Chapter 9

# Climate, Coastal Proximity, and Development

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## Abstract

MOST studies of economic growth have tended to ignore or underplay the role of physical geography. Our recent analyses have shown, however, that physical geography (including climate, access to the sea, soil quality, and so forth) plays an important role in economic development, and can help to account for cross-country differences in the level and growth of per capita GDP. Coastal and temperate-zone economies significantly and consistently outperform landlocked and tropical regions. In this chapter, geographic information systems (GIS) data on global and regional scales are used to examine the relationship between climate (ecozones), water navigability, and economic development in terms of GDP per capita. GDP per capita and the spatial density of economic activity measured as GDP per sq km are high in temperate ecozones and in regions proximate to the sea (within 100 km of the ocean or a sea-navigable waterway). Temperate ecozones proximate to the sea account for 8 per cent of the world's inhabited land area, 23 per cent of the world's population, and 53 per cent of the world's GDP. The GDP densities in temperate ecozones proximate to the sea are on average eighteen times higher than in non-proximate non-temperate areas. We speculate as to why these strong patterns exist and persist, and we propose some future research directions to better integrate physical geography into the study of long-term economic development.

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## Introduction

One of the central issues of economics is the enormous disparity in economic performance between rich and poor regions of the world. Modern economics got its start, in fact, with Adam Smith's *Inquiry into the Wealth of Nations* in 1776, in which Smith identified social and geographical factors that could account for differential economic performance across regions of the world. Smith is remembered today mainly for his theory that market institutions would enable societies to develop a richer division of labor, and therefore higher living standards, than societies subject to extensive government controls. He is less remembered for his equally astute geographical observations. Smith asserted that the division of labor is limited by the extent of the market, and that coastal regions, by virtue of their ability to engage in sea-based trade, enjoy a wider scope of the market than interior regions. In Smith's words:

> 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 the sea-coast, and along the banks of navigable rivers that industry of every kind 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

Based on the importance of sea-based trade, Smith drew pessimistic conclusions regarding inland Africa and large parts of Russia, Siberia, and Central Asia:

> All the inland parts of Africa, and all that part of Asia which lies any considerable way north of the Black and Caspian Seas, the ancient Scythia, the modern Tartary and Siberia, seem in all ages of the world to have been in the same barbarous and uncivilized state in which we find them at present . . . There are in Africa none of those great inlets . . . to carry maritime trade into the interior parts of that great continent . . .

Smith was less aware of the effects of climate on economic performance. Climatic conditions have pervasive effects on disease, agriculture, human physiology, and other factors that may affect economic performance. Recent studies (Gallup *et al.* 1998; Bloom and Sachs 1999) have noted that tropical areas are consistently poorer than temperate-zone areas, because of the intrinsic effects of tropical ecology on human health and agricultural productivity. Tropical infectious diseases, for example, impose very high burdens on human health, that in turn may lead to shortfalls in economic performance much larger than their direct, short-run effects on health. Another recent study (Gallup and Sachs 1999*a*), found that after controlling for material inputs such as capital, labor, and fertilizers, the productivity of tropical food production still falls far short of the productivity of temperate-zone food production. This poor performance in food productivity probably has serious adverse effects on nutrition levels, with adverse consequences for human capital accumulation, labor productivity, and susceptibility to infectious disease.

In an overview of economic development and geography (Gallup *et al.* 1998), the latitudinal belt between the Tropics of Cancer (23.45 N) and Capricorn (23.45 S) was used to separate the geographical tropics and the rest of the world. They showed that economies in the geographic tropics have lower income levels and lower growth rates than the rest of the world, and that the shortfall is evident after controlling for other standard economic variables that affect economic performance. Indeed, in a ranking of all countries with populations greater than 1 million in 1995, only two economies out of the top thirty countries were predominantly in the geographical tropics: Hong Kong and Singapore. Less than 1 per cent of the population of the richest thirty countries resides in the geographical tropics. Their analysis is extended here by using ecological measures of the tropics rather than the simple latitudinal definitions.

One of the surprising aspects of the modern study of economic growth and development is the almost total neglect of geographical factors. In the hundreds of cross-country studies of comparative economic growth, following the framework established by Barro (1991), almost none has included geographical variables as conditioning variables. Typical cross-country regression studies seek to explain economic growth over an interval of time as a function of the initial income level, the initial level of human capital, and the economic policies and institutions during the period of observation (such as trade policy, fiscal policy, and measures of the rule of law). None the less, when geography variables are added to such equations, they turn out to be highly significant, both economically and statistically. Variables such as climate zone, disease ecology (e.g. the prevalence of malaria), and access to sea-based trade, are important factors in addition to the standard conditioning variables.

The 'new economic geography' which emphasizes the interaction of transport costs, imperfect competition, and increasing returns to scale, treats geography in a wholly different manner. Rather than emphasizing the role of geographical differences across economies, the new geography argues that spatial differences in economic performance—some regions becoming rich while others remain poor—may arise even when the economies are initially similar in structure. The interaction of transport costs and increasing returns to scale impart positive and negative feedback processes to economic development. Some rich regions become even richer as they attract capital and labor from abroad, while other regions become poor (or remain at subsistence), because they fail to reach the scale of population and production needed for economic 'take off'.

While we argue that many important differences between economies have fundamental geographical sources—climate, coastal access, soil quality—the new geography suggests that many differences are accidents of history. The two approaches are potentially complementary, even though their points of view are distinct. It could be, for example, that physical geography helps to explain initial differences in outcomes across regions, and that the new economic geography helps to account for ways in which those initial differences are magnified through positive and negative feedbacks.

In the following sections, we use new GIS data to present evidence on the geographic distribution of per capita GDP, GDP density (defined as GDP per sq km), and population density. These variables are highly influenced by climate and proximity to the sea. We find strong evidence that the ecological tropics, the dry regions, and the sub-tropical regions are systematically poorer than temperate ecozones. Moreover, the temperate ecozones proximate to the sea, though a small part of the world's inhabited landmass, account for a remarkably high proportion of the world's annual economic output. The next section reviews the theoretical debate linking geography and economic development, and clarifies our own hypotheses within this broad debate. The third section describes the data set we developed for this research. The fourth section describes the global distributions of GDP and population across the ecozones. The fifth section examines the distributions within continents. The sixth section offers some further discussion of the results, and explores the ways in which physical geography and the new economic geography might be combined to give a more complete picture of modern economic development.

## Linkages of Geography and Development: Perspectives on the Debate

The linkages between geography and economic development have been much debated, and in our view, much misunderstood. Therefore, it is worthwhile stating some basic propositions regarding our hypotheses and empirical approach, to dispel some misunderstandings that might arise. Philosophers, historians, and social scientists have long noted various correlations of geography and development, even though most economists (and indeed geographers) have downplayed or simply ignored those relationships in recent years. At least seven types of hypotheses have been offered.

- Early philosophers, such as Montesquieu, surmised that climate might have direct effects on temperament, work effort, or social harmony.
- Many writers, activists, and politicians have argued that the link from geography to development is the result of a link from race to development.
- Some philosophers and social scientists (such as Karl Wittfogel 1957) have linked geography and climate to the form of government, for example Wittfogel's famous and much contested claim that riparian civilizations are prone to despotism because of centralized control of water systems and the large public works to support irrigation.
- Some social scientists have argued that climate helps to determine the means of production—yeoman farming in the temperate regions, plantation agri-

culture in the tropics—and therefore the organization of society and the propensity to economic development.

