Biogeography and Long-Run Economic Development

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Abstract

The transition from a hunter-gather economy to agricultural production, which made possible the endogenous technological progress that ultimately led to the industrial revolution, is one of the most important events in the thousands of years of humankind's economic development. In this paper we present theory and evidence showing that exogenous geography and initial condition biogeography exerted decisive influence on the location and timing of transitions to sedentary agriculture, to complex social organization and, eventually, to modern industrial production. Evidence from a large cross-section of countries indicates that the effects of geographic and biogeographic endowments on contemporary levels of economic development are remarkably strong.

Keywords: Geography, biogeography and growth; Economic development; Agricultural revolution; Institutions and growth; Plants, animals and growth.

JEL Codes: N10; N50; O10; O41

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1. Introduction

According to conventional wisdom in economic growth theory, geography is irrelevant for explaining relative income levels of countries. The accumulation of capital and knowledge is deemed independent of prevailing natural conditions, but instead depends on sectoral allocations of production factors, factor returns, saving rates, time discount rates and, in recent literature, political institutions. In neoclassical growth theory, history should not matter much either since well-functioning capital markets ensure that countries sooner or later converge to their steady-state levels regardless of initial conditions. The argument made in this paper is that exogenous geography and initial biogeographic endowments – and the diverging historical paths that these give rise to – in fact account for a significant part of the highly unequal distribution of productive income in the world. Favorable biogeographic initial conditions – in particular the prevalence in prehistory of plants and animals suited to domestication – led in some parts of the world to an early transition to sedentary agriculture and the rise of "civilization", which conferred on some societies a development head start of thousands of years over less fortunate areas. We argue in this paper that the impact of this head start can still be detected in the contemporary international distribution of prosperity.

Many attempts to explain long run patterns of economic development have followed Malthusian analysis in focusing on the relationship between population growth and economic development. Boserup (1981) argues that the transition from the primitive hunter-gatherer stage of development to sedentary agriculture based on domesticated plants and animals was a reaction to population pressures and climatic changes that made the hunter-gatherer lifestyle unfeasible. Kremer (1993) models technological progress from one million B.C. to the present as being endogenously determined by population growth. As support for this hypothesis, Kremer compares population size and the level of technology observed by 1500 A.D. in the Old World (Eurasia and Africa) with the situation in Australia and Tasmania. He finds, as predicted, that population size was relatively greater and the level of technology more advanced in the Old World. Population growth is also what drives historical development in the models of Goodfriend and McDermott (1995) and Galor and Weil (1998).

Another fundamental influence on historical economic development is the institutions that societies embrace. Thanks to pioneering works such as North (1990) and Knack and Keefer (1995), we have significant new insights about how institutions can help create diverging paths of economic progress. In a long run model of world development, Jones (1999a) follows Kremer (1993) in assuming a close relationship between population growth and technological advance. However, per capita consumption is more or less unchanged over thousands of years until an institutional shock in the form of improved property rights propels economies toward the Industrial Revolution and the ensuing rise in living standards. Institutions play an even greater role in Hall and Jones (1999), where the quality of “social infrastructures” is the primes mobile of international variations in productivity and incomes.

A problem with demographic and institutional explanations of long run economic development, however, is that the factors underlying population growth and the development of good institutions are not identified. Why did population growth and institutional advance occur in some parts of the world and not in others? The models above have very little to say about this important question. Population and institutions are usually regarded as exogenously given. The main contention of this paper is that the ultimate factors in historical economic development – shaping the broad contours of population growth, and the capacity for institutional development and technological change – are *geography* and *biogeography*.

The notion that geography broadly conceived matters for societal development is not new. As early as the eighteenth century Montesquieu (1750) had advanced a theory featuring the political influence of climate. But subsequently geographic explanations of development fell into disrepute. Yet when thinking about geography and economic development, two empirical regularities inevitably stand out: First, the majority of poor countries in today’s world are found in the tropical climate zone; near the equator. Second, peoples from Eurasia (above all from the Western part) developed superior technology and colonized and dominated lands on all other continents. The first regularity has recently been observed by several authors (Sala-i-Martin, 1997; Bloom and Sachs, 1998; Hall and Jones, 1999). Hall and Jones (1999) use a measure of absolute distance from the equator as an instrumental variable for social infrastructure. They show that distance from the equator not only has a significant positive effect on social infrastructure, but it also exhibits a significant positive effect on output per capita.

Hall and Jones interpret this relationship as having nothing to do with geography per se; by their thinking countries further from the equator just tend to have good institutions.

Landes (1998), Bloom and Sachs (1998) and Gallup et al. (1999) take a different standpoint. Landes identifies at least three reasons why development has been relatively slow in the tropics: Heat, water supply, and disease. Severe heat typically reduces human working capacity. Water supply is problematic since it tends to be either too scarce (as in the Sahara) or too abundant (as in Amazonia) for agriculture based on annual grasses. The prevalence of serious tropical diseases like malaria, schistosomiasis, and River Blindness, poses a major obstacle to the use of animals like horses and cattle, apart from its obvious detrimental effects on human health. Bloom and Sachs (1998) point out that due to more hours of sunlight during the growing season, the photosynthetic potential for annual plants is actually greater in mid-latitude regions than in the tropics. Bloom and Sachs (1998) and Gallup et al. (1999) also show that conditions for transport in Africa and other poor regions have remarkable disadvantages: A relatively small coastline, few natural ports, the highest proportion of the population within landlocked states, and the absence of rivers navigable for ocean-going vessels. Kamarck (1976) further points to the often poor quality of the soil in the tropics. Tropical soils contain little organic material.

A far more general biogeographic framework for explaining the dominance of the Western world is presented in the remarkable study of Diamond (1997). Diamond argues that the enormous size of the Eurasian continent, its large Mediterranean zone in the western part and the East-West orientation of its major axis, meant that Eurasia was disproportionately endowed with plants suited to cultivation, animals suited to domestication, and natural corridors of transit and communication suited to the diffusion of innovations. Because of these biogeographic advantages, the agricultural revolution occurred earlier in Eurasia than anywhere else. The surplus that was generated by the superior agricultural mode of production made possible the establishment of a non-producing class whose members were crucial for the rapid development of writing, science, cities, technology-based military prowess and states. When the continents finally collided in the late fifteenth century, the crops, horses, knowledge, institutions, weapons, and animal-based germs that had evolved in Eurasia over thousands of years overwhelmed the indigenous communities of the Americas, Africa, and Australia.

The model presented in this paper builds upon Diamond's sweeping study by proposing fundamental links between exogenous geography, initial biogeography and subsequent economic development; links so powerful that their consequences may still be detected today in international variations in output and productivity. Societies enjoying biogeographic environments with great productive potential were the first to experience an agricultural revolution making possible the development of a non-food producing sector of political and administrative elites that produced and organized knowledge. After the transition from hunting and gathering to sedentary agriculture, economies enter a path of endogenous technological progress and increased population growth. Per capita output, however, does not start growing until the Industrial Revolution when the Malthusian link between rising output and population is broken. The central hypothesis we investigate quantitatively is that present levels of per capita income still register the effects of exogenous geographic conditions and initial biogeographic endowments. This hypothesis receives remarkably strong empirical support from data for a broad cross-section of countries.

The outline of the rest of this paper is as follows. Section two reviews modern archeological evidence on the emergence of horticulture and and animal husbandry ("sedentary agriculture"). Section three develops a stylized theoretical framework showing how exogenous geographic conditions and initial biogeographic endowments affected the timing of transitions thousands of years ago from hunter-gatherer to agricultural production, thereby unleashing sustained technological progress that eventually led to the Industrial Revolution. Section four supplies empirical evidence on the model's principal implications regarding the importance of geography and biogeography to economic development. Section five concludes by summarizing the theory and evidence featured in our research.

2. The Agricultural Revolution[1]

Around 11,000 B.C. humankind was on the verge of entering an era of yet to be surpassed economic development. The retreat of the great glaciers that marked the end of the Pleistocene geological epoch and the beginning of the Holocene, brought a warmer and wetter climate and a reoccupation of the ecological vacuum that the ices had

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[1] Section two below relies, except where noted, on Diamond (1997) and Smith (1998).

left. Modern Cro-Magnon humans – capable of marvelous cave paintings and equipped with standardized stone tools and sewn clothing – had by this time populated all the major continents on earth. As noted by Diamond (1997, p 52) "…an observer transported back to 11,000 B.C. could not have predicted on which continent human societies would develop most quickly, but could have made a strong case for any of the continents." Nevertheless, we know with hindsight that the paths to sedentary agriculture would be radically different across continents.

It turned out that the transition from a hunter-gatherer lifestyle to sedentary agriculture, based on domesticated plants and animals, first occurred in the so called Fertile Crescent of the Near East, encompassing the present-day countries Israel, Lebanon, Syria, Jordan and Iraq.[2] By 8500 B.C. the first signs of domesticated barley, emmer, and einkorn wheat appear in the Jordan Valley and in the Southern Levant. Within the following thousand years agricultural development in the Fertile Crescent continued with the domestication of goats, sheep, pigs, and, somewhat later, cattle. The new form of economic life created a rising population density, new demands on social organization, and a food surplus that could be used to feed a non-producing class of chiefs, priests, warriors, and bureaucrats. About 4500 years after the initial steps toward agriculture, the first civilization with writing, science, religion, cities and states, emerged in the river valleys of Tigris and Euphrates. The change from hunting and gathering to sedentary agriculture would forever alter human life and activate a radically new path of rapid development along which we are still traveling.

As Table 1 shows, the Near East was far from the only center of independent domestication of plants and animals. China (or possibly Central Mexico) was the next area to develop an agricultural system that was dependent on rice and millet cultivation and domesticated pigs. As for China, it is probable that the domestication of rice took place in the South along the Yangtze River, while millet was introduced in the North along the Yellow River. The agricultural practices of Central Mexico did not spread south of the tropical rain forests. Hunter-gatherers in the Andes independently created food production based on potato, manioc, and llamas. New research has found that plants were domesticated also in Eastern United states around 2500 B.C., whereas the

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[2] Domestication of a species is defined as "…the human creation of a new plant or animal – one that is identifiably different from its wild ancestors and extant wild relatives…/and which/…has been changed so much that it has lost its ability to survive in the wild." (Smith, 1998, p 18-19).

most recent center of independently developed agriculture is Sub-Saharan Africa; around 4000 B.C. There are, however, other possible candidates. Claims are sometimes made that Ethiopia and New Guinea might have domesticated plants, while cattle might have been independently domesticated in India.

Table 1. Independent Origins of Sedentary Agriculture

Area	Date	Domesticated Plants	Domesticated Animals
1. Near East	8500 B.C.	wheat, barley, pea	goats, sheep
2. China	7500 B.C.	rice, millet	pig
3. Central Mexico	3500 B.C. (8000 B.C.)	corn, beans	turkey
4. South Central Andes	3500 B.C. (5800 B.C.)	potato, manioc	llama, guinea pig
5. Eastern United States	2500 B.C. (3200 B.C.)	sunflower	none
6. Sub-Saharan Africa	4000 B.C.	sorghum	none

Notes: Dates refer to the first attested date of domestication of an animal or plant. All dates here and elsewhere in the text are calibrated radiocarbon dates. The dates of the three American regions are from Diamond (1997). Due to uncertainty about these dates, Smith's (1998) much earlier approximations are shown in parentheses. The domesticated plants and animals in the right hand side columns are examples, rather than a complete listing, of domesticated species in the area.
Source: Diamond (1997), p 100 and Smith (1998), p 13.

