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Geography and Economic Transition:
Global Spatial Analysis at the Grid Cell Level

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Geography and Economic Transition: Global Spatial Analyses at the Grid Cell Level

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Abstract

This paper addresses the timing of historical transition from rural to urban activity. In our model, rural production has constant returns and meets subsistence needs, while urban production has scale economies and meets the demands of higher-income consumers. Urbanization occurs sooner when rural or urban productivity is higher or transport costs are lower. We test the model on worldwide data that divides the earth's surface at half-degree intervals into over 60,000 cells. From an independent estimate of each cell's rural and urban population history, we identify the date at which each cell achieves various thresholds of urbanization. Controlling for country fixed effects and neighbors' urbanization using spatial techniques, we find that the date at which each cell passes each urbanization threshold is positively associated with its suitability for cultivation, having seasonal frosts, more access to navigable waterways and lower elevation. Aggregating cells into countries, an earlier urbanization date is linked to higher per capita income today.

JEL: C21, N50, O11, O18, R1

Keywords: economic growth, economic geography, urbanization, agriculture

1 Introduction

This paper addresses the role of physical geography in the timing and location of urbanization. Our central hypothesis is that, for any given place, higher local agricultural productivity and lower transportation costs facilitate the growth of cities and hence economic growth in surrounding locations. These results could help explain late urbanization and the persistence of rural poverty in regions with limited agro-ecological potential and significant transportation barriers.

Our focus on the initial formation and early growth of cities is consistent with new work on the historical roots of economic development (Nunn, 2009). That line of research

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provides econometric evidence linking events in the distant past, such as early technology adoption, European colonization and African enslavement, to countries' current state of economic development (Comin et al., 2006; Acemoglu et al., 2002; Banerjee and Iyer, 2005; Nunn, 2008). Some of this literature aims to identify how physical geography influences those events. Most notably, Sokoloff and Engerman (2000) introduce agroecological conditions as a determinant of crop choice and hence the location of slavery and inequality in the New World. They argue that climate and soils favorable to sugar, coffee, and tobacco plantations, in contrast to grain crops, favored the concentration of land, and thus wealth, into relatively few hands. Ultimately, this arrangement predisposed the formation of institutions to preserve the power and status of landholding elites, with effects persisting until today. Similarly, Acemoglu et al. (2001) linked disease ecology and the mortality of colonial settlers to the kinds of institutions they established in the New World. Nunn and Puga (2007) consider a transport-related feature of geography, ruggedness, and show that within Africa ruggedness is associated with lower modern incomes via its effects on transport costs and agriculture, but also exerts a much stronger positive effect via history by having aided a population's ancestors to more successfully resist–or escape–slave traders' incursions and raids.

Jared Diamond's *Guns, Germs, and Steel* (Diamond, 1997) is perhaps the most popular exposition of geography's role in shaping human history. He focuses on soil fertility and the presence of edible plants, potentially domesticated wildlife, and infectious diseases, tracing their role in the development of ancient societies around the world. Olsson and Hibbs (2005), in a direct test of Diamond's hypotheses, use continent size, east-west orientation, climate, and availability of potentially domesticated plants and animals to explain the timing of a region's transition into sedentary agriculture. Putterman (2008), in an extension of Olsson and Hibbs (2005), refines the analysis by observing these variables' effects on population density in the year 1500 as well as on modern-day income, controlling for the transmission of agricultural technologies via migration.[1]

The analysis in this paper focuses on urbanization, which is a particularly visible and economically important historical event with strongly persistent effects. Urbanization is

[1]The papers discussed here all focus on how physical geography might have influenced historical events and institutions. A related but different literature looks at the contemporary effects of geography, including for example the role of access to navigable waterways, frost prevalence, and malarial ecology (Gallup et al., 1999; Masters and McMillan, 2001; Sachs, 2003). Some authors such as Easterly and Levine (2003) find that geography-related variables have no contemporary effect but influence modern incomes only through their historical effect on institutions.