- Many commentators have argued that geographical correlations are accidental reflections of historical events: the temperate-zone societies succeeded, in some sense accidentally, in dominating tropical societies through military conquest and colonial rule.
- Another approach argues that geography is important because geographical endowments (climate, access to navigable waterways) directly affect productivity, through transport costs, health and disease, nutrition, population density, and so forth.
- Geography may also affect the pace and diffusion of technological changes. Certain innovations—in health, energy production and use, agriculture—are likely to be ecologically specific, not easily applicable across ecological zones.
- A final approach argues that ecological and geographical conditions were once very important, but are no longer so important because of technological progress. Geographical correlations with economic development would therefore reflect past relationships plus the continuing path dependence of history (early forces, no longer operating, continue to affect present conditions).

Many of these approaches have been discredited. Indeed, as a general matter, the role of geography in economic development has been downplayed in recent decades, partly because of exaggerated claims made in the past (that geography could explain everything about development) and partly because of the deep discrediting of racist theories of development that had been associated with geographical claims. Because of this inherited skepticism, it behoves us to state our own hypotheses more clearly.

First, we are not suggesting any kind of geographical determinism. Geography is but one of several conditioning variables in the case of economic development. We believe that tropical ecozones and landlocked countries face obstacles to development not faced by temperate-zone and coastal economies. None the less, the role of tropical ecology and coastal access are but two of many factors that contribute to the success or failure of economic development. Secondly, we are not claiming any linkages whatsoever between climate and race, work effort, or culture. Such claims have been predominant in past ages, especially during periods of colonial rule and scientific racism associated with social Darwinism. They have been systematically rejected, and deserve to remain so. Thirdly, we hypothesize that geography has direct links to the economy (through effects on health, agriculture, transport, population density) as well as indirect links through effects on the pace and diffusion of new technologies. We suspect that some of the observed correlations of climate and economic development do indeed reflect past patterns that are of declining relevance, but we also find evidence that at least some of the linkages have remained powerful in the past thirty years.

## Data and Methods

A new geographic information system (GIS) database was constructed with four key variables: climate zone, population, navigable rivers, and gross domestic product on a per capita basis for 152 countries with a population of 1 million or more in 1995. In 1995 these countries had a combined population of 5.65 billion, 99.7 per cent of the world's population (Tobler *et al.* 1995). GIS is a computer-based relational database used for the storage, analysis, and display of geographically referenced data. The inherent advantage to using a GIS is that data can be analyzed spatially.

A digital map of climate was constructed using the classification devised by Wladmir Köppen (1918) and later revised by his students Geiger and Pohl (1953) to determine climate boundaries that coincided with major vegetation types. The version we use was digitized from Strahler and Strahler (1992). The usefulness of this approach to classification lies in its empirical delineation of climatic boundaries based on either monthly or annual actual temperature and precipitation values. The Köppen–Geiger–Pohl classification designates major climate groups, subgroups within the major groups, and further divides the subgroups to capture seasonal differences in temperature and precipitation. There are, of course, many alternative climate classification systems. We do not believe that our major findings of strong inter-relations among climate, GDP, and population depend on the particular system that we are using, in this case the Köppen–Gieger–Pohl classification, but we are in the process of exploring other classification systems in our ongoing research.

The six major categories of climate zones are designated by a capital letter: A = tropical, rainy; B = dry; C = mild, humid; D = snow, forest; E = polar; and H = highland. The subgroups are classified by the addition of another letter. Adding the lower case *f* used with Af, Cf, and Df indicates climates that are moist with adequate precipitation in all months with no dry season. The *w* used with Aw and Cw denotes a dry winter season in the respective hemisphere. The *m*, which is only used with the A climate, indicates a rainforest climate despite a short, dry season in monsoon-like precipitation cycles. The *s* used with Cs indicates a dry season in the summer of the respective hemisphere. The upper case *W* represents arid, desert climates and the *S* indicates semi-arid, steppe climates. The *W* and *S* are used only with the dry B climates. The H and E zones do not have further subdivision. Figure 9.1 depicts the global extent of the subgroups. We mainly are concerned with the eleven classifications of the second tier, Af, Am, Aw, BS, BW, Cf, Cs, Cw, Df, DW, and H. The E climate is generally excluded because the 4 per cent of the world's land area in this polar zone (e.g. the tundra of Northern Russia) has almost no human population.

Figure 9.2 shows the global distribution of population density as of 1994 (Tobler *et al.* 1995) measured as population per sq km. Tobler *et al.* (1995)

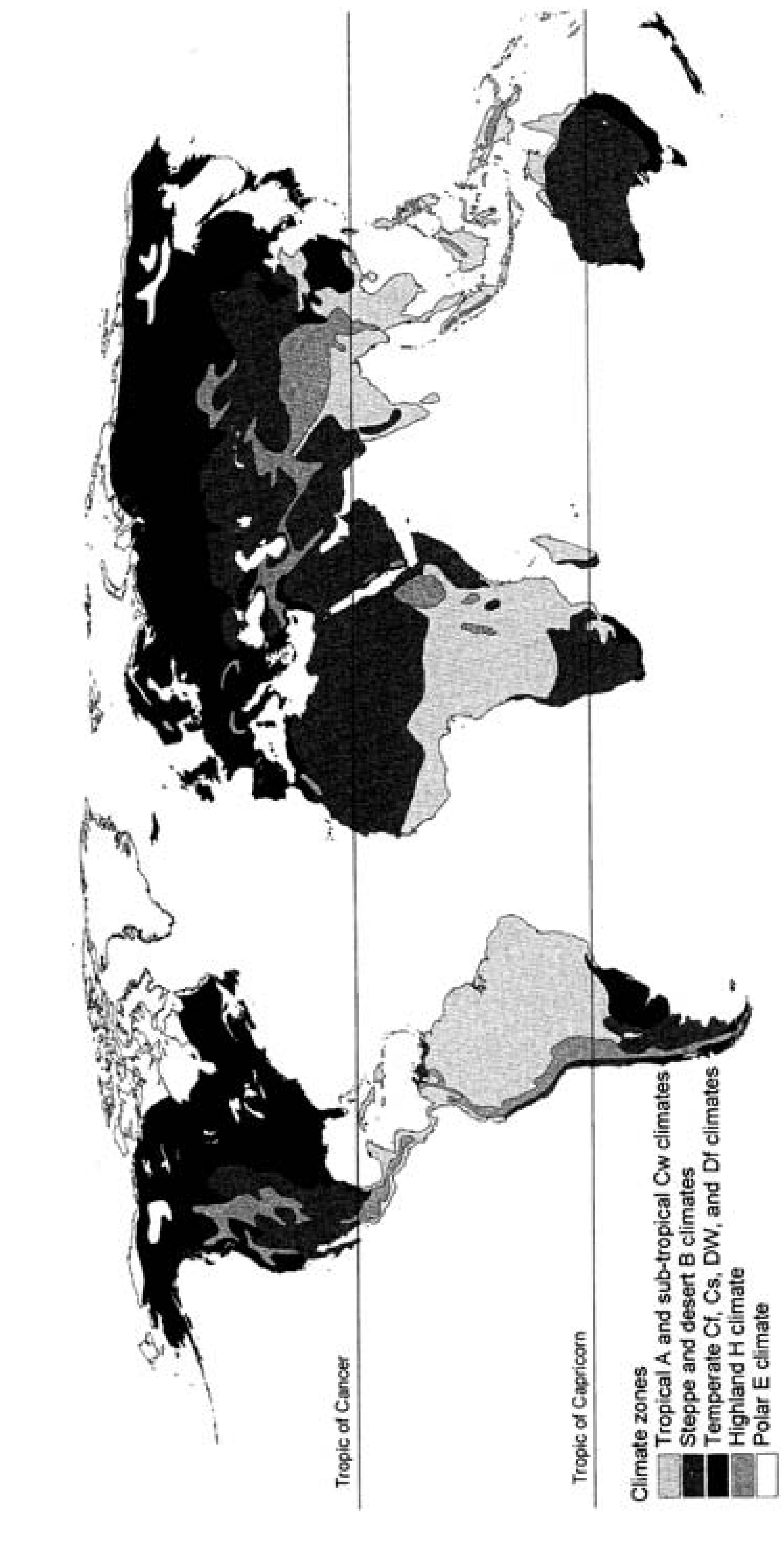


**Fig. 9.1.** Köppen–Geiger climate zones

*Source*: Strahler and Strahler (1992).