How, then, did the agricultural revolution occur? What was it that prompted hunter-gatherers to domesticate plants and animals? These issues have been intensely debated for decades within the scientific community. In what is probably the most comprehensive survey of modern research on the subject, Smith (1998) identifies a number of factors that the independent transitions to agriculture in the Levant, in the Southern Sahara and in the Eastern United States had in common. First, in all three regions, the species brought under domestication were seed plants rather than root crops or animals. Second, in all three regions, the wild ancestors of these domesticates appear to have been important food sources before their domestication. Third, the people who domesticated these seed plants lived in relatively large, permanent communities occupied throughout most, if not all, of the year. Fourth, these societies were relatively affluent, having access to a broad spectrum of wild plants and animals in their diets, as well as to the resources of rich aquatic habitats. Fifth, since these early agricultural settlements were located near lakes or rivers, they also had access to a reliable supply of groundwater. Sixth, it appears that the agricultural communities were bounded in time and space by less secure environments. Preceding the emergence of agriculture in all three regions were climatic changes that worsened the conditions for the hunter-gatherer way of living in the areas surrounding the richer environments near lakes and rivers.

It is important to stress, however, that the emergence of food production was far from a deliberate revolution in human lifestyle. Diamond (1997) describes vividly how the first stands of domesticated wheat in the Fertile Crescent probably appeared near latrines, garbage heaps, forest paths and cooking-places where humans unintentionally had disseminated seeds from their favorite wild grasses, growing nearby. More conscious experimentation was presumably then carried out in the fertile riverbank soils on the outskirts of the villages by people whose relative affluence gave them time for such risky activities. Furthermore, by 11,000 B.C all the necessary technological prerequisites were in place in the Fertile Crescent for an agricultural lifestyle; flint blades in wooden handles for cutting grass, baskets, mortars, and the techniques for roasting grains and storing food underground.

A key issue is whether the agricultural revolution took place out of necessity or because of opportunity. In the language of the economics of innovation, was the emergence of agriculture a result of “demand-pull” or “supply-push”? Advocates of the former view usually argue that an exogenous increase in population forced hunter-gatherers to adopt a more efficient mode of production which did not necessarily increase average standards of living (Boserup, 1981). Climatic changes at the end of the Pleistocene might also have reduced the availability of wild game, thereby making the domestication of animals more or less necessary. Jacobs (1969) takes the opposite view. On the basis of archeological evidence from the ancient Anatolian city Catal Hüyük, Jacobs maintains that a prospering town population that specialized in obsidian trade developed first. The accumulation of imported wild foods in the trading settlement at Catal Hüyük then spontaneously led to the emergence of agricultural practices. This hypothesis is well in line with modern research which has de-emphasized the importance of exogenous, demand driven explanations. Rather than being societies sorely in need of a more efficient way of living, the first agriculturists appear to have belonged to relatively prosperous groups who possessed the technology, time, and energy to conduct experimental search for ways of reducing long-term risk. Observing the immediate and impressive gains from such experiments, a transition then followed within a relatively short span of time.

Can the stunning success of the hunter-gatherers' agricultural experiments in the Fertile Crescent be explained by their extraordinary capacity to exploit their environment – a capacity greater than, for instance, that of the last remaining hunter-gatherers in New Guinea? Diamond (1997) convincingly refutes this argument. Having lived among hunter-gatherers in New Guinea, Diamond describes these native New Guineans as "walking encyclopedias" with detailed knowledge of every imaginable use that could be made of hundreds of plants and animals. This profound knowledge of the natural environment, gained through thousands of years of observation, has also been recorded among other primitive peoples. The notion that native New Guineans or Aboriginals perhaps might have "missed" some crops or animals that could have been successfully domesticated, therefore seems highly unlikely. Furthermore, when for example cattle spread south of the Sahara, hunter-gatherers there quickly adopted a pastoral lifestyle. When horses were introduced in North and South America, native Indians immediately developed great skills in using them. Indeed, nothing seems to suggest that hunter-gatherers in some regions had greater inherent ability to domesticate plants and animals than hunter-gatherers in other areas.

A crucial element for the success of agricultural experiments is rather to have good material to work with. With no suitable species naturally available for domestication, there can be no fruitful experimentation and no agriculture. In a careful taxonomy of wild plants and animals suitable for domestication, Diamond (1997) demonstrates that the distribution of such species is indeed very uneven across continents. Out of about 200,000 wild plant species in the world, only a few thousand are edible, and just a few hundred have ever been domesticated. In a compilation by Blumler (1992) of the 56 heaviest-seeded wild grasses on earth – that is, the most obvious candidates for plant domestication – it is shown that as many as 33 grow naturally somewhere in the Western part of Eurasia, predominantly in the Mediterranean areas of the Near East. (See Table 2.) Six species are confined to Eastern Asia, whereas only two grow in Australia and South America.

The pattern is roughly the same for animals. The animals most suited to domestication are big, terrestrial, herbivorous mammals. Out of 148 species of such mammals weighing more than 45 kilos, only 14 have ever been domesticated. The remaining 134 have all proven impossible to domesticate for various reasons; they are naturally too nasty, they have a tendency to panic, they do not breed in captivity, they have a maturation rate that is too slow, or they do not have the required dominance hierarchy in their social structure that humans can use to gain control. Only 14 big mammals were not disqualified on the grounds above, and as many as 9 of these were found in the Near East, among them “the big four”: The wild ancestors of goat, sheep, pig, and cattle. Contrast this with South America’s single suitable species (the llama) and the total lack of suitable species in North and Central America, Australia, and Sub-Saharan Africa. The Sub-Saharan case is particularly sad because the region has as many as 51 of the 148 heaviest mammals on earth, but not a single one passed the audition for domestication.

Table 2 shows that Western Eurasia in particular, but also East Asia, had superior initial biogeographic conditions for agricultural experimentation. Why was this the case? The answer lies in the continent’s geography and climate. First, Eurasia is by far the largest landmass on the planet and it is naturally endowed with the greatest variation of species. Second, the early success of food production in the Fertile Crescent, and its rapid diffusion to Europe and North Africa, can largely be explained by its Mediterranean climate. All the major crops cultivated in the Fertile Crescent were annual grasses. As shown by Blumler (1992) and others, a Mediterranean climate with wet winters and dry summers is particularly favorable for annual grasses. There are Mediterranean zones also in other parts of the world - in Chile, South Africa, Southern California, and Northern Australia – but none of these were nearly as big as the Eurasian zone. Although wet tropical habitats typically show an enormous biological diversity, their lack of seasonal changes, the irregularity of water supply, the relatively poor quality of soils, and the prevalence of diseases and pests harmful to humans, animals and crops, make agriculture complicated (Kamarck, 1976).

Table 2. Distribution of Species Suitable for Domestication

Area[a]	Number of Plants[b]	Number of Animals[c]
Near East, Europe, North Africa	33	9
East Asia	6	7
Southeast Asia	6	2
Sub-Saharan Africa	4	0
North America	4	0
Central America	5	0
South America	2	1
Australia	2	0
Pacific Islands and Iceland	0	0

[a] The division of Eurasia into three subcontinents is made since food production systems evolved independently and with very different features in the East and West with arid Central Asia as a barrier between them. Early agriculture in the Near East spread to Europe and North Africa but not to Sub-Saharan Africa. Diffusion also took place from China to Southeast Asia, but due to the tropical climate in Southeast Asia, a different set of species was used there. Because of the north-south axis, diffusion of plants and animals was limited between the Northern, Central, and Southern parts of America.

[b] The numbers refer to the geographical distribution of the world's 56 heaviest wild grasses (Blumler, 1992). The figures do not add to 56 because some species are found in more than one continent.

[c] The numbers refer to the geographical distribution of the world's 14 domesticable herbivorous or omnivorous, terrestrial mammals weighing more than 45 kilos (Nowak, 1991; Diamond, 1997).

Sources: Nowak (1991), Blumler (1992), and Diamond (1997).

A third important reason, emphasized by Diamond (1997), is the East-West orientation of Eurasia's major axis. An East-West axis orientation facilitates diffusion of plants and animals. There are a number of reasons for this: Along the same latitude, regions will typically have the same day length, the same seasonal variations, the same regimes of temperature and rainfall, and even the same diseases. Imported domesticated species can easily adapt to such similar environments even though their wild ancestors live elsewhere. All other continents have North-South as the main axis of orientation, and this hampered the diffusion of agricultural innovations.

A picture thus emerges of opportunity rather than need as being the prime causal factor that tipped development in favor of agriculture in certain areas. The advantages would soon become obvious; domesticated plants gave a reliable source of food with high nutritional value which could feed a much greater population per unit area than hunting-gathering. Domesticated animals gave meat, milk, fertilization, wool, leather, and were subsequently used for transport, plowing, and warfare. The close physical proximity of man and animal also eventually gave agriculturists a high resistance to animal related germs such as those causing smallpox, measles, and tuberculosis. All these advantages gradually made organized food production the dominant way of living in all of Eurasia where expanding agricultural communities swept away most of the remaining hunter-gatherers.

The path to civilization was now inevitable. In densely populated towns and cities, a nonproducing class emerged which was able to dominate the rest of the population by gaining control of the agricultural surplus. Among these classes of chiefs, priests, warriors, bureaucrats, and skilled craftsmen, an explosion of new knowledge occurred in astronomy, mathematics, geometry, construction, and social organization. Writing, probably the most important innovation of all times, first appeared in Sumer around 4000 B.C. Great empires soon emerged; Akkad, Egypt, Assyria, Babylon, Persia, and the most advanced of them all, the Greek and Roman civilizations, which today still serve as the pillars of Western civilization. Meanwhile, in less well-endowed areas like Sub-Saharan Africa and Australia – areas with hardly any domesticable species – development was much slower. Agriculture was eventually adopted in Sub-Saharan Africa through the expansion of the Bantu peoples, but when the Europeans finally arrived in Australia, they found an Aboriginal population that was still at the hunter-gatherer stage of development. Judging from the data in Table 2 and from the argument developed above, this was not at all surprising.

3. A Theoretical Framework

We now present a simple theoretical framework of economic development over the three major stages of history; the hunter-gatherer stage, the agricultural stage, and the industrial stage. The aim is to provide a formal representation of the link between initial geographic and biogeographic conditions and the present level of economic well-being. In so doing, we will make use of four stylized facts that were derived in the previous section: (1) Agriculture was first developed in relatively rich environments. (2) There were no differences across continents in hunter-gatherers' inherent ability to exploit their natural environments. (3) The agricultural revolution made possible the emergence of a class of chiefs, craftsmen, and bureaucrats that lived on the surplus from the food producing sector. (4) The introduction of a non-food sector initiated a process of endogenous knowledge creation and an increase in population growth. In addition to these four stylized facts, we introduce a fifth, derived from the empirical literature on long run growth: (5) Standards of living did not significantly increase until the Industrial Revolution (Maddison, 1982; Fogel, 1999; Johnson, 2000).

3.1 *Initial Biogeographic Endowments*

As discussed in the previous section, the date 11,000 B.C. appears to be a good starting point for an analysis of the transition from primitive to modern production. All major continents had been populated and technologies for collecting, processing and storing food were widely known (Diamond, 1997). Let us assume that by this time there are N variations of geographic conditions and biogeographic endowments in those parts of the world that were settled by human beings. Such environments would include tropical rainforests, arctic tundra, lowland deserts, Mediterranean grasslands, and so on. For simplicity, we imagine that all environments are constant from this time forward.[3]

Let us further assume that with each variation $n=\{1,2,\ldots N\}$ in the natural conditions of early human life, there is associated a *biogeographic productive potential* $\tilde{A}_n$, where $\tilde{A}_n$ is a positive real number. This variable reflects the number of *plants* and *animals* suited to domestication under conditions n. It is the maximum number of species that non-agriculturists in n could possibly domesticate for the production of food. As shown above, only a very small fraction of all plants and animals are edible, even in those environments that have the greatest variety of species. An even smaller fraction of species is domesticable. Hence, $\tilde{A}_n$ might be thought of as an indicator of the quality of initial biogeography in n.

