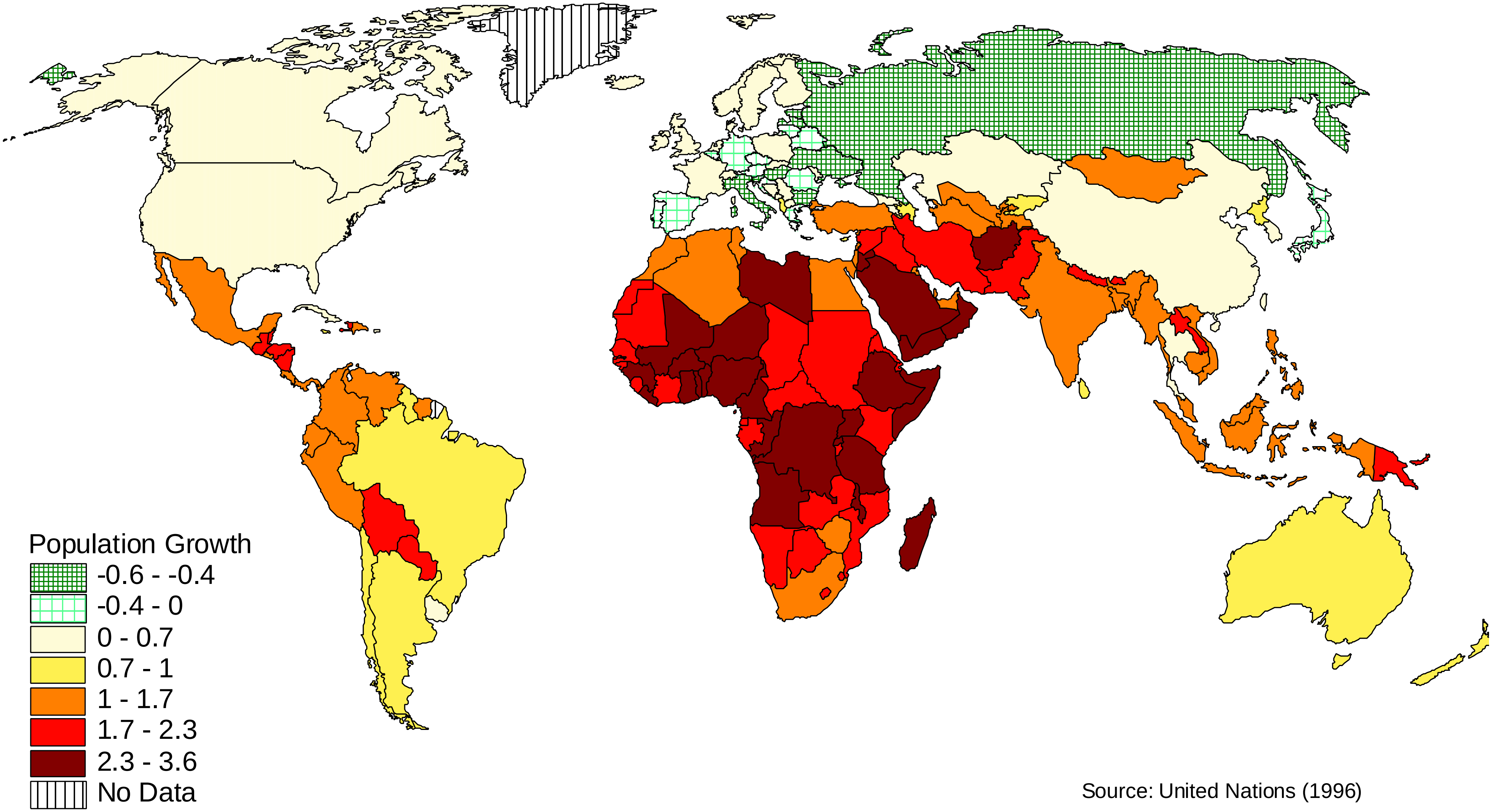


Figure 10.

Projected annual population growth 1995 - 2030



Source: United Nations (1996)