**Fig. 9.2.** Population density, 1994

*Source:* See Tobler *et al.* (1995).

obtained a resolution of 5 minutes by 5 minutes, approximately 7.5 sq km at the equator. Some of the underlying data, however, is less refined, with population interpolated to the 5 minute by 5 minute grid. A detailed description of the gridded population data set is in Tobler *et al.* (1995).

Since we are concerned with modern economic development as driven by international trade, rivers were mapped based on navigability for ocean-going vessels. Rivers categorized as navigable in the ArcAtlas (ESRI 1996*a*) database are pared down according to three rules using information taken from Rand McNally (1980), Britannica Online (1998), and *Encyclopaedia Encarta* (1998): whether a river accommodates vessels with a minimum draft of approximately 3 meters (anything smaller is not considered ocean-going); the point at which a navigable river becomes obstructed by falls, rapids, locks, or dams; and whether the river is frozen during winter. The coastline used is free from pack ice throughout the year (ESRI 1996*b*; Rand McNally 1980). Using this classification Figure 9.3 shows the land area in the world that is within 100 km of the ocean coast or a sea-navigable river. As Adam Smith noted, Africa has no sea-navigable rivers that extend from the oceans to the interior of the continent. High continental tableland precludes navigability, even with investment. By contrast, North America has two navigable waterways that link the continent's vast interior with the ocean: the St Lawrence Seaway and Great Lakes system, and the Mississippi River system (and its major tributaries such as the Missouri and Ohio Rivers).[1]

Per capita gross domestic product (GDP) was measured at standardized purchasing power parity (PPP) at both the national and sub-national level. Figure 9.4 depicts global distribution of GDP per capita in 1995. To capture intra-country variance in income distribution, sub-national per capita GDP data was gathered for 19 of the 152 countries in our GIS, including most of the large economies. These are Australia, Belgium, Brazil, Canada, Chile, China, Colombia, France, Germany, Greece, India, Italy, Japan, Mexico, Netherlands, Spain, the UK, the USA, and Uruguay. Since the sub-national data of these countries was collected in local currency rather than on a comparable US dollar purchasing power parity basis, the local-currency measures were adjusted to create internationally comparable sub-national measures.[2] The two major

[1] The St Lawrence Seaway is partly man-made, but the improvements upon its already largely navigable course made this river system fully passable to the Atlantic.

[2] The country-level \$US PPP-adjusted GDP is used for each country for 1995 (GDP per capita below), available from the World Bank (1998), supplemented by CIA (1996, 1997) estimates. For each sub-national region i, the \$US PPP $GDP_i$ is calculated accordingly:

$$\$US\ PPP\ GDP_i = GDP_c \times (GDP_i / GDP_a)$$

$GDP_i$ is the GDP per capita of region i in local currency, and $GDP_a$ is the country-average per capita GDP in local currency. $GDP_a$ is calculated as $\Sigma(GDP_i \times Pop_i)/\Sigma(Pop_i)$. Sub-national regional GDP was collected from national sources, mainly government statistical yearbooks. Thus, provincial populations and provincial income data are used to calculate a country's average GDP per capita,