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[3] It is well known that environmental conditions have not been constant during the Holocene geological epoch. The tremendous increase in rainfall during the early Holocene, which for instance made possible permanent hunter-gatherer presence in the Sahara and in the now arid parts of Israel, eventually reached a peak and was followed by cooler and drier periods. Although such changing conditions surely affected human life, they did not change the *fundamental* character of the environment in relation to other regions; even if the Sahara temporarily had higher precipitation, it was still a tropical dry region in the north of the African continent which lacked suitable species for domestication.

A crucial assumption in the model below is that the initial conditions for environment n, $\tilde{A}_n$, are different from the initial conditions of all other environments, that is, $\tilde{A}_n \neq \tilde{A}_{n+1}$ for all $n=\{1,2,\ldots N\}$. This means that a ranking of the productive potentials is possible. The quality of $\tilde{A}_n$ in turn is exogenously determined by geographic conditions. Climate is an important factor in this regard. For various reasons, the biogeographic productive potential of Mediterranean habitats is greater than that of, for instance, arctic regions. In fact, as we pointed out in the previous section, the agricultural potential of the Mediterranean climate zone in Eurasia appears to be superior to all others. The size of the continent also influences $\tilde{A}_n$, as does the orientation of its major axis.

3.2 *The Hunter-Gatherer Economy*

There are three fundamental stages of economic development: The *hunter-gatherer economy*, *sedentary agriculture,* and *modern industrial production*.[4] During the greater part of human history, hunting and gathering predominated. In the beginning, all human beings across all environments were hunter-gatherers. At some point in time $t_n^A \in (0,T)$ – where 0 is the starting point of our analysis at approximately 11,000 B.C. and T =13,000 is the present day – the n-th economy makes the switch to full scale agriculture. However, in between these two "pure" stages is a transition period $\tau \in (0,t_n^A)$ in which both hunting-gathering and primitive agriculture is practiced.

Output per capita in the pure hunter-gatherer stage is simply at a subsistence level $\underline{y}$ that is invariant across environments and time during hundreds of thousands of years in the prehistoric time span $\tau \in (-\infty,0)$. By $\tau=0$, the transition to sedentary agriculture begins. Inhabitants of n have now attained a level of technology facilitating domestication of plants and animals for use as intermediate capital goods. The production function describing a hunter-gatherer economy under natural conditions n during this transition period, is

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[4] Like Galor and Weil (1998), our model below has three fundamental stages, but they do not fully correspond to Galor and Weil's *Malthusian*, *post-Malthusian* and *Modern regimes*. The links between population and knowledge in our model have similarities to Kremer (1993). See also Goodfriend and McDermott (1995) and Hansen and Prescott (1999) for models of the historical development from pre-market to market economies and from *Malthusian* to *Solowian* growth, respectively.

$$y_n^H(\tau) = \delta^H \int_{i=0}^{A_n} x_n(i)^\alpha di \cdot \left(L_n(\tau)\right)^{-\alpha} = \delta^H A_n(\tau)\left(x_n^A\right)^\alpha \cdot \left(L_n(\tau)\right)^{-\alpha}. \tag{1}$$

Output per capita at time $\tau \in \left(0, t_n^A\right)$ is $y_n^H = Y_n^H / L_n$ where total output is $Y_n^H = \delta^H \int_{i=0}^{A_n} x_n(i)^\alpha \, di \cdot (L_n(\tau))^{1-\alpha}$, and where $L_n(\tau)$ is total population which for convenience is equated to the size of the labor force. A continuum $A_n \in (0, \tilde{A}_n)$ of biogeographic production factors are used.[5] Note that $A_n(\tau) < \tilde{A}_n$, which implies that the people in n at time $\tau \in (0, t_n)$ still have not been able to make use of all domesticable plants and animals. Each production factor i is employed at a quantity $x_n(i)$. For simplicity we will assume identical marginal productivities: $x_n(i) = x_n^A$ for all i. Hence, $\int_{i=0}^{A_n} x_n(i)^\alpha \, di = A_n(\tau) \cdot \left(x_n^A\right)^\alpha$, where $0<\alpha<1$ gives the return to capital. $\delta^H>1$ is an exogenous productivity parameter for early agriculture which is constant across all n.

In our long run perspective, we assume that all physical production factors are nondurable so that individual budget constraints at each time are $y_n^H(\tau) = c_n^H(\tau) + A_n(\tau) x_n^A / L_n(\tau)$. What is produced can either be used for consumption or as next period's capital. For example, a domesticated mouflon sheep can either be killed and eaten immediately or be saved and used for milk, wool, fertilizer and breeding. Since x_n^A is constant by (highly stylized) assumption, the only source of growth in the stock of intermediate capital goods is the domestication of new plants and animals, that is increases in $A_n(\tau)$.[6]

Over time we assume that $A_n(\tau)$ grows according to a stochastic process $\dot{A}_n / A_n = f\left(\tilde{A}_n\right)$. Growth in productive knowledge is random because no resources are devoted to experimental research activities. The discovery of production methods is

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[5] The function in (1) is a very simple variant of the well-known Dixit and Stiglitz (1977) product variety specification, used for instance by Romer (1990). The specification implies that the capital goods are neither perfect complements, nor perfect substitutes, that there is no knowledge obsolescence, and that each good's marginal productivity is independent of the use of other capital goods.

[6] As in the endogenous growth literature, we will occasionally refer to A_n as "technological knowledge" since it captures the extent to which the hunter-gatherer society has made productive use of its physical environment.

therefore to a large extent a matter of luck or pure chance. However, the expected growth rate of productive knowledge is

$$E\left(\frac{\dot{A}_n}{A_n}\right) = E(f(\tilde{A}_n)) = \gamma\tilde{A}_n \tag{2}$$

where $f'(\tilde{A}_n) = \gamma > 0$ is a parameter reflecting people's propensity to learn from nature. Equation (2) implies that the greater the biogeographic productive potential of n, the greater its expected growth rate of productive knowledge. Note also the central assumption that γ is constant across all n. In line with the stylized facts discussed above, this means that there are no differences between societies in their inherent ability to learn about and exploit their environments. Differences in the growth of productive knowledge derive solely from differences in initial conditions $\tilde{A}_n$, that is, there are simply more useful things to learn from a richer environment.

It is often argued in a Malthusian manner that there is a link between the growth of productive knowledge and population. There are at least three reasons for such an assumption. First, more people means more potential innovators of nonrivalrous ideas. Second, during times of increasing population density, there will be an increasing demand for new technology to cope with population pressure. Third, an increase in productive knowledge creates production surpluses that allow an increased level of population. Kremer (1993) models the growth of knowledge as a function of population size on the grounds of the first argument. Boserup (1981) claims that population pressure is the main determinant of the switch to agricultural technology, in line with the second argument. However, as was discussed above, modern archeological research, influenced by Smith (1998), has de-emphasized the importance of population pressure as a direct influence on the transition to agricultural production.

The fundamental assumption in our model is rather that knowledge growth before the appearance of sedentary agriculture is opportunity-driven; it is a function of the productive potential of the environment. We further believe that technological advance temporarily results in rising living standards, which in turn allow population increases. Seen over the whole transition period to full-scale agriculture, we will therefore have that $\dot{L}_n/L_n = g\left(\dot{A}_n/A_n\right)$ where $g' > 0$. More specifically, we assume that the expected rate of population growth is $E\left(g\left(\dot{A}_n/A_n\right)\right)=\dot{A}_n/\alpha A_n$. Increases in technological knowledge thus lead to a proportional increase in the growth rate of the population.[7]

Since x_n^A is constant over time, the expected growth rate of output per capita during the transition period $\tau\in\left(0,t_n^A\right)$ is $E\left(\dot{y}_n^H/y_n^H\right)=E\left(\dot{A}_n/A_n-\alpha\dot{L}_n/L_n\right)=0$. In other words, the effects of technological progress are offset in a Malthusian manner by increases in population. Thus, output per capita remains at subsistence level $\underline{y}$.

The variance of the growth rate is likely to be substantial, however, yielding famine and threats of extinction in some periods and relative prosperity in others. If we make the simplifying assumption that in the long run $\dot{A}_n/A_n=\gamma\tilde{A}_n$, then the solution to the differential equation for A_n is

$$A_n(\tau)=A(0)\cdot\exp\left(\gamma\tilde{A}_n\tau\right). \tag{3}$$

$A(0)$, the number of domesticated plants and animals at the beginning of the transition period, is equal across all n and is here normalized to be $A(0)=1$.

The agricultural revolution occurs when A_n reaches a certain threshold value A^A. This threshold value reflects the minimum number of domesticated species that have to be in place for the great revolution to occur.[8] Like γ, we assume that A^A is identical everywhere. Sedentary agriculture with domesticated plants and animals demands at least one heavy, herbivorous mammal and two to three domesticated staple crops. The composition of these domesticates can vary. In the Fertile Crescent, the food production package included sheep, goats, pigs, cattle, emmer wheat, einkorn wheat, and barley, while in East Asia it included rice, foxtail millet, soybean, pigs, water buffalo, and chickens (Diamond, 1997; Smith, 1998).

One tragic reality of nature is that in some environments, $\tilde{A}_n<A^A$. An indigenous population could never introduce agriculture in such areas.[9] When development has

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[7] This assumption follows Kremer (1993).

[8] See Azariadis and Drazen (1990) for a model of threshold levels in economic development.

[9] The nonrival factor A_n is indexed because knowledge is nonrival *only within n*. There is no idea diffusion between environments or continents in the hunter-gatherer stage. As will be shown below, we do allow for knowledge diffusion between environments in the agricultural era.

reached the stage $A_n = \tilde{A}_n < A^A$, then $E\left(\dot{A}_n / A_n\right) = 0$. Without external shocks, such as colonization by people from richer environments, such societies are doomed to technological stagnation. For instance, aboriginal Australians never passed the hunter-gatherer stage and the nearby Tasmanians even lost their once acquired ability to make stone tools. A persuasive body of evidence suggests that the reason for this failure was the lack of suitable species for domestication (Diamond, 1997) and hence an inadequate quality of initial conditions.

Let us assume that society n with $\tilde{A}_n > A^A$ attains the threshold level $A_n = A^A$ at time t_n^A. From (3) we then have that $A_n\left(t_n^A\right) = A^A = \exp\left(\gamma \tilde{A}_n t_n^A\right)$. Taking logs and rearranging, we obtain an explicit expression for t_n^A:

$$t_n^A = \frac{\ln A^A}{\gamma} \cdot \frac{1}{\tilde{A}_n} = \frac{\kappa}{\tilde{A}_n} \tag{4}$$

In (4) κ is a positive constant that is identical across environments; t_n^A thus depends only on $\tilde{A}_n$. To make things even clearer, let $T - t_n^A = T - \kappa/\tilde{A}_n$ be the number of years from the present; then $\partial\left(T - t_n^A\right)/\left(\partial \tilde{A}_n\right) = \kappa / \tilde{A}_n^{\,2} > 0$ and $\partial^2\left(T - t_n^A\right)/\left(\partial \tilde{A}_n\right)^2 = -2\kappa / \tilde{A}_n^{\,3} < 0$. The number of years since the adoption of sedentary agriculture in environment n is thus a positive concave function of $\tilde{A}_n$, implying that the greater the productive potential of n afforded by biogeographic endowments, the earlier the transition out of hunter-gatherer production. This is a central prediction of the model. The concavity in $T - t_n^A$ further suggests that the positive impact of initial biogeographic conditions on years elapsed since the transition to agriculture should be decreasing with $\tilde{A}_n$. These implications are investigated empirically in section four.