rarely reversed and usually proceeds cumulatively at a given location. One can think of urbanization in terms of a break from Malthusian dependence on natural resources, facilitating the start of modern economic growth (Lucas, 2000). Variation in the timing of such breaks have been linked to differences in institutional quality, total factor productivity, and geography (Ngai, 2004; Gollin et al., 2002). Economic transition itself entails a variety of contemporaneous changes, including rising productivity in both agriculture and manufacturing, sectoral shifts in employment, output and expenditure from agriculture to manufacturing and services, and a demographic transition in mortality, fertility and the age structure of the population (Kuznets, 1973; Williamson, 1988). We focus only on the most visible aspect of economic transition, which is the shift from rural to urban residence.

Our approach to economic geography relies on global grid cell data, disaggregating the whole world into regular cells defined only by their latitude and longitude. To our knowledge, the first paper on economic growth to exploit such data directly is Masters and McMillan (2001), who test a variety of possible influences on cell-level population density, and then aggregate cell-level attributes to the country level to test their relationship with national per-capita income growth. More recently, Nordhaus (2006) disaggregates all economic activity into 1° by 1° cells, and finds the level of activity to be highly correlated with climate and topography. Other variables have also been analyzed at the cell level, including for example Michalopoulos (2008) who explains ethno-linguistic diversity using data covering agricultural potential from Ramankutty et al. (2002).

Economic data rendered in grid cell units, as opposed to political, administrative, or other geographic regions, offer important advantages for empirical analysis. Such regions are smaller than most countries or even provinces, and thus offer a larger number of potentially independent observations. The boundaries of each observation are defined arbitrarily in regular intervals of geographic coordinates, and so are not subject to the endogeneity of administrative boundaries. (For example, country borders may reflect historical conquests.) The corresponding challenge is to allocate socioeconomic activity across grid cells, when the underlying data were originally collected according to administrative boundaries. The location of cities is generally unambiguous, however, so grid-cell data on urbanization involves relatively little use of arbitrary allocation rules.

In this paper we use grid cell data not only to match urbanization rates with each cell's own geographic circumstances, but also to permit the use of spatial econometric techniques to control for unobserved neighborhood effects. Our starting place is a stylized model of urbanization in a closed economy. Initial diagnostic tests reject the hypothesis that each cell is in fact an independent observation in our model. Such spatial dependence could be due to unobserved interactions between cells through trade, migration, investment or other channels, or through spatially correlated omitted variables. To control for many different kinds of distance-dependent spatial processes, we use a very general spatial error model. The resulting estimates find significant links among neighbors, and also an additional role for each cell's own attributes.

The remainder of this paper is organized as follows. Section 2 motivates the examination of geography's relationship to economic transition. Section 3 introduces the data, Section 4 presents the methods and discusses the results, and Section 5 concludes.

2 Motivation

2.1 The transition from Malthusian stagnation to modern growth

In the standard literature on economic growth, explanations for the extreme differences in present-day worldwide incomes have revolved primarily around disparities in national savings rates, technical change, human capital, and institutions (Solow, 1956; North, 1990; Mankiw et al., 1992). Most models focus on differences in parameters that are stable over time, but some focus instead on differences in the date at which economies transition from a Malthusian regime to modern growth (Lucas, 2000). To the extent that growth paths in each regime are similar and differences are attributable to timing, then the relevant research question is historical: not what differences exist today, but rather why some places start down the path of modern economic growth earlier than others.

Figure 1 suggests that both the start date and the pace of modern growth are important. For each region, per capita income has a clear structural break. Western Europe's income began to rise soon after 1800, Latin America's approximately fifty years later, and Asia about fifty years after that. Africa's income breaks with the past less clearly, though it certainly occurs at the end of the sequence.

Most evidence suggests that per-capita incomes grew negligibly prior to industrialization.