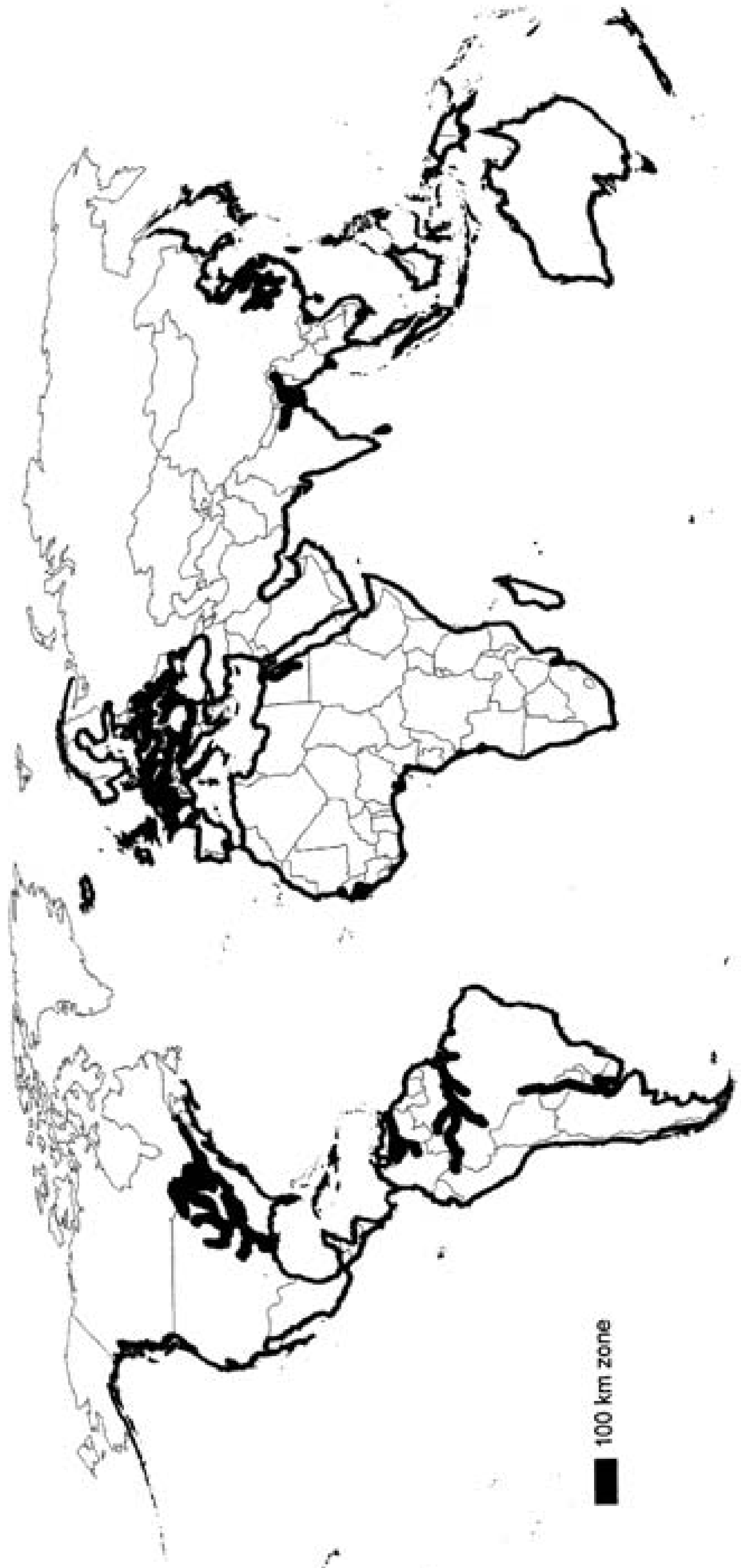


Fig. 9.3. Land within 100 km of an ice-free coast or sea-navigable river

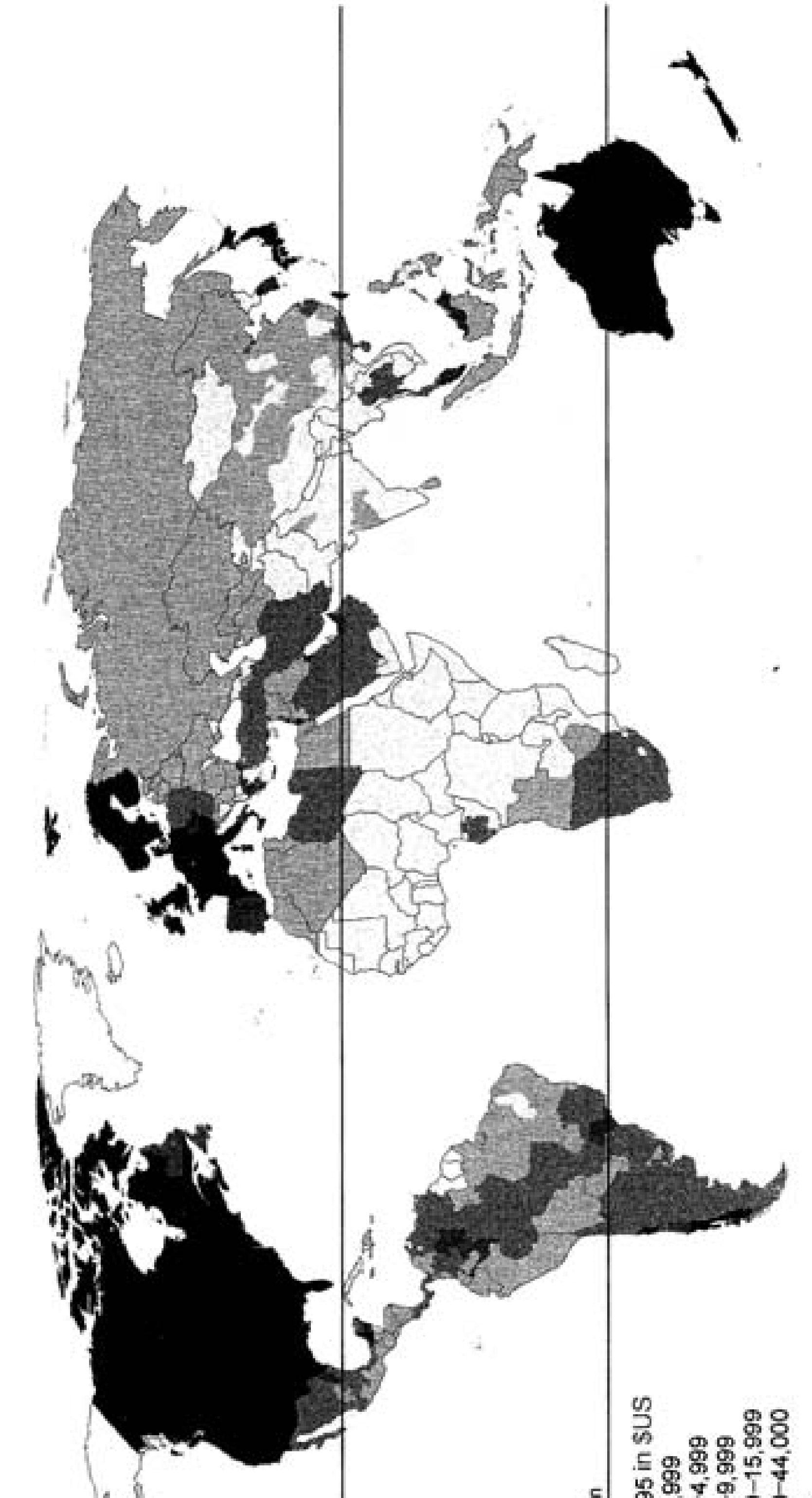


**Fig. 9.4.** Income per person, 1995 (with sub-national data for 19 countries)

*Note:* GDP PPP = 1995 Gross Domestic Product per person in purchasing power parity international dollars.
*Sources:* World Bank (1998) and CIA (1996, 1997).

**Table 9.1.** Land area by climate zone

| Climate zone | Land area (%) Near | Far | Total |
|---|---|---|---|
| Af | 1.7 | 2.3 | 4.0 |
| Am | 0.7 | 0.1 | 0.8 |
| Aw | 2.5 | 8.3 | 10.8 |
| Cw | 0.6 | 3.7 | 4.3 |
| BS | 1.1 | 11.2 | 12.3 |
| BW | 1.9 | 15.4 | 17.3 |
| H | 0.4 | 6.9 | 7.3 |
| E | 0.1 | 3.9 | 4.0 |
| Cf | 4.8 | 2.9 | 7.7 |
| Cs | 1.3 | 0.8 | 2.2 |
| Df | 2.0 | 21.0 | 23.0 |
| DW | 0.2 | 6.2 | 6.4 |
| Tropical[1] | 5.5 | 14.4 | 19.9 |
| Non-temperate[2] | 9.0 | 51.8 | 60.8 |
| Temperate[3] | 8.4 | 30.9 | 39.2 |
| **Total** | **17.4** | **82.6** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, H, and E.
3. Temperate = Cf, Cs, Df, and DW.

gradients of per capita GDP that result are climate and distance from the coast. The tropical regions are almost all poor and coastal regions tend to have higher incomes than interior regions. These effects are quantified in the next section.

## Spatial Distribution of Population and Economic Density

Using the GIS population data, GDP per capita, and climate zone, the distribution of economic activity and global population according to ecozones and proximity to the sea is calculated. Tables 9.1 to 9.3 show the proportions of global land area, population, and total GDP within each of the eleven climate zones. Each climate zone is separated into two sub-regions: 'near', signifying within 100 km of the sea (i.e. ocean coast or ocean-navigable river); and 'far', signifying beyond 100 km from the sea. Four sub-zones (Cf, Cs, Dw, and Df) are classified as 'temperate'. The Cw zone is mainly sub-tropical but is included here as part of the tropical zone rather than the temperate zone (it encompasses

and then used to calculate the ratio of each province's per capita GDP to the national average. We then multiply that ratio by the $US PPP GDP, to calculate a GDP on a PPP basis for each region. This calculation assumes that the ratio of the regional GDP per capita to national GDP per capita in local currency equals the ratio of the regional GDP to national GDP on a PPP basis.

**Table 9.2.** Population by climate zone

| Climate zone | Population (%) Near | Far | Total |
|---|---|---|---|
| Af | 3.8 | 0.6 | 4.4 |
| Am | 2.3 | 0.1 | 2.4 |
| Aw | 9.3 | 8.2 | 17.5 |
| Cw | 6.4 | 9.6 | 16.0 |
| BS | 2.3 | 9.4 | 11.8 |
| BW | 2.1 | 4.1 | 6.2 |
| H | 0.9 | 5.9 | 6.8 |
| E | 0.0 | 0.0 | 0.0 |
| Cf | 15.0 | 4.5 | 19.5 |
| Cs | 3.6 | 0.7 | 4.3 |
| Df | 2.7 | 3.1 | 5.8 |
| DW | 1.5 | 3.8 | 5.3 |
| Tropical[1] | 21.8 | 18.5 | 40.3 |
| Non-temperate[2] | 27.1 | 38.0 | 65.1 |
| Temperate[3] | 22.8 | 12.1 | 34.9 |
| **Total** | **49.9** | **50.1** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, H, and E.
3. Temperate = Cf, Cs, Df, and DW.