3.3 *The Agricultural Economy*

The greater efficiency of agricultural food production had major implications for the n-th economy. It allowed resources to be transferred to a separate knowledge producing sector, which in turn led to an increase in the growth rate of new knowledge. Although this process initially created surpluses and rising living standards, Malthusian forces soon led to a proportional increase in population which neutralized technological advance and kept per capita income levels at subsistence level.[10] A more predictable supply of food with a higher nutritional value, in combination with the reduced need of continual migration, also contributed to increased fertility and reduced mortality.

The establishment of a non-food sector in settled communities, whose members lived on the agricultural surplus, was nonetheless one of the most fundamental societal changes in human history. In this sector were the kings, the warriors, the bureaucrats, the priests, and the specialized craftsmen. Their activities ("output") were a prerequisite for the gradual evolution of civilization.[11] These elites coordinated labor and allocated resources. In so doing they also invented written language, mathematics, science, law and institutions for social control and governance. New knowledge was created more systematically. Old knowledge began to be recorded and codified. Specialists, for instance in heavy grasses, could develop a deeper understanding of their object of study by carrying out natural experiments and analyzing carefully the results over time. The reduction of risk in food production must also have had important consequences for people's way of thinking about their place in nature and about what it was possible for their community to achieve. The first states based on these developments were formed around 4000 B.C. in the river valley economies of Tigris and Euphrates.[12]

The production function for the food and capital producing sector is shown in (5). Output per capita at time $\tau > t_n^A$ is a function of the quantity of each intermediate capital good x_n^A, of the range of intermediate capital goods (or knowledge) A_n,, and of the labor engaged in the food and capital sector $v_n^A L_n$.[13] $\delta^A > \delta^H > 1$ is an exogenous

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[10] The archeological record suggests that standards of living were roughly the same in early agricultural societies and in hunter-gatherer communities; see, for example, the monograph of Boserup (1981) and the review of Johnson (2000).

[11] One might of course argue that the emergence of specialized elites and ruling classes was a mixed blessing. The agricultural revolution inevitably led to social stratification and the invention of slavery, and it made possible centralized tyrannical rule.

[12] Landes (1998) argues that the Jewish-Christian tradition of nature's subordination to man explains the rise of norms among Western peoples that promoted efficient exploitation of natural resources and related impulses to economic progress. It appears to be no coincidence that this tradition had its roots in the Fertile Crescent.

[13] $Y=f(A,x,vL)$. Dividing this function for total output by L yields (5).

productivity parameter, reflecting the higher productivity in the full scale agricultural economy.

$$y_n^A(\tau) = \delta_A \left(v_n^A\right)^{\alpha} L_n(\tau)^{-\alpha} \int_{i=0}^{A_n(\tau)} x_n(i)^{\alpha} di = \delta^A A_n(\tau)\left(x_n^A\right)^{\alpha} \left(v_n^A\right)^{1-\alpha} L_n(\tau)^{-\alpha} \tag{5}$$

The range of capital goods $A_n(\tau)$ now exceeds the threshold level A^A. However, it might also be the case that $A_n(\tau) > \tilde{A}_n$. The establishment of a nonproducing sector made it possible for the people in n to learn about and create capital goods beyond the limit set by n's initial environmental conditions. Apart from sheep, cows and wheat, the farming communities now invest in town walls, irrigation systems, and public storehouses. In a hunter-gatherer society, such capital goods are useless, but in a relatively densely populated farming community, inventions like these are vital. Embodied in each of such capital goods is a human idea or piece of knowledge. A_n might thus be seen as reflecting the general state of technological knowledge in society.

x_n^A is the constant quantity of the $A_n(\tau)$ nondurable physical goods used in production. The economy's budget constraint is still $y_n^A(\tau) = c_n(\tau) + A_n(\tau) x_n^A / L_n(\tau)$ and as before progress in our model takes place through the discovery of new capital goods that can be used in production. The fraction of labor engaged in the food producing sector, $v_n^A \in (0,1)$, is treated as exogenously determined.

A separate non-food sector is made possible by the surplus that the transition to full scale agriculture creates. The fraction of the labor force active in this sector, $\left(1 - v_n^A\right)$, comprises a small societal elite of chiefs, bureaucrats, scientists, and specialized craftsmen. Being in control of the agricultural surplus, this elite controls the masses of small scale farmers.[14] Whereas $v_n^A = 1$ would be the optimal solution in a short-sighted, egalitarian hunter-gatherer society where survival is the primary aim, the social planners in the ruling elite of town-based agriculturists now have longer planning horizons and realize that investments in a knowledge producing sector are necessary in order to increase technological knowledge beyond the limits set by the environment.

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[14] It is well known that the societies of early civilizations were strictly hierarchical. In Sumer, for instance, a class of priests kept the majority of the population in near slavery. Even in Athens, where a kind of democracy was introduced, the vast majority of the population was made up of slaves.

Improvements in technology also increase population, which increases the military power and prestige of the incumbent ruler. During the greater part of history, however, $(1 - v_n^A)$ has been close to 0.

The outputs of the non-food sector are viewed here as innovations, or increases in the existing stock of knowledge. Although strictly speaking these innovations are defined in our model as introductions of new capital goods, we recognize the close link between this kind of technological knowledge and the state of societal knowledge in general. It was within the non-food sector that the great advances in mathematics, science, engineering and socio-political organization were made in the early civilizations. Writing was invented as a bureaucratic device for keeping track of taxes and tributes. Chiefs and their advisors designed more efficient ways of social organization in order to monitor the complex, densely populated city-states that began to emerge. To stay in power they also had to develop political skills and military technologies. To legitimize their rule, chiefs needed to create convincing webs of myths and religion. By the construction of ever more imposing monuments, the incumbent rulers would demonstrate the superiority of their own city, dynasty, or empire. The development of science, technology, politics, and institutions was thus to a great extent a necessary response of ruling elites to the new demands of a sedentary lifestyle and to competitive threats from other agricultural societies.

Knowledge growth is described by the following function:

$$\dot{A}_n(\tau) = A_n(\tau)\left[\left(1 - v_n^A\right) + D_n\right] \tag{6}$$

The rate of knowledge growth is therefore $\left(1 - v_n^A\right) + D_n > 0$. Since $A_n(\tau)$ is a nonrivalrous production factor, it can be used both in the regular sector and for the creation of new knowledge. Growth of knowledge in n has two sources; endogenous creation in n and diffusion from other environments. Endogenous knowledge production is captured by the first term inside the parenthesis, where $\left(1 - v_n^A\right)$ is the share of the labor force in the non-food sector. The growth rate of knowledge thus increases linearly with $\left(1-v_n^A\right)$, but there is no “scale effect” in (6) since the growth rate does not increase with the level of the population.[15]

D_n is the diffusion of knowledge from other continents.[16] Such diffusion could arguably be modeled as a function of several factors; for instance geography and the knowledge gap between n and the rest of the world (Olsson, 1999). It might also be modeled as a function of time. During the greater part of history, intercontinental diffusion has been nonexistent or very insignificant. Until around 1500 A.D., human societies in Eurasia, North and South America, Africa, and Australia followed completely separate knowledge trajectories. When advances in ship technology made it possible for European vessels to cross the big oceans, ideas finally began to diffuse between continents, which to some extent offset the initial advantages enjoyed by the richer environments. Yet although the speed and strength of knowledge diffusion probably has increased over time, important geographical differences in knowledge stocks still persist.[17]

The previously assumed Malthusian link between technological advance and population growth is still in place so that $\dot{L}_n / L_n = \dot{A}_n / \alpha A_n = \left(\left(1-v_n^A\right)+D_n\right) / \alpha$. It also follows from (5)-(6) that steady state output growth in the agricultural economy is $\dot{y}_n / y_n = \dot{A}_n / A_n - \alpha \dot{L}_n / L_n = 0$. Despite significant progress in technological knowledge, standards of living remain at subsistence level.[18]

3.4 *The Industrial Economy*

The third fundamental stage in economic history is the modern industrial economy. This stage is generally regarded to have been initiated in the Western world by the end of the eighteenth century. Numerous researchers have extensively analyzed the era[19] and a full treatment is beyond the scope of this paper. Here, we will only briefly sketch

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[15] See Jones (1999b) for an overview of the debate on scale effects in modern growth theory.

[16] D_n might also be thought of as the exogenous component of knowledge growth in general.

[17] For more elaborate treatments of this argument and of knowledge diffusion in general, see Jaffe et al (1993), Acemoglu and Zilibotti (1999), and Olsson (1999).

[18] See Maddison (1982), DeLong (1998), Fogel (1999), or Johnson (2000) for long run empirical estimates that support this feature of the model.

[19] See for instance Mokyr (1990).

what by our understanding are the main lines of development: An increased rate of endogenous technological progress, the collapse of the Malthusian link between technology (or output) and population, and a rapid rise in living standards.

In our highly simplified framework, the Industrial Revolution occurs when the technology variable attains the industrial threshold level A^{IR}. This happens at time t_n^{IR}, so that $A^{IR} = A\left(t_n^{IR}\right)$. In eighteenth century Britain, the final pieces of technological knowledge, which were in place before the threshold level was reached and development took off, included the insights in atmospheric pressure inherent in the first primitive steam engines of Newcomen and Watt, the principles behind Hargreaves' early spinning jenny and Crompton's mule, and a number of new precision tools such as planing machines and lathes which would be crucial for standardized production (Mokyr, 1990).

Output per capita in the industrial era is given by the production function

$$y_n^{IR}(\tau) = \delta^{IR} A_n(\tau)\left(x_n^{IR}\right)^{\alpha}\left(v_n^{IR}\right)^{1-\alpha} L_n(\tau)^{-\alpha}. \tag{7}$$

Equation (7) is meant to describe both agricultural and industrial production. This new structure of production differs from agricultural production in (5) in several respects: Productivity is higher ($\delta^{IR} > \delta^{A}$), a capital deepening has taken place ($x_n^{IR} > x_n^{A}$), and the intermediate capital goods in the range $A_n(\tau) - A_n^{IR} > 0$ are very different in nature from those in the agricultural era. Another important change is that a larger fraction of the labor force is now active in the sector that does not produce physical goods ($v_n^{IR} < v_n^{A}$). An "R&D" sector is gradually coming into place which together with a growing education sector make up the knowledge producers in the economy. The function describing their creation process is shown in (8).

$$\dot{A}_n(\tau) = A_n(\tau)\left[\left(1 - v_n^{IR}\right) + D_n\right] \tag{8}$$

The partly endogenous, partly exogenous knowledge formation from the agricultural era is thus continued, with the important difference that $\left(1 - v_n^{IR}\right) > \left(1 - v_n^{A}\right)$.

Apart from the change in levels of certain parameters, the fundamental difference between the agricultural and the industrial eras concerns the Malthusian link between technological advancement and population growth. After the Industrial Revolution the link disappears; $\dot{L}_n / L_n = \eta_n \geq 0$ where η_n is independent of $\dot{A}_n / A_n$ and assumed to be constant over all n.[20] The reason for this empirical regularity has been widely discussed. Galor and Weil (1998) argue that improved technology increased the returns to human capital, which made parents switch from child "quantity" to child "quality". We believe this may be an important reason, although we do not explicitly model it. The implication of the termination of the Malthusian link is that $\dot{y}_n^{IR} / y_n^{IR} = \dot{A}_n / A_n - \alpha \dot{L}_n / L_n = 1 - v_n^{IR} + D_n - \alpha\eta_n > 0$. Thus, the growth rate of technology finally dominates the growth rate of population, which results in rapidly rising living standards.