**Table 9.3.** GDP by climate zone

| Climate zone | GDP (%) Near | Far | Total |
|---|---|---|---|
| Af | 2.5 | 0.3 | 2.8 |
| Am | 1.0 | 0.0 | 1.0 |
| Aw | 3.6 | 3.0 | 6.6 |
| Cw | 3.4 | 3.6 | 7.0 |
| BS | 1.9 | 4.6 | 6.5 |
| BW | 1.4 | 2.2 | 3.6 |
| H | 0.9 | 4.4 | 5.3 |
| Cf | 36.3 | 7.4 | 43.7 |
| Cs | 7.9 | 1.1 | 9.1 |
| Df | 7.3 | 3.7 | 11.0 |
| DW | 1.4 | 2.0 | 3.4 |
| Tropical[1] | 10.5 | 6.9 | 17.4 |
| Non-temperate[2] | 14.7 | 18.1 | 32.8 |
| Temperate[3] | 52.9 | 14.3 | 67.2 |
| **Total** | **67.6** | **32.4** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

the Gangetic valley of India, parts of South America south of the Amazon, in Southern Africa, and a small belt in northeastern Australia).

The near temperate zone which is within 100 km of the sea and in a temperate climate plays a dominant role in the world economy (see Fig. 9.5). Note that much of the USA's coasts, Great Lakes, and Mississippi River are included, almost all of Western Europe, much of East Asia, including coastal China, South Korea, and Japan, coastal Australia, New Zealand, South America's Chile, coastal Argentina, and a small part of coastal Brazil, part of North Africa's coast, and the southern tip of South Africa. These regions contain almost all of the world's economic powerhouse economies, and as is demonstrated a significant proportion of global production.

Table 9.1 shows the proportion of global land area in each ecozone. Note that 17.4 per cent of the world's land area is within 100 km of the sea. Moreover 39.2 per cent of the world's land area lies within the four sub-zones designated 'temperate'. By calculating the intersection of the two areas, the near temperate zone constitutes 8.3 per cent of the world's land. Nearly one-third of the world's land area (29.6%) lies in the dry climate zones (desert and steppes), along with a smaller proportion of the world's population (18.0%). The dry zones tend to be among the least densely populated places on the planet; 19.9 per cent of the world's land area lies within the tropics (Af, Am, Aw, and Cw), and 7.3 per cent within the populated highlands.

Table 9.2 repeats this exercise for world population: 34.9 per cent live in the temperate zone, and 49.9 per cent live within 100 km of the sea. The near temperate region includes 22.8 per cent of the world's population, located on 8.4 per cent of the world's landmass, making it a densely populated part of the world. Meanwhile 24.3 per cent live in the tropical A zones, while another 16.0 per cent of the world, mainly in India and China, live in the sub-tropical Cw zone. Only 6.2 per cent of the world's population lives in desert (BW) regions, which comprises 17.3 per cent of the land.

Table 9.3 shows the spatial distribution of the world's GDP by climate zone. For each sub-region, per capita GDP (measured at PPP) is multiplied by the population, giving the total GDP for the sub-region. The world's GDP is the sum of these sub-regional GDPs. A striking 67.6 per cent of the world's GDP is produced within 100 km of the sea, though that area comprises only 17.4 per cent of the world's landmass. Meanwhile 67.2 per cent of the world's GDP is produced in the temperate climates, though these account for only 39.2 per cent of the world's landmass. The near-temperate region, with 8.3 per cent of the world's landmass and 22.8 per cent of the world's population, produces a remarkable 52.9 per cent of the world's GDP.

By dividing the cells of Table 9.2 by those of Table 9.1, as shown in Table 9.4, the population density of the climate zones is shown relative to the global average population density, which is 42.5 inhabitants per sq km (Tobler *et al.* 1995). Thus, the Cf near zone has a relative population density of 3.15, or a population

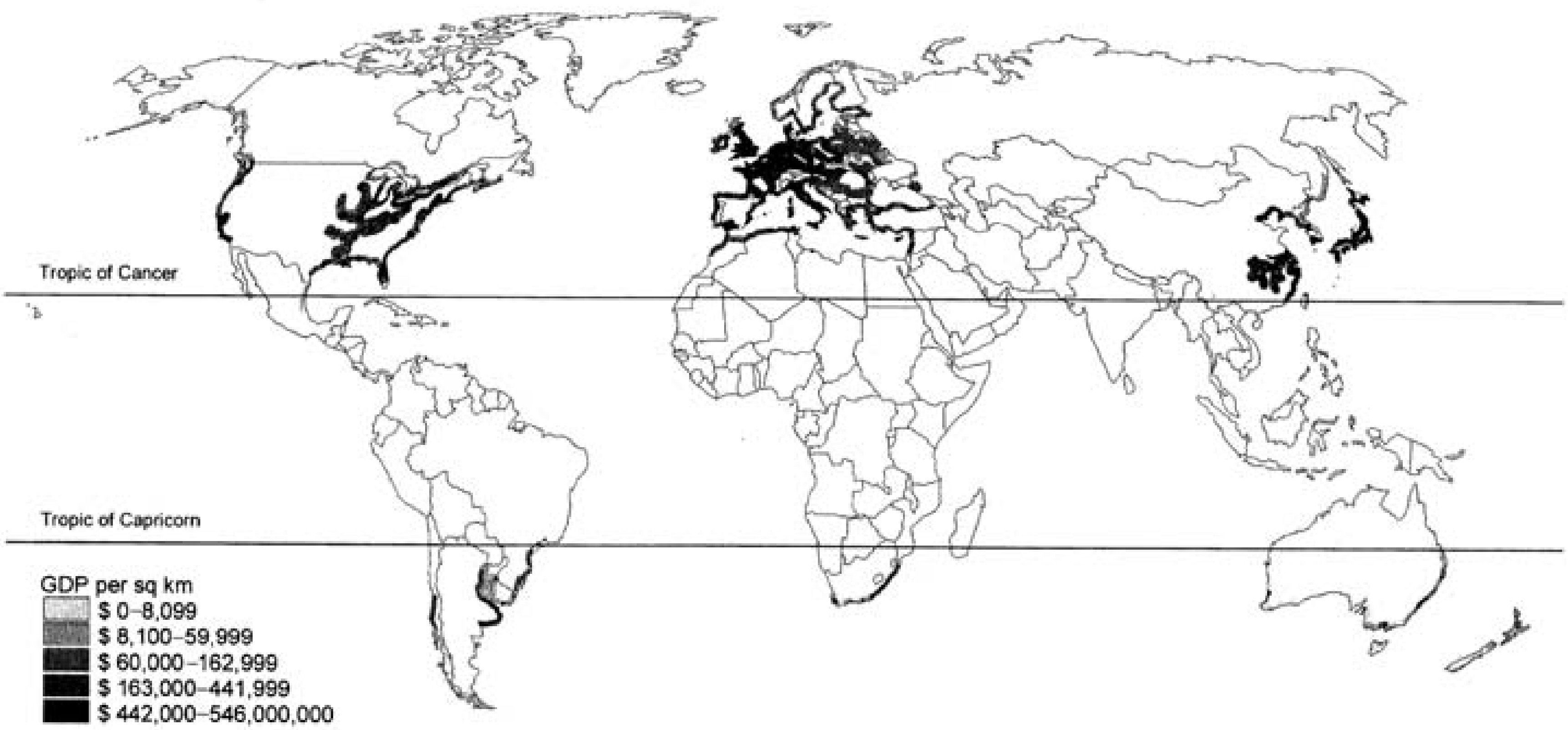


**Fig: 9.5.** Income density in temperate climate zones 0–100 km from the coast and sea-navigable rivers

*Sources:* Figs. 9.1, 9.3, and 4.