3.5 *Comparative Statics*

The solution to the differential equation in (6) yields the level of productive knowledge at the time of the Industrial Revolution, that is at time $\tau = t_n^{IR}$, as

$$A_n\left(t_n^{IR}\right) \equiv A^{IR} = A^A \cdot \exp\left[\left(1 - v_n^A + D_n\right)\left(t_n^{IR} - t_n^A\right)\right] \quad . \tag{9}$$

Equation (9) can in turn be rewritten into an expression for the time of the Industrial Revolution as a function of the time of the agricultural revolution

$$t_n^{IR} = \frac{\ln A^{IR} - \ln A^A}{1 - v_n^A + D_n} + t_n^A = \theta_n + t_n^A$$

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[20] A more appropriate description than what we have suggested is perhaps that the Malthusian link was still strong during the initial phases of the Industrial Revolution, allowing rapid population growth (Fogel, 1999). We will not take this aspect into account in this model.

where the length of the agricultural era $\theta_n = t_n^{IR} - t_n^A$ is an environment-specific constant. The important insight from this result is that, all else equal, the later the transition to agricultural production, the later the transition to an industrial economy.

Next, since we have already established that income per capita did not start growing until the start of the Industrial Revolution, we can express the present level of log income at $\tau = T$ as

$$\begin{aligned} \ln y_n^{IR}(T) &= \ln\left(\underline{y}\cdot\exp\left[\left(1 - v_n^{IR} + D_n - \alpha\eta_n\right)\left(T - t_n^{IR}\right)\right]\right) \\ &= \ln\underline{y} + \left(1 - v_n^{IR} + D_n - \alpha\eta_n\right)\left(T - \theta_n - t_n^A\right) \end{aligned} \tag{10a}$$

where the first part of the exponential expression is the output per capita growth rate during the industrial era. Simple comparative statics of the second line of (10a), where we have substituted in $\theta_n + t_n^A$ for t_n^{IR}, gives the intuitive result that $\partial \ln y_n^{IR} \big/ \partial t_n^A = -\left(1 - v_n^{IR} + D_n - \alpha\eta_n\right) < 0$. Hence the later was the transition to sedentary agriculture (and, therefore, the later was the onset of sustained knowledge growth), the lower is the present level of income per person. Log income per capita increases with time *T*, with knowledge diffusion D_n, and with the allocation of labor in the knowledge sector, $\left(1 - v_n^{IR}\right)$. The population growth rate η_n has a negative effect on output per capita.

The dependence of current income on exogenous geography and initial biogeography, however, are the relations we want to emphasize. We know from earlier results that $A_n\left(t_n^A\right) = \exp\left(\gamma \tilde{A}_n t_n^A\right)$ and that $t_n^A = \ln A_A / \gamma \tilde{A}_n = \kappa / \tilde{A}_n$ (Eq. 4). Writing output per capita as a function of $\tilde{A}_n$ instead of t_n^A yields

$$\ln y_n^{IR}(T) = \ln\underline{y} + \left(1 - v_n^{IR} + D_n - \alpha\eta_n\right)\left(T - \theta_n - \frac{\kappa}{\tilde{A}_n}\right). \tag{10b}$$

With (10b) we establish a link between the present level of log income per capita and biogeographic endowments before the agricultural revolution. The key variables in this regard are of course represented by $\tilde{A}_n$. Differentiation of $\ln\, y_n^{IR}(T)$ with respect to $\tilde{A}_n$ yields $\partial \ln y_n^{IR} / \partial \tilde{A}_n = \left(1 - v_n^{IR} + D_n - \alpha\eta_n\right) \cdot \kappa / \tilde{A}_n^2 > 0$, that is, log output per capita increases with the initial productive potential of environment n. As pointed out before, a large $\tilde{A}_n$ implies a small t_n^A, which in turn implies a small t_n^{IR}; in other words early transitions to agricultural and industrial production and a long period of positive, endogenous growth. Regions with a well endowed natural environment, which consequently made the transitions to agriculture and industry comparatively early should, other things equal, therefore have higher income per capita today than more poorly endowed regions where the transitions came later. This central proposition of the model is evaluated empirically in the next section. Note that the second derivative of $\ln\, y_n^{IR}(T)$ with respect to $\tilde{A}_n$ in (10b) is negative, implying that the positive relationship between $\ln\, y_n^{IR}(T)$ and $\tilde{A}_n$. is concave.

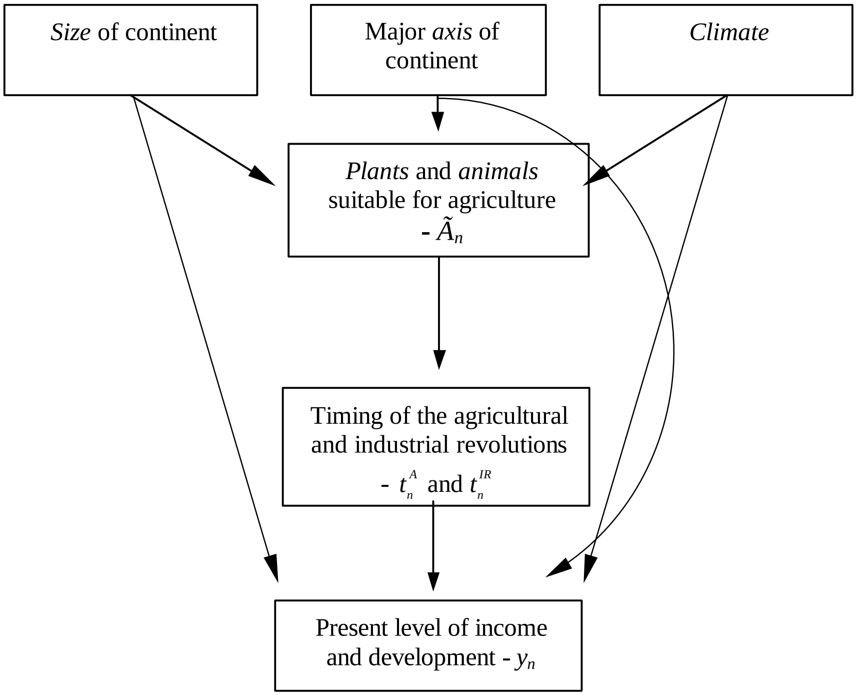
4. Some Empirical Evidence

The principal prediction of the theoretical exercises in section three is that the contemporary level of economic development should be positively related to initial biogeographic endowments, that is, to biogeographies favoring an early transition to agriculture. Calibration of initial conditions, $\tilde{A}_n$, is necessarily imprecise. However, there are a number of plausible proxies. In line with Diamond (1997) and the reasoning above, we obtain measurements of five key geographic and biogeographic variables: size of continent, major axis of continent, climate (calibrated in two ways), and the number of animal and plant candidates for domestication.

The sequence of relationships is depicted in Figure 1. All else equal, the larger the size of a continent or landmass, the greater the biodiversity and the greater the number of species suitable for domestication. The greater the East-West orientation of the major axis, the easier was the diffusion of agricultural innovations between areas. A temperate climate, and in particular the Mediterranean subtype, favors annual grasses like wheat and barley. Geography (inclusive of climate) affects the number of plant and animal species suited to domestication, which in turn determined the timing of the agricultural revolution and the subsequent evolution of endogenously created knowledge, the formation of modern sociopolitical institutions and the onset of sustained growth.

Yet even after the transition to agriculture, it seems likely that the size, axis, and climate of continents continued to exert influence on development.[21] Greater continental size meant greater population and fiercer competition between societies. An East-West orientation of the landmass continued to facilitate the diffusion of knowledge since transmitters of innovations had to pass through fewer rain forests or deserts. A temperate climate still meant fewer diseases harmful to humans and livestock, rainfall patterns and soil qualities favoring stable growth of nutritious plants, as well as temperatures favoring hard manual work.

Figure 1. Biogeography and Long-Run Economic Development



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[21] The observant reader will note that such a direct influence is not explicitly modeled in the theoretical section.

4.1 *Samples and Measurement*[22]

Table 3 reports descriptive statistics on variables appearing in the regressions reported ahead. We obtained measurement of pertinent variables for the largest possible samples, but excluded (i) countries whose current income per capita is based primarily on extractive wealth (mainly oil production based initially on foreign technology and skilled labor), and (ii) "neo European" countries (Australia, Canada, New Zealand and the US) where the food and technology package was transferred by European colonizers hundreds of years ago, rather than having developed indigenously. Countries with these characteristics are omitted because our model and principal hypothesis are not germane to the sources of their present prosperity.

The metrics of some of our variables have no natural or intuitive interpretation. Hence to facilitate assessments of relative effects we convert all variables, except output per capita, to 'standard' form, which yields variates with mean zero and unit variance.[23] Exogenous geographic conditions are measured by four variables: *Climate* is based on Köppen´s system of climatic classification. It takes four discrete values; with 3 denoting the best climate for agriculture (Mediterranean and West Coast climates) and 0 denoting the worst (tropical dry). *Latitude* is the distance from the equator in absolute latitude degrees. It captures well known climatic effects not picked up by the somewhat crude Köppen classification; low latitudes are associated with poor soil quality, highly variable rainfall and a high incidence of debilitating tropical disease. *Axis* is a measure of the east-west orientation of the major landmasses and is calibrated with degrees of longitude. As pointed out earlier, it measures barriers to the transmission of goods, people and ideas. *Size* is the number of square kilometers of the landmass to which each country belongs. As indicated in Table 4, the measures of geography (and biogeography) exhibit fairly high correlations. (Multicollinearity is of course more pronounced than the magnitudes of shared variance implied by the bivariate

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[22] Sources of all variables, and definitions more precise than what appear below, are given in the Data Appendix.

[23] In standard form (or "z form") a variate X is transformed $\left(X - \bar{X}\right)/\hat{s}_x$. Standardization of the regressors of course affects only the scale of slope coefficient estimates facilitating, as noted, comparisons of relative magnitudes (responses of a regressand to standard deviation changes in regressors).

correlations.) Hence we compute *Geo Conditions* – the first principal component of the four geographic variables just described.

Initial biogeographic endowments are measured by two variables: *Plants* is the number of annual or perennial wild grasses with a mean kernel weight exceeding 10 milligrams known to exist in prehistory in various parts of the world. *Animals* is the number of domesticable mammals weighing more than 45 kilograms known to exist in prehistory in various parts of the world. (See Table 2) *Bio Conditions* is the first principal component of these variables.

Political Environment and *Social Infrastructure* are "institutional" variables that geography and biogeography are conditioned on in some of the log output per capita regression experiments. The former is the average of Knack and Keefer's (1995) coding over 1986-95 of five political-institutional characteristics of each country: (i) quality of bureaucracy, (ii) rule of law, (iii) government corruption, (iv) risk of expropriation and (v) risk of government repudiation of contracts. The later variable was developed by Hall and Jones (1999) to quantify the wedge between social and private returns to productive activity; it is the average of Knack and Keefer's political codings and Sachs and Warner's (1995) index of the openness of each country to free trade during 1950 to 1994. Finally, *1997 GDP per capita* is expressed in constant US dollars at base year 1985 international prices.

Table 3. Statistics

Variable	N Obs	Mean	Std Dev	Minimum	Maximum
Climate	112	0	1.0	-1.52	1.45
Latitude	112	0	1.0	-1.43	2.32
Axis	112	0	1.0	-1.48	2.22
Size	112	0	1.0	-1.77	1.04
Geo Conditions	112	0	1.0	-1.28	1.89
Plants	112	0	1.0	-0.95	1.53
Animals	112	0	1.0	-0.91	1.28
Bio Conditions	112	0	1.0	-0.97	1.39
Political Environment	102	0	1.0	-1.93	2.05
Social Infrastructure	100	0	1.0	-1.45	2.15
1997 GDP per capita	112	4850	5291	369	21974
log 1997 GDP per capita	112	7.9	1.1	5.9	10.0

Notes: Except for the GDP terms, all variables are in standard form with mean zero and unit variance. Geo Conditions is the first principal component of Climate, Latitude, Axis and Size. Bio Conditions is the first principal component of Plants and Animals. The Data Appendix gives detailed definitions and sources of all variables.