**Table 9.4.** Population density by climate zone

| Climate zone | Population Near | Population Far | Total |
|---|---|---|---|
| Af | 2.17 | 0.28 | 1.10 |
| Am | 3.56 | 0.62 | 3.16 |
| Aw | 3.67 | 0.99 | 1.62 |
| Cw | 11.03 | 2.57 | 3.70 |
| BS | 2.19 | 0.84 | 0.96 |
| BW | 1.12 | 0.27 | 0.36 |
| H | 2.23 | 0.85 | 0.93 |
| Cf | 3.15 | 1.57 | 2.55 |
| Cs | 2.66 | 0.90 | 1.99 |
| Df | 1.36 | 0.15 | 0.25 |
| DW | 6.05 | 0.61 | 0.82 |
| Tropical[1] | 3.95 | 1.29 | 2.02 |
| Non-temperate[2] | 3.01 | 0.73 | 1.07 |
| Temperate[3] | 2.72 | 0.39 | 0.89 |
| **Total** | **2.87** | **0.61** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

density 3.15 times the world average, which is 133.9 people per sqkm (= 3.15 × 42.5). The overall near-temperate region is densely populated, with a relative density of 2.72. The near zones are more densely populated than the far zones in every climate zone.

Dividing the cells of Table 9.3 by those of Table 9.2, as shown in Table 9.5, the GDP per capita relative to the world average (or $5,500 at PPP) is presented. The GDP per capita shows two systematic gradients: the near regions are higher than the far regions for every ecozone averaging 1.4 times the world average in the near regions and 0.7 times the world average in the far regions. And the temperate ecozones' GDP per capita is higher than the non-temperate (except in the DW zone which mostly encompasses Siberia), averaging 1.9 times the world average in the temperate zones and 0.5 times the world average in the non-temperate zones. The highest total income ecozone is the Cf (mild, temperate) climate, followed by the Cs (Mediterranean) climate and the Df (snow) climate (the order of these three changes when you compare near and far GDP per capita). Per capita GDP is especially high in the regions that are both temperate and proximate to the sea, with 2.32 times the world average or $12,760 in PPP currency units (2.32 × $5,500). The near-temperate zone has 6 times the per capita GDP of the far tropical zone.

GDP density, measured as total GDP per sq km, is a useful measure for understanding where overall production of goods and services takes place. Since GDP

**Table 9.5.** GDP per capita (GDP/pop.)

| Climate zone | GDP per capita Near | Far | Total |
|---|---|---|---|
| Af | 0.66 | 0.54 | 0.64 |
| Am | 0.41 | 0.30 | 0.41 |
| Aw | 0.39 | 0.36 | 0.38 |
| Cw | 0.54 | 0.37 | 0.44 |
| BS | 0.80 | 0.49 | 0.55 |
| BW | 0.65 | 0.54 | 0.58 |
| H | 1.01 | 0.75 | 0.78 |
| Cf | 2.42 | 1.63 | 2.24 |
| Cs | 2.22 | 1.51 | 2.10 |
| Df | 2.67 | 1.22 | 1.90 |
| DW | 0.92 | 0.53 | 0.64 |
| Tropical[1] | 0.48 | 0.37 | 0.43 |
| Non-temperate[2] | 0.54 | 0.48 | 0.50 |
| Temperate[3] | 2.32 | 1.18 | 1.94 |
| **Total** | **1.35** | **0.65** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

density is equal to per capita GDP multiplied by population density, and since both GDP per capita and population density are especially high in the near temperate zones, the GDP density is extremely high in those regions. Table 9.6 shows GDP density calculated by dividing the cells of Table 9.3 by those of Table 9.1. The GDP density in the Cf near zone is a remarkable 7.63 times the world average GDP density, equaling $230,000 per sq km. The highest income densities are found in the near zones, the temperate climates, and also the subtropical Cw climate. The latter ecozone is characterized by a relatively low GDP per capita, but an extremely high population density. The near ecozones have on average 10 times the GDP densities of the far zones. The near temperate ecozones produce income densities that average 18 times that of the far non-temperate ecozones.

Thus far averages have been examined for population density, GDP per capita, and GDP per sq km by region. Sharp differences were found according to coastal proximity and ecozone. But how significant are these differences? While *formal* statistical tests of differences of means are not readily usable (there being little justification in assuming that the variables are drawn from any particular underlying distribution), the overall distributions of the variables were examined to assess how different these distributions are across regions. Table 9.7 shows the distribution of GDP per capita by ecozone in both the near and far

**Table 9.6.** GDP density (GDP/sq km)

| Climate zone | GDP Density Near | Far | Total |
|---|---|---|---|
| Af | 1.42 | 0.15 | 0.70 |
| Am | 1.46 | 0.19 | 1.28 |
| Aw | 1.43 | 0.36 | 0.61 |
| Cw | 5.91 | 0.95 | 1.61 |
| BS | 1.75 | 0.41 | 0.53 |
| BW | 0.73 | 0.15 | 0.21 |
| H | 2.26 | 0.64 | 0.73 |
| Cf | 7.63 | 2.56 | 5.71 |
| Cs | 5.91 | 1.37 | 4.18 |
| Df | 3.63 | 0.18 | 0.48 |
| DW | 5.57 | 0.33 | 0.53 |
| Tropical[1] | 1.90 | 0.48 | 0.87 |
| Non-temperate[2] | 1.63 | 0.35 | 0.53 |
| Temperate[3] | 6.32 | 0.46 | 1.72 |
| **Total** | **3.89** | **0.39** | |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

regions. The top half of the table refers to regions proximate to the sea, and the bottom half refers to regions far from the sea. For each ecozone, the percentage of the population living at each level of GDP per capita[3] is calculated.

Differences in per capita income across ecozones are reflected in sharp differences in the overall distribution, not just in the means. Among the near regions, for example, no more than 1 per cent of the populations in tropical regions (Af, Am, Aw, or Cw) are in the high-income category ($16,000 or more), while 47 per cent of the populations of the temperate regions are in the high-income category. The tropical regions are nearly uniformly poor, while temperate regions have a wide income range with a small proportion (7%) of the temperate-zone populations at income levels below $2,000, compared with 42 per cent of the tropical zone population.

The same calculations are made for distribution of population density by ecozone, shown in Table 9.8, again dividing the near and far regions for separate analysis. One systematic gradient is that the near ecozones are uniformly more

[3] Note that we have GDP per capita on a national basis for most countries (133 with population of 1 million or more), and a sub-national (provincial or state) basis for 19 countries, giving us 455 administrative units in total for which we have an estimate of average GDP per capita. To make the calculations for Tables 9.3, 9.5, and 9.7, we assume that the entire population within each administrative unit has the average GDP per capita of that unit. Thus, we ignore income inequality *within* administrative units.

**Table 9.7.** GDP per capita distribution

Percentage of population within each zone

| Zone | \$0–1,000 | \$1,000–2,000 | \$2,000–4,000 | \$4,000–8,000 | \$8,000–16,000 | \$16,000+ |
|---|---|---|---|---|---|---|
| **Near** | | | | | | |
| Af | 16 | 6 | 59 | 8 | 10 | 1 |
| Am | 4 | 40 | 52 | 3 | 0 | 0 |
| Aw | 29 | 37 | 21 | 12 | 1 | 1 |
| Cw | 25 | 15 | 34 | 20 | 6 | 0 |
| BS | 2 | 21 | 55 | 8 | 9 | 5 |
| BW | 11 | 11 | 50 | 15 | 11 | 2 |
| H | 5 | 3 | 52 | 22 | 8 | 10 |
| Cf | 0 | 5 | 15 | 21 | 6 | 53 |
| Cs | 1 | 2 | 11 | 30 | 24 | 33 |
| Df | 0 | 1 | 13 | 30 | 0 | 56 |
| DW | 22 | 0 | 15 | 39 | 24 | 0 |
| Tropical[1] | 23 | 26 | 35 | 13 | 4 | 1 |
| Non-temperate[2] | 19 | 23 | 38 | 13 | 5 | 1 |
| Temperate[3] | 2 | 3 | 14 | 24 | 9 | 47 |

**Table 9.7.** Continued

| Percentage of population within each zone<br>Zone | $0–1,000 | $1,000–2,000 | $2,000–4,000 | $4,000–8,000 | $8,000–16,000 | $16,000+ |
|---|---|---|---|---|---|---|
| **Far** | | | | | | |
| Af | 39 | 9 | 18 | 20 | 7 | 7 |
| Am | 3 | 67 | 30 | 0 | 0 | 0 |
| Aw | 35 | 37 | 9 | 12 | 3 | 3 |
| Cw | 27 | 29 | 29 | 9 | 3 | 3 |
| BS | 21 | 26 | 37 | 12 | 2 | 2 |
| BW | 11 | 47 | 19 | 8 | 7 | 7 |
| H | 24 | 26 | 12 | 29 | 5 | 5 |
| Cf | 1 | 10 | 48 | 21 | 10 | 10 |
| Cs | 2 | 3 | 32 | 30 | 16 | 16 |
| Df | 0 | 0 | 8 | 91 | 0 | 0 |
| DW | 1 | 15 | 59 | 14 | 5 | 5 |
| Tropical[1] | 31 | 32 | 20 | 11 | 3 | 3 |
| Non-temperate[2] | 25 | 31 | 23 | 13 | 4 | 4 |
| Temperate[3] | 1 | 9 | 41 | 36 | 6 | 6 |
| **Total** | | | | | | |
| Tropical[1] | 26 | 29 | 28 | 12 | 4 | 2 |
| Non-temperate[2] | 23 | 28 | 29 | 13 | 4 | 3 |
| Temperate[3] | 2 | 5 | 23 | 28 | 8 | 34 |

*Notes:* 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

**Table 9.8.** Population density distribution (pop. per sq km)

| Percentage of regional population<br>Zone | 0–20 | 20–40 | 40–80 | 80–160 | 160–320 | 320+ |
|---|---|---|---|---|---|---|
| **Near** | | | | | | |
| Af | 4 | 7 | 11 | 17 | 13 | 48 |
| Am | 3 | 1 | 5 | 14 | 26 | 51 |
| Aw | 2 | 3 | 7 | 7 | 15 | 67 |
| Cw | 0 | 0 | 1 | 3 | 8 | 88 |
| BS | 3 | 2 | 14 | 15 | 18 | 49 |
| BW | 9 | 8 | 8 | 7 | 13 | 56 |
| H | 4 | 7 | 13 | 26 | 16 | 34 |
| Cf | 2 | 2 | 7 | 16 | 18 | 54 |
| Cs | 1 | 3 | 12 | 25 | 24 | 35 |
| Df | 4 | 5 | 25 | 25 | 13 | 27 |
| DW | 2 | 0 | 1 | 11 | 20 | 66 |
| Tropical[1] | 2 | 3 | 7 | 13 | 17 | 57 |
| Non-temperate[2] | 3 | 3 | 7 | 9 | 14 | 65 |
| Temperate[3] | 2 | 3 | 10 | 18 | 18 | 49 |
| **Far** | | | | | | |
| Af | 42 | 16 | 20 | 13 | 7 | 2 |
| Am | 28 | 11 | 7 | 2 | 11 | 42 |
| Aw | 14 | 9 | 14 | 22 | 27 | 14 |
| Cw | 4 | 3 | 6 | 16 | 25 | 46 |
| BS | 11 | 7 | 12 | 11 | 19 | 39 |
| BW | 24 | 12 | 7 | 16 | 16 | 25 |
| H | 10 | 12 | 19 | 22 | 13 | 24 |
| Cf | 5 | 8 | 14 | 20 | 21 | 32 |
| Cs | 6 | 20 | 33 | 28 | 11 | 3 |
| Df | 27 | 20 | 29 | 11 | 3 | 10 |
| DW | 6 | 3 | 8 | 18 | 25 | 39 |
| Tropical[1] | 12 | 9 | 14 | 21 | 24 | 20 |
| Non-temperate[2] | 12 | 8 | 12 | 17 | 21 | 31 |
| Temperate[3] | 12 | 11 | 18 | 17 | 16 | 26 |
| **Total** | | | | | | |
| Tropical[1] | 5 | 5 | 9 | 15 | 19 | 46 |
| Non-temperate[2] | 8 | 6 | 10 | 14 | 18 | 45 |
| Temperate[3] | 6 | 6 | 13 | 18 | 18 | 41 |

*Notes*: 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

densely populated than the far ecozones. There is much less homogeneity of population density within the tropical and temperate ecozones. The ecozones are less defining of population density than they are of GDP per capita. The tropical zones display regions of both high population densities, 320+

per sq km, and low population densities, 0–20 per sq km. The same is true of temperate ecozones.

## Continental Patterns

As a final exercise in this section, the allocation of populations of major continental regions into ecozones and coastal proximity is shown in Table 9.9. The near temperate regions were noted earlier for having much higher levels of income per capita than all other categories. The continental regions differ markedly in the shares of their populations and land areas that fall within these advantaged or disadvantaged zones. We divide the world into nine broad regions: North America, Latin America, Western Europe, Middle East and North Africa, Sub-Saharan Africa, East Asia, South Asia, Oceania, and Eastern Europe and Former Soviet Union.

Four continental regions have large populations living in non-temperate climates; South Asia has no temperate climate, 96 per cent of Sub-Saharan Africans, 88 per cent of Latin Americans, and 70 per cent of Middle Eastern and North Africans live in non-temperate climates. The global average shows 65 per cent of the population residing in non-temperate climates. The global average for population living in non-temperate far regions is 38 per cent. The same four continental regions again have higher shares: 78 per cent of Sub-Saharan Africans, 59 per cent of South Asians, 48 per cent of Latin Americans, and 45 per cent of the Middle Eastern and North Africans live in non-temperate far regions. In Latin America, one-fifth of the population lives in a highland (H) climate far from the coast.

The people living in the other five continental regions are distributed mostly among the temperate climates. East Asia is included in this grouping because its non-temperate far population of 25 per cent is lower than the global average of 38 per cent. East Asia also has an advantage with the majority of its population living in a region near to the sea. Eastern Europe and the Former Soviet Union have 74 per cent of the population in temperate climates, but only 33 per cent in a near temperate zone. For Russia alone, the population share in the near temperate region is only 6 per cent.