Table 4. Correlations

Variable	1	2	3	4	5	6	7	8	9	10
1 Geo Conditions	1.0									
2 Climate	.80	1.0								
3 Latitude	.84	.74	1.0							
4 Axis	.84	.48	.53	1.0						
5 Size	.69	.30	.33	.67	1.0					
6 Bio Conditions	.88	.82	.78	.68	.50	1.0				
7 Plants	.84	.81	.77	.60	.48	.96	1.0			
8 Animals	.86	.77	.74	.72	.49	.96	.86	1.0		
9 Political Environment	.68	.61	.73	.49	.26	.62	.57	.63	1.0	
10 Social Infrastructure	.59	.52	.60	.49	.18	.56	.48	.60	.87	1.0

Notes: Geo Conditions is the first principal component of Climate, Latitude, Axis and Size. Bio Conditions is the first principal component of Plants and Animals. All variables are in standard form with mean zero and unit variance; therefore correlations between a principal component and the variables used to generate it are identical to the component's loading factor. The Data Appendix gives detailed definitions and sources of all variables.

4.2 *Regressions*

Tables 5 and 6 report evidence from regressions. The regression setups are far from perfect representations of the equations presented in section three, which themselves are merely stylized mechanisms designed to aid thinking about the connections of geography and biogeography to contemporary levels of economic development. Regressions 1 to 4 in Table 5 pertain to the first link of the long-run causal scheme featured in our historical analysis and illustrated by Figure 1. These regression experiments show that exogenous geographic conditions explain around 80 percent of the variance of the international distribution of heavy seeded plants and large domesticable animals that are known to have existed in prehistory.[24]

Regression 5 pertains to the second link in the long-run causal chain: The influence of initial biogeographic endowments on the timing of the transition to sedentary agriculture, which we regard as one of the most important events in the thousands of years of humankind's economic development. The transition dates are based on calibrated radiocarbon dating of the first domestication of any plant or animal, with the first transition occurring approximately 10,500 years ago (8,500 B.C. in Western Eurasia) and the most recent around 4,500 years ago (2,500 B.C. in North America).[25,26] Such information is available for 8 regions of the world. This limited body of data nonetheless supports the thesis that the richer was a region's initial biogeographic endowment, the earlier was the transition out of hunter-gatherer production to agriculture. The composite *Bio Conditions* variable explains 67 percent of the variance in calibrations of the number of years since the transition to agricultural production $\left(T - t_n^A\right)$, and it shows some sign of the concavity implied by equation (4).

Table 6 reports regressions for log 1997 GDP per capita, the end-point of the long causal sequence depicted in Figure 1. International variation in contemporary per capita incomes is truly staggering. Across the 112 countries in our sample, 1997 GDP per capita expressed in 1985 US dollars ranges from 369 (Ethiopia) to 21974 (Luxembourg), a nearly sixty-fold difference. The first three regression experiments indicate that geography and biogeography are able to account for between 40 and 50 percent of the variance in 1997 log incomes per capita. Our crude measurement of biogeographic endowments fits almost 40 percent of the international variation all by itself, and reveals some signs of the concave effects implied by Equation (10b) (the quadratic *Bio Conditions* term in Regressions 2 and 3). In view of the fact that we have only seven

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[24] As indicated by Table 2, note that Plants, Animals and Bio Conditions do not take N=112 independent variations. The composite Bio Conditions variable takes just 7 variations over the N=112 countries.

[25] See Diamond (1997) and Smith (1998). The 8 regions include the six independent origins of agriculture in Table 1, plus Australia and the Pacific where agriculture was never independently developed.

[26] It should be noted that the first attested dates of domestication used in the regression, do not fully correspond to the transition dates to full scale agriculture (t_n^A) discussed in the theoretical section. However, the dates that we use in this section are undoubtedly closely connected in time to the true transition dates. Archeological evidence suggests that once one animal or plant was domesticated, the others soon followed.

independent variations of prehistorical *Bio Conditions* (*Plants* and *Animals*) in the 112 country sample (cf. Table 2), we take this to be a quite remarkable result.

Yet the evidence in regressions 1 to 4 in Table 6 should not be over interpreted. For example, taken at face value the estimates for regression 3 imply that a change from the worst *Bio* and *Geo Conditions* to the best would yield a shift in 1997 GDP per capita from around 1000 dollars to around 8600 dollars.[27] Given measurement imprecision, exogenous geography and initial condition biogeography therefore are able to account for at least eight and one-half of the nearly sixty-fold difference in contemporary incomes per head which is observed in a broad international cross-section of countries. This corresponds to the development gaps between, for instance, Ghana, Nigeria or Zimbabwe (where incomes are in the vicinity of 1000 dollars of income per head) and Greece, Malaysia or Portugal (where incomes lie in the interval 7,300 to 8,700 dollars per head).

The full range of international variation in incomes per person, however, runs from the 400 to 500 dollars per person typical of the poorest countries to the 15,000 to 20,000 dollars per person enjoyed by the richest. Hence, a complete accounting of contemporary variations in economic prosperity requires explanatory variables generating predictions that halve the per capita incomes implied by the worst geography and biogeography, and that double the per capita incomes implied by best. The leading candidates are the political and institutional arrangements that constrain, and at times influence decisively, the effectiveness of economic activity.

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[27] These estimates are computed simply by applying the coefficients in regression 3, Table 6 (along with the omitted constant) to the range of variation (reported in Table 3) of *Geo* and *Bio Conditions*, and then finding the implied levels of *GDP per capita* from the predicted log values.

Table 5. Regressions for Initial Bio Conditions, $\tilde{A}_n$, and Years Since Transition to Sedentary Agriculture, $(T - t_n^A)$

	Plants (1)	Animals (2)	Bio Conditions (3)	Bio Conditions (4)	Years Since Transition to Agriculture (5)
Climate	0.50 (7.2 | .00)	0.42 (6.1 | .00)	0.47 (7.8 | .00)		
Latitude	0.31 (4.3 | .00)	0.21 (2.9 | 00)	0.26 (4.2 | 00)		
Axis	0.08 (1.1 | .26)	0.37 (0.37 | .00)	0.23 (3.8 | .00)		
Size	0.17 (2.8 | 00)	0.04 (0.65 | .50)	0.11 (2.0 | .05)		
Geo Conditions				0.83 (19.8 | .00)	
Bio Conditions					6458 (3.1 | .02)
Bio Conditions Squared					-2281 (-1.8 | .13)
Adjusted R-Squared	.77	.76	.81	.78	.67
St. Error	0.48	0.49	0.42	0.46	2196
N	112	112	112	112	8 (regions)

Notes: In parentheses are t-ratios | significance levels (p-values). All variables are in standard form with mean zero and unit variance. Geo Conditions is the first principal component of Climate, Latitude, Axis and Size. Bio Conditions is the first principal component of Plants and Animals. The Data Appendix gives detailed definitions and sources of all variables.

Table 6. Regressions for 1997 log GDP per capita

<table>
<tr><th></th><th colspan="7">log GDP per capita</th></tr>
<tr><th></th><th>(1)</th><th>(2)</th><th>(3)</th><th>(4)</th><th>(5)</th><th>(6)</th><th>(7)</th></tr>
<tr><td>Climate</td><td>0.35
(3.1 | .00)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Axis</td><td>0.17
(1.8 | .07)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Latitude</td><td>0.40
(3.4 | 00)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geo Conditions</td><td></td><td></td><td>0.42
(2.5 | .01)</td><td>0.27
(3.1 | .00)</td><td></td><td>0.33
(4.8 | .00)</td><td></td></tr>
<tr><td>Bio Conditions</td><td></td><td>0.88
(6.3 | .00)</td><td>0.48
(2.2 | .02)</td><td></td><td>0.28
(3.4 | .00)</td><td></td><td>0.32
(4.4 | .00)</td></tr>
<tr><td>Bio Conditions Squared</td><td></td><td>-0.32
(-1.6 | .11)</td><td>-0.31
(-1.6 |.11)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Political Environment</td><td></td><td></td><td></td><td>0.77
(8.7 | .00)</td><td>0.78
(9.6 | .00)</td><td></td><td></td></tr>
<tr><td>Social Infrastructure</td><td></td><td></td><td></td><td></td><td></td><td>0.80
(11.3 | .00)</td><td>0.82
(11.8 | .00)</td></tr>
<tr><td>Adjusted R-Squared</td><td>.49</td><td>.38</td><td>.41</td><td>.69</td><td>.69</td><td>.77</td><td>.76</td></tr>
<tr><td>St. Error</td><td>0.80</td><td>0.88</td><td>0.86</td><td>0.65</td><td>0.65</td><td>0.57</td><td>0.58</td></tr>
<tr><td>N</td><td>112</td><td>112</td><td>112</td><td>102</td><td>102</td><td>100</td><td>100</td></tr>
</table>

Notes: In parentheses are t-ratios | significance levels (p-values). Regression constants are omitted. All regressors are in standard form with mean zero and unit variance. Geo Conditions is the first principal component of Climate, Latitude, Axis and Size. Bio Conditions is the first principal component of Plants and Animals. The Data Appendix gives detailed definitions and sources of all variables.

In regressions 4 and 5 of Table 6 the *Political Environment* variable introduced earlier is added to equations including *Geo Conditions* and *Bio Conditions*. Regressions 6 and 7 are specified with the *Social Infrastructure* variable that was discussed earlier. Estimates for these models reinforce results reported in earlier papers by Acemoglu et al. (2000), Gallup et al. (1999), Hall and Jones (1999), Knack and Keefer (1995), Olson et al. (2000) and Rodrik (1997) which indicate that the quality of political-institutional arrangements has potent statistical influence on the levels and growth rates of output and productivity recorded across countries. Unlike equations specified with geography and biogeography alone, regressions 4 to 7 explain the lion's share of cross-national variance in log output per capita, with R^2's running from .75 to .80. More pragmatically, these models yield fits that come much closer to spanning the full dispersion of per capita incomes observed internationally. Applying the estimates from regression 5, for instance, we calculate that the incomes per person associated with the worst and best combinations of *Bio Conditions* and *Political Environment* are around 600 dollars and 13,700 dollars, respectively.

Political and institutional arrangements clearly have proximate, statistically powerful effect on economic performance. Yet regressions 4 to 7 show that *Bio* and *Geo Conditions* retain significance and substantive importance in the presence of these variables. Moreover, every one of our measures of geography is truly exogenous (unlike, for example, many of the geographic variables featured in the papers of Gallup et al. 1999 and Sachs and Warner, 1997). And our measurements of initial condition, biogeography (*Plants, Animals* and their first principal component, *Bio Conditions*) are dated, in most recent vintage, from approximately 4,500 years ago. Although endogenous in our very long-run historical causal sequence (Figure 1), biogeography is indisputably exogenous with respect to current incomes. Problems of joint endogeneity and reverse causation are therefore decisively ruled out in our theoretical setups and in our empirical assessments of the effects of geography and biogeography on present day leves of economic development.