Western Europe, North America, and Oceania are all especially favored. Western Europe has a striking 96 per cent of the population in a temperate ecozone, with 87 per cent in near temperate ecozones. North America has 88 per cent of the population in temperate ecozones and 63 per cent of the population in near temperate ecozones. In Oceania, 74 per cent of the population lives in temperate ecozones, with 63 per cent of the population in near temperate ecozones. Figures 9.1 and 9.5 show that the continents with the highest concentrations of near temperate populations, Western Europe, North America, and Oceania, are also the richest. Conversely, the two continents with the highest

**Table 9.9.** Population by continent (%)

| Continent | Tropical[1] Near | Tropical[1] Far | Non-temperate[2] Near | Non-temperate[2] Far | Temperate[3] Near | Temperate[3] Far | Total Near | Total Far |
|---|---|---|---|---|---|---|---|---|
| Sub-Saharan Africa | 15 | 47 | 18 | 78 | 3 | 1 | 21 | 79 |
| Eastern Europe and Former Soviet Union | 0 | 0 | 6 | 20 | 33 | 41 | 39 | 61 |
| South Asia | 38 | 32 | 41 | 59 | 0 | 0 | 41 | 59 |
| Latin America | 31 | 25 | 40 | 48 | 5 | 7 | 45 | 55 |
| Middle East and North Africa | 0 | 0 | 25 | 45 | 23 | 7 | 48 | 52 |
| *Global average* | *22* | *18* | *27* | *38* | *23* | *12* | 50 | 50 |
| East Asia | 28 | 14 | 32 | 25 | 26 | 17 | 58 | 42 |
| North America | 1 | 0 | 3 | 8 | 63 | 26 | 67 | 33 |
| Oceania | 15 | 2 | 17 | 8 | 66 | 8 | 83 | 17 |
| Western Europe | 0 | 0 | 2 | 2 | 87 | 9 | 89 | 11 |

*Notes*: 1. Tropical = Af, Am, Aw, and Cw.
2. Non-temperate = Tropical plus BS, BW, and H.
3. Temperate = Cf, Cs, Df, and DW.

population in far tropical ecozones, Sub-Saharan Africa and South Asia, are also the poorest.

## Discussion and Future Research

Climate and coastal proximity are two key geographical gradients of economic development. Temperate ecozones and regions within 100 km of sea-navigable waterways are home to more than 50 per cent of the world's economic output, but encompass only 8 per cent of the world's inhabited landmass. The near ecozones contain on average ten times the GDP densities of the far ecozones. Comparing the economic density of the near temperate ecozones with the far non-temperate ecozones, the GDP densities are on average 18 times greater. It is the task of the science of economic development to give an interpretation of these patterns.

Following our discussion above, at least three hypotheses seem appropriate for further exploration. The simplest hypothesis is that the intrinsic characteristics of the tropics and interior regions are indeed highly detrimental to long-term economic development. Tropical climates are burdened by much higher levels of infectious disease than temperate climates (Gallup and Sachs 1999*a*, in the case of malaria), and are generally less productive in food production (Gallup and Sachs 1999*b*). Interior regions suffer from much higher transport costs than coastal regions. The combination of being both interior and non-temperate is therefore doubly detrimental. Sub-Saharan Africa has no less than 78 per cent of its population living in far and non-temperate regions.

A second hypothesis is that tropical climates are detrimental, but only modestly so. If the world is subject to increasing-returns-to-scale production technologies, however, then small initial disadvantages can cumulate into larger and larger differences over time. An example might be the following. Suppose that tropical climates were only, say, 25 per cent disadvantaged 200 years ago, but that innovative activity is ecozone-specific (for example in health and agricultural technology) and is determined by the size of the market. A small initial advantage in the temperate zone could then multiply as a result of much larger induced innovative activity in the temperate zones as a result of the initial modest advantage. Modern endogenous growth models would have this property, in which the rate of innovation depends on the scale of the market. In this case, the main policy implication would be the importance of re-directing scientific and technological efforts towards tropical ecozone problems. The importance of the lack of diffusion of innovations across ecological zones is advocated in Sachs (1999).

A third kind of hypothesis would hold that the technological disadvantages of the tropics, or of interior regions, is a thing of the past; that the disadvantages were once important, but no longer are. In this case, the major differences in income levels across regions would tend to diminish over time, except to the extent that increasing-returns-to-scale processes (such as innovative activity, or the agglomeration economies emphasized in the new economic geography) continue to magnify the former disadvantages into permanent differences.

We have been beginning some of this work, by examining the role of climate in the process of technological innovation and technological diffusion. It seems, for example, to be the case that innovative efforts in public health are still overwhelmingly directed at 'temperate-zone diseases', and that the resulting technological innovations do not always cross the ecological divide. There is remarkably little research on malaria vaccines, for example, even though the technological barriers could likely be overcome in just a few years (Hamoudi *et al.* 1999). We have also found that the growth in total factor productivity in agriculture was considerably higher in the temperate zones than the tropical zones during the period 1961–94 (See Gallup and Sachs forthcoming *a*). With regard to coastal proximity, it might be supposed that the vast cost reductions in air and land travel, and in telecommunications and data transmission, during the twentieth century would have greatly reduced the advantages of a coastal location. Such does not seem to be the case, however. In the USA, for example, the proportion of the population living near the sea coast has been rising steadily (Rappaport and Sachs 1999). Also, coastal proximity has given developing countries a clear advantage in the past thirty years in establishing competitive manufacturing export sectors, which in turn have been important contributors to overall economic growth (Radelet and Sachs 1998).

In a recent study of economic growth in Africa, Bloom and Sachs (1999) examined whether geography factors continued to operate directly on economic growth during the time period 1965–90, after controlling for initial income in 1965, human capital in 1965, and economic policies and institutions during the period 1965–90. Using the Barro cross-country growth framework, this study found that Africa's growth shortfall was materially affected by its high prevalence of landlocked populations (only 21% of the Sub-Saharan African population, we have noted, lives within 100 km of the coast), its high concentration of population in the ecological tropics, and the high prevalence of malaria. These factors, together with Africa's low life expectancy (itself a result in large part of the tropical disease environment), accounted for around 1 percentage point per year of Africa's growth shortfall relative to the rest of the developing countries. In general, the analysis underscores the continuing role of coastal access, climate, and disease ecology in the period since 1965, calling into doubt the view that geographical factors are a 'thing of the past'. They have continued to operate with powerful effect in the past thirty years.

A major research priority for economic development is to understand the continuing linkages between ecological zone, disease, agricultural productivity, nutrition, and economic development. In each of these areas, it is surprising how little is known. For example, in the case of malaria, studied recently by Gallup and Sachs (forthcoming, *b*), the basic data on disease incidence and prevalence by region are remarkably incomplete, making difficult a precise measure of the economic burden of the disease. Moreover, the interactions of malaria with nutrition, and with other diseases, is even less well understood. In short, for a major infectious disease that causes more than 1 million deaths per year, and perhaps 200 million clinical cases if not more, very little is understood about the linkages of the disease and broader patterns of economic development—except for the powerful correlation of malarial prevalence and poor economic growth across countries and over time within countries. In general, whether the issue is to analyze the interactions of tropical diseases and growth, or tropical agricultural productivity, nutrition, human capital accumulation, and development, research in this area will require a sophisticated mobilization of cross-disciplinary research approaches.

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