The same is not true, however, of the political-institutional variables; among other reasons because rich countries have the resources to build institutions of high quality.[28] Researchers have struggled with the joint endogeneity issue, proposing various instrumental variables to obtain consistent estimates of the proximate effects of politics and institutions on economic performance. None of these attempts is entirely persuasive

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[28] The related idea that a relatively high level of economic development (and perhaps also distributions of wealth and income that are not too inequitable) are prerequistes for democractic political development (conceived in terms of competitive politics, the rule of law, security of property rights and individual liberties, and so forth) can be traced in the modern social science literature back at least to Lipset (1959), and before that back to the Aristotle and other ancient thinkers. Lipset (1981, chapter 14) comments on the more systematic quantitative demonstrations of the economic development to political democracy thesis that were undertaken in the 1960s and early 1970s by Cutright, Olsen, McCrone and Cnudde, Winham, Diamond, among other political sociologists and poltical scientists. Here, as in other lines of recent research on politics, institutions and economic growth and development, economists are beginning to replicate and extend the earlier work of political sociologists and political scientists. A prominent recent example is Barro (1999).

in our view.[29] If our theoretical model and empirical results are to be believed, geographic and biogeographic variables are certainly invalid instruments for politics and institutions because of the remarkably strong direct effects of *Geo* and *Bio Conditions* on contemporary levels of development registered by our regression results. Indeed, we are tempted to model political-institutional arrangements affecting economic prosperity as an intervening variable(s) driven at least to some degree by the same geographic and biogeographic variables that are the first movers of the timing of the transition to agriculture and the onset of sustained positive growth. Regressing the *Political Environment* variable on *Geo Conditions* and *Bio Conditions* (with *t*-ratios and *p*-values in parentheses as before) we obtain in our 112 country sample:

$$\mathit{Political\ Environment} = \underset{(9.2|.OO)}{0.669}\ \mathit{Geo\ Conditions}, \qquad R^2 = .45$$

$$\mathit{Political\ Environment} = \underset{(7.8|.OO)}{0.639}\ \mathit{Bio\ Conditions}, \qquad R^2 = .37$$

These regressions notwithstanding, we believe along with many others that the political-institutional environment has powerful and genuinely independent causal effect on economic growth and development. Yet because of difficult-to-resolve identification problems, just how big an influence politics and institutions exert on economic performance has not been (and may never be) pinned down with great precision.

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[29] As an illustration, take the Hall and Jones (1999) study which uses latitude, the fraction of the population speaking English and the fraction speaking another European language as instruments for *Social Infrastructure*. However, a high incidence of English and other European languages in current periods is strongly associated with non-extractive colonization (what Acemoglu et al., 2000, call the creation of “neo Europes”), which meant the wholesale transference of an advanced food and technological package from the most advanced societies to the new worlds that most likely still affects development. Latitude is even more difficult to defend as a valid instrument. The unstable rainfall, poor soil quality and prevalence of disease associated with the lower latitudes almost surely depresses economic development directly.

5. Concluding Summary

Archeological and related evidence strongly suggests that the timing and location of transitions from hunting and gathering to horticulture and animal husbandry were decisively affected by biogeographic endowments of various regions of the world in prehistory. This historical observation is a key feature of our stylized model of economic growth and development. In our model biogeographic productive potentials drive transitions to sedentary agriculture, which in turn make possible the formation of non-food sectors of knowledge producers whose activities fuel endogenous technological progress and sustained positive growth. The model implies that the earlier the transition from hunter-gatherer to agricultural production, the longer the period of endogenous growth of knowledge, the longer the period of positive steady state growth of output, and the higher the level of economic development – even in the present day.

The main implications of our reading of history and of our theoretical setup received quite strong support in the data. Consistent with the long-run causal scheme depicted in Figure 1, we found that measures of exogenous geographic conditions explain more than three-quarters of the regional variation in prehistoric biogeography. As implied by our theoretical model, these admittedly rough measurements of biogeography are positively (and perhaps concavely) related to our equally rough assessments of the transition dates to sedentary agriculture; our Bio Conditions variable accounts for around two-thirds of the regional variation in the estimated dates of transition.

Our empirical analyses, however, focused principally on contemporary levels of economic development. Our regressions showed that as much as half of the 1997 international variation in log output per person can be explained by our noisy measures of exogenous geography and prehistoric biogeography. We interpreted this regression evidence to give remarkably strong support to a central prediction of our theoretical model and the associated historical analysis: Current variations in economic prosperity still embody the effects of the prehistoric productive potentials of various environments. Moreover, the geographic and biogeographic signals we detected in current levels of income per person were robust to controls for political and institutional variables that are known to exert powerful, proximate statistical influence on international variations in economic prosperity.

Data Appendix

Definitions and Sources of Variables

Climate is constructed on the basis of Köppen's widely used system of climatic classification.[30] The classification schedule is vegetation-based and divides climate into five major types which Köppen refers to as *A,B,C,D,* and *E*. Climate *A* corresponds to wet tropical climates, *B* to dry tropical climates, *C* and *D* to temperate, mid-latitude climates, and *E* to tundra and ice. In constructing our *Climate* variable we made a ranking of climates according to how favorable they are to agriculture. Countries with type *B* climates have been given a value of 0. Most of the countries in this category are found in the Sahara and on the Arabian peninsula. The tropical climates in the *B* category were scored 1. Precipitation is abundant and biodiversity great, but the heavy rainfall typically does not favor annual grasses. Countries with temperate climates of type *Cfa*, *Cwa*, and *D* (humid subtropical and continental) were scored 2. A particular subgroup within the non-tropical climates is the Mediterranean and west coast climates (*Csa*, *Csb*, *Cfb, Cfc*) with more or less hot, dry summers and wet winters. These types of climate are found in the western parts of continents; in Europe, North Africa, California, Chile, South Africa, and the northwestern parts of Australia. As discussed by Blumler (1992) and Diamond (1997), this type of climate is particularly favorable to agriculture based on annual, heavy grasses. Countries that fall into this category were scored 3. Hence, *Climate* has four units of variation with a mean value normalized to 0.

Latitude is the absolute distance from the equator in latitude degrees. The data are from World Bank (1999).

Axis captures the rate of East-West orientation. The variable was constructed by measuring the distance in longitudinal degrees between the eastern and westernmost points of each continent and dividing this number by the distance in latitudinal degrees between the northernmost and southernmost points. A value of, for instance, 2 indicates that the landmass in question is about two times more East-West oriented than north-south. The Eurasian landmass is by far the most East-West oriented of the major continents, while South America is the most north-south oriented.

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[30] The data and the discussion of climate have been derived from Britannica (2000).

Size is just the size of the landmass to which the country belongs in millions of square kilometers. The variation is enormous ranging from Eurasia's 44 million square kilometers to the tiny Malta and Comoros islands of less than 1000 square kilometers.

Geo Conditions is the first principal component of *Climate, Latitude, Axis,* and *Size.*

Plants is the number of annual or perennial wild grasses known to exist in prehistory with a mean kernel weight exceeding 10 milligrams. These data are from Blumler (1992) and are equivalent to the numbers shown and discussed in Table 2. The geographical distribution ranges between 33 species in the Near East, Europe, and North Africa - including wild barley, emmer and einkorn wheat – to 0 in the Pacific islands. As noted above, we have divided Eurasia into three subcontinents which had different and independent experiences of plant and animal domestication. The Western part reaches its limit in the Indus Valley in Pakistan, where the easternmost archeological evidence of crops from the Fertile Crescent has been found (Smith, 1998). Southeast Asia includes Indonesia, the Philippines, and Papua-New Guinea. Also America is split up into three zones of independent agricultural origins; Central, North, and South. Caribbean islands and islands near Africa are regarded as belonging to the Central American and African zones respectively, while the Pacific islands are treated as independent of the Asian zone of agricultural origin (and hence have zero species suitable for domestication).

Animals is the number of domesticable big mammals, weighing more than 45 kilos, which are believed to have been present in prehistory in various regions. The data were presented in Table 2. The 14 animals are the ancient ancestors of sheep, goat, cattle, horse, pig, Bakhtrian camel, Arabian camel, llama, yak, bali cattle, reindeer, water buffalo, donkey, and the mithan (Diamond, 1997). Out of these 14, western Eurasia and North Africa had access to 9, Eastern Eurasia 7, Southeast Asia 2, Central and North America, Sub-Saharan Africa, Australia and the Pacific islands 0 (Nowak, 1991). On average, early hunter-gatherers across the world had access to somewhere between 3-4 domesticable animals.

Bio Conditions is the first principal component of *Plants* and *Animals*.

Political Environment is from Knack and Keefer's (1995), who in turn have used data from the private risk service *International Coutry Risk Guide*. The data exhibit the average of coding over 1986-95 of five political-institutional characteristics of each country: (i) quality of bureaucracy, (ii) rule of law, (iii) government corruption, (iv) risk of expropriation and (v) risk of government repudiation of contracts.

Social Infrastructure was developed by Hall and Jones (1999) to quantify the wedge between social and private returns to productive activity; it is the average of Knack and Keefer's political codings and Sachs and Warner's (1995) index of the openness of each country to free trade during 1950 to 1994.

1997 GDP per capita is expressed in constant US dollars (international prices, base year 1985). The data are from World Bank (1999) and were compiled by William Easterly on the basis of Penn World Table 5.6 and other sources.

Years since transition to agriculture is the number of years before the present that agriculture was adopted in eight world areas of independent agricultural development. The only missing region is Southeast Asia (Indonesia, Philippines, Papua-New Guinea) where transition data are very uncertain. The data builds upon Diamond (1997) and were partly presented in Table 1.

Data Series

Country	1997 GDP per capita	Climate	Latitude	Axis	Size	Geo Conditions
Argentina	6489	2	0.4075	0.791	17.814	-0.1083
Austria	13921	3	0.5359	2.355	44.614	1.7026
Bangladesh	1779	1	0.2653	2.355	44.614	0.5534
Belgium	14305	3	0.5649	2.355	44.614	1.7591
Belize	4191	1	0.1983	1.575	24.23	-0.3216
Benin	1048	1	0.0707	1	30.365	-0.7545
Bolivia	1896	1	0.1688	0.791	17.814	-0.8847
Botswana	2681	0	0.2393	1	30.365	-0.7364
Brazil	4449	1	0.2173	0.791	17.814	-0.7900
Bulgaria	4617	3	0.4675	2.355	44.614	1.5691
Burkina Faso	530	1	0.1339	1	30.365	-0.6313
Burundi	397	1	0.0374	1	30.365	-0.8195
Cameroon	965	1	0.1192	1	30.365	-0.6599
Cape Verde	1169	1	0.1677	1	0.004	-1.0881
Central African Rep.	528	0	0.0481	1	30.365	-1.1093
Chad	392	0	0.1153	1	30.365	-0.9783
Chile	6518	3	0.3728	0.791	17.814	0.1348
China	2387	2	0.3285	2.355	44.614	0.9872

Colombia	3813	1	0.0532	0.791	17.814	-1.1101
Comoros	434	1	0.1297	1	0.002	-1.1623
Congo, Republic	1978	1	0.0409	1	30.365	-0.8126
Costa Rica	3801	1	0.1105	1.575	24.23	-0.4928
Cote d'Ivoire	1187	1	0.0611	1	30.365	-0.7734
Czech Republic	3751	3	0.5556	2.355	44.614	1.7409
Denmark	16178	3	0.6191	2.355	44.614	1.8648
Dominican Republic	2687	1	0.2062	1	0.076	-1.0117
Ecuador	2926	1	0.0229	0.791	17.814	-1.1692
Egypt, Arab Rep.	2106	3	0.3333	1	30.365	0.3791
El Salvador	2158	1	0.1531	1.575	24.23	-0.4097
Equatorial Guinea	2301	1	0.0258	1	30.365	-0.8421
Ethiopia	369	0	0.1001	1	30.365	-1.0080
Fiji	4143	1	0.1981	1	0.018	-1.0286
Finland	14028	2	0.6690	2.355	44.614	1.6515
France	14650	3	0.5429	2.355	44.614	1.7161
Gambia, The	747	1	0.1473	1	30.365	-0.6051
Georgia	1246	2	0.4670	2.355	44.614	1.2575
Ghana	1031	1	0.0744	1	30.365	-0.7474
Greece	7346	3	0.4229	2.355	44.614	1.4821
Guatemala	2401	1	0.1625	1.575	24.23	-0.3914
Guinea	843	1	0.1297	1	30.365	-0.6395
Guinea-Bissau	689	1	0.1362	1	30.365	-0.6267
Haiti	621	1	0.2104	1	0.076	-1.0036
Honduras	1424	1	0.1577	1.575	24.23	-0.4006
Hong Kong	18811	2	0.2523	2.355	44.614	0.8386
Hungary	5200	3	0.5269	2.355	44.614	1.6850
Iceland	14155	2	0.7099	1.667	0.103	0.6182
India	1624	1	0.2808	2.355	44.614	0.5836
Indonesia	2735	1	0.0729	3	1.919	-0.2319
Ireland	13943	3	0.6068	0.75	0.07	0.2650
Israel	11181	3	0.3565	2.355	44.614	1.3526
Italy	13357	3	0.5046	2.355	44.614	1.6415
Jamaica	2326	1	0.2006	1	0.011	-1.0238
Japan	16003	2	0.3968	1.214	0.377	-0.2162
Jordan	3098	3	0.3511	2.355	44.614	1.3422
Kenya	916	1	0.0057	1	30.365	-0.8813
Korea, Rep.	10131	2	0.4173	2.355	44.614	1.1604
Lao PDR	1765	1	0.1839	2.355	44.614	0.3944
Latvia	2691	3	0.6318	2.355	44.614	1.8895
Lesotho	1331	0	0.3288	1	30.365	-0.5618
Luxembourg	21974	3	0.5531	2.355	44.614	1.7361
Madagascar	577	1	0.2106	0.615	0.587	-1.1883

Malawi	571	1	0.1757	1	30.365	-0.5498
Malaysia	7696	1	0.0363	2.355	44.614	0.1067
Maldives	2424	1	0.1859	1	0.001	-1.0526
Mali	535	0	0.1390	1	30.365	-0.9321
Malta	9066	3	0.3987	1	0.001	-0.0160
Mauritania	922	0	0.1992	1	30.365	-0.8147
Mauritius	7391	1	0.2248	1	0.002	-0.9767
Mexico	6435	0	0.1862	1.575	24.23	-0.6558
Mongolia	1474	0	0.5277	2.355	44.614	0.7544
Morocco	2231	3	0.3733	1	30.365	0.4570
Mozambique	914	1	0.2055	1	30.365	-0.4915
Namibia	2764	0	0.1998	1	30.365	-0.8135
Nepal	1232	2	0.3079	2.355	44.614	0.9471
Netherlands	14683	3	0.5764	2.355	44.614	1.7815
Niger	424	0	0.1542	1	30.365	-0.9025
Norway	18547	2	0.6664	2.355	44.614	1.6464
Pakistan	1472	2	0.3464	2.355	44.614	1.0222
Panama	3612	1	0.1023	1.575	24.23	-0.5088
Papua New Guinea	1660	1	0.0733	2	0.462	-0.7602
Paraguay	2240	2	0.2843	0.791	17.814	-0.3487
Peru	2732	1	0.1310	0.791	17.814	-0.9583
Philippines	1873	1	0.1547	0.769	0.3	-1.2248
Poland	5034	3	0.5583	2.355	44.614	1.7462
Portugal	8684	3	0.4313	2.355	44.614	1.4985
Romania	1724	2	0.4947	2.355	44.614	1.3116
Rwanda	579	1	0.0226	1	30.365	-0.8484
Samoa	2171	1	0.1515	1	0.003	-1.1197
Senegal	1146	1	0.1641	1	30.365	-0.5723
Sierra Leone	507	1	0.0967	1	30.365	-0.7039
Singapore	17559	1	0.0151	2.355	44.614	0.0652
Slovak Republic	5393	3	0.5333	2.355	44.614	1.6976
Solomon Islands	2260	1	0.1069	1	0.028	-1.2062
South Africa	3134	3	0.3237	1	30.365	0.3603
Spain	10685	3	0.4155	2.355	44.614	1.4678
Sri Lanka	2734	1	0.0763	1	0.065	-1.2653
Sudan	1032	0	0.1560	1	24.614	-0.9978
Swaziland	2664	0	0.2949	1	30.365	-0.6279
Sweden	14827	2	0.6586	2.355	44.614	1.6313
Switzerland	15768	3	0.5268	2.355	44.614	1.6847
Syria	4772	3	0.3718	2.355	44.614	1.3824
Taiwan	11729	2	0.2667	0.67	0.036	-0.7501
Tanzania	540	1	0.0239	1	30.365	-0.8458
Thailand	5038	1	0.1530	2.355	44.614	0.3343

Togo	547	1	0.0688	1	30.365	-0.7582
Tunisia	3465	3	0.4091	1	30.365	0.5269
Turkey	4396	3	0.4578	2.355	44.614	1.5502
Uganda	697	1	0.0025	1	30.365	-0.8875
United Kingdom	14472	3	0.5723	0.5	0.244	0.0747
Uruguay	5949	2	0.3869	0.791	17.814	-0.1485
Zambia	649	1	0.1438	1	30.365	-0.6120
Zimbabwe	1242	0	0.1986	1	30.365	-0.8158

Country	Plants	Animals	Bio Conditions	Political Environment	Social Infrastructure
Argentina	2	1	-0.7689	0.579	0.3341
Austria	33	9	1.3884	0.949	0.8636
Bangladesh	6	7	0.1224	0.313	0.1563
Belgium	33	9	1.3884	0.954	0.8657
Belize	5	0	-0.7791	#N/A	#N/A
Benin	4	0	-0.8168	0.376	0.2437
Bolivia	2	1	-0.7689	0.381	0.5573
Botswana	4	0	-0.8168	0.713	0.5343
Brazil	2	1	-0.7689	0.682	0.3853
Bulgaria	33	9	1.3884	0.706	0.3973
Burkina Faso	4	0	-0.8168	0.498	0.2492
Burundi	4	0	-0.8168	0.528	0.2639
Cameroon	4	0	-0.8168	0.563	0.3593
Cape Verde	4	0	-0.8168	0.387	0.2291
Central African Rep.	4	0	-0.8168	0.42	0.2099
Chad	4	0	-0.8168	0.554	0.2770
Chile	2	1	-0.7689	0.646	0.5343
China	6	7	0.1224	0.641	0.3203
Colombia	2	1	-0.7689	0.565	0.3268
Comoros	4	0	-0.8168	0.567	0.5084
Congo, Republic	4	0	-0.8168	0.415	0.2073
Costa Rica	5	0	-0.7791	0.67	0.5461
Cote d'Ivoire	4	0	-0.8168	0.626	0.3128
Czech Republic	33	9	1.3884	#N/A	#N/A
Denmark	33	9	1.3884	0.984	0.8809
Dominican Republic	5	0	-0.7791	0.51	0.2548
Ecuador	2	1	-0.7689	0.573	0.7089
Egypt, Arab Rep.	33	9	1.3884	0.551	0.2755
El Salvador	5	0	-0.7791	0.372	0.3858

Equatorial Guinea	4	0	-0.8168	#N/A	#N/A
Ethiopia	4	0	-0.8168	0.399	0.1993
Fiji	0	0	-0.9678	0.611	0.5098
Finland	33	9	1.3884	0.98	0.8789
France	33	9	1.3884	0.941	0.8707
Gambia, The	4	0	-0.8168	0.568	0.3949
Georgia	33	9	1.3884	#N/A	#N/A
Ghana	4	0	-0.8168	0.54	0.3813
Greece	33	9	1.3884	0.712	0.7560
Guatemala	5	0	-0.7791	0.371	0.3968
Guinea	4	0	-0.8168	0.504	0.3518
Guinea-Bissau	4	0	-0.8168	0.34	0.2587
Haiti	5	0	-0.7791	0.236	0.1178
Honduras	5	0	-0.7791	0.424	0.3896
Hong Kong	6	7	0.1224	0.791	0.8957
Hungary	33	9	1.3884	0.788	0.4496
Iceland	0	0	-0.9678	0.986	0.8957
India	6	7	0.1224	0.591	0.3064
Indonesia	6	2	-0.4946	0.484	0.5196
Ireland	33	9	1.3884	0.889	0.7667
Israel	33	9	1.3884	0.756	0.4891
Italy	33	9	1.3884	0.815	0.8077
Jamaica	5	0	-0.7791	0.544	0.4831
Japan	6	7	0.1224	0.932	0.8327
Jordan	33	9	1.3884	0.562	0.6145
Kenya	4	0	-0.8168	0.582	0.3131
Korea, Rep.	6	7	0.1224	0.735	0.6673
Lao PDR	6	7	0.1224	0.574	#N/A
Latvia	33	9	1.3884	#N/A	#N/A
Lesotho	4	0	-0.8168	0.661	0.5515
Luxembourg	33	9	1.3884	1	0.9000
Madagascar	4	0	-0.8168	0.476	0.2380
Malawi	4	0	-0.8168	0.503	0.2513
Malaysia	6	7	0.1224	0.687	0.8437
Maldives	6	7	0.1224	#N/A	#N/A
Mali	4	0	-0.8168	0.311	0.2333
Malta	33	9	1.3884	0.622	0.5786
Mauritania	4	0	-0.8168	0.406	0.2031
Mauritius	4	0	-0.8168	0.704	0.8519
Mexico	5	0	-0.7791	0.592	0.3962
Mongolia	6	7	0.1224	0.582	#N/A
Morocco	33	9	1.3884	0.563	0.5037
Mozambique	4	0	-0.8168	0.536	0.2680

Namibia	4	0	-0.8168	0.462	0.3685
Nepal	6	7	0.1224	#N/A	#N/A
Netherlands	33	9	1.3884	0.988	0.8940
Niger	4	0	-0.8168	0.514	0.2570
Norway	33	9	1.3884	0.968	0.8727
Pakistan	33	9	1.3884	0.453	0.2265
Panama	5	0	-0.7791	0.41	0.3345
Papua New Guinea	6	2	-0.4946	0.625	0.3123
Paraguay	2	1	-0.7689	0.486	0.3097
Peru	2	1	-0.7689	0.438	0.4636
Philippines	6	2	-0.4946	0.407	0.2811
Poland	33	9	1.3884	0.694	0.4024
Portugal	33	9	1.3884	0.811	0.7946
Romania	33	9	1.3884	0.516	0.2912
Rwanda	4	0	-0.8168	0.387	0.1934
Samoa	0	0	-0.9678	#N/A	#N/A
Senegal	4	0	-0.8168	0.487	0.2433
Sierra Leone	4	0	-0.8168	0.398	0.1990
Singapore	6	7	0.1224	0.859	0.9297
Slovak Republic	33	9	1.3884	#N/A	#N/A
Solomon Islands	0	0	-0.9678	#N/A	#N/A
South Africa	4	0	-0.8168	0.74	0.4143
Spain	33	9	1.3884	0.802	0.7901
Sri Lanka	6	7	0.1224	0.463	0.4315
Sudan	4	0	-0.8168	0.308	0.1671
Swaziland	4	0	-0.8168	0.602	0.5312
Sweden	33	9	1.3884	0.987	0.8824
Switzerland	33	9	1.3884	1	1.0000
Syria	33	9	1.3884	0.491	0.4123
Taiwan	6	7	0.1224	0.823	0.7669
Tanzania	4	0	-0.8168	0.551	0.2757
Thailand	6	7	0.1224	0.711	0.8555
Togo	4	0	-0.8168	0.446	0.2228
Tunisia	33	9	1.3884	0.541	0.3373
Turkey	33	9	1.3884	0.601	0.3673
Uganda	4	0	-0.8168	0.368	0.2618
United Kingdom	33	9	1.3884	0.933	0.8556
Uruguay	2	1	-0.7689	0.564	0.3374
Zambia	4	0	-0.8168	0.424	0.2342
Zimbabwe	4	0	-0.8168	0.545	0.2725

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