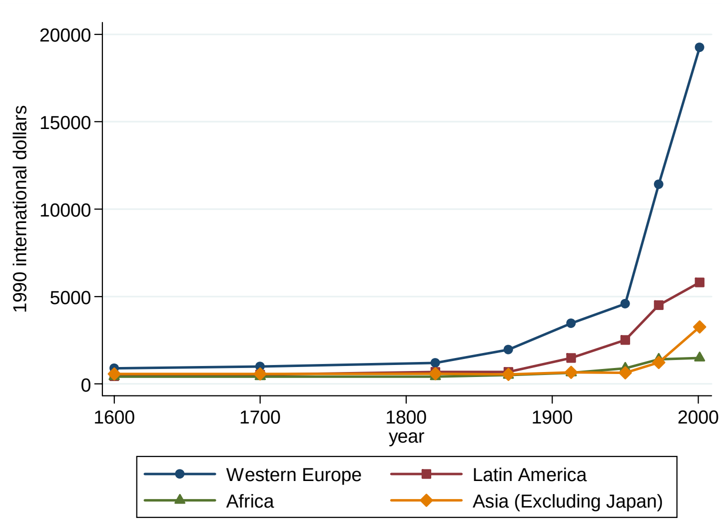

Figure 1: Regional per capita GDP, 1600-2000 AD, Source: Maddison et al. (2001)

Over the millennia, human development resulted in considerable population growth but not much improvement in living standards (Birdsall, 1988). Despite constant incomes, however, population growth and the accumulation of knowledge could have changed things so that switching to new technologies eventually became profitable (Galor and Weil, 2000; Hansen and Prescott, 2002; Strulik and Weisdorf, 2008). Such a switch is said to have occurred in eighteenth-century England, perhaps involving changes in property rights (McCloskey, 1972; Clark, 1992; Clark and Clark, 2001) and improved soil fertility through animal manure (Chorley, 1981) or nitrogen-fixing legumes (Allen, 2008), raising farm productivity in a way that could have facilitated subsequent industrialization.

Improvements in agricultural productivity have long been seen as necessary for the growth of industry (Johnston and Mellor, 1961), typically because of nutrition constraints and non-homothetic preferences (Matsuyama, 1992; Kögel and Prskawetz, 2001; Gollin et al., 2002). Engel's law implies that, in a closed economy, low farm productivity traps workers in agriculture. Only when agricultural production per worker rises above subsistence needs can resources shift to non-farm activities.

A location's successful agriculture, however, does not guarantee industrialization, especially if manufacturing involves scale economies and transport costs. Krugman (1991) demonstrated how scale economies interact with transport costs to drive agglomerations of firms in a particular place.[2] Murata (2008) links Engel's Law to the spatial location of firms to show that falling transport costs can raise real wages, drive up consumption of food initially and then later manufactured goods, and ultimately spur agglomeration. Capital accumulation and the use of intermediate goods can accelerate this process, as in the model of Gallup et al. (1999) where lower transport costs help make capital investment more profitable.

In this paper we build on the Matsuyama (1992) model of a closed dual sector economy, modified to include intra-regional transport costs for nonfarm activity. In our model the rural setor is defined simply as dispersed activity that occurs close to consumption and produces, among other things, some subsistence goods such as basic foods. The urban sector is agglomerated activity, whose profitability depends on transport costs into and out of the city. We reduce the model to a single period and do not distinguish between capital accumulation, scale economies or technical change, all of which are captured by a single labor productivity parameter in each sector. This stripped-down framework leaves just two distinct channels through which physical geography can affect the timing of transition from rural to urban life: (1) through higher agricultural productivity, which releases labor and creates purchasing power in rural areas, and (2) through lower transport costs around cities, which raises the profitability of urban activity.

2.2 The model

An area's labor force is divided between rural and urban inhabitants, denoted N_r and N_u, respectively. Without loss of generality, their sum is normalized to unity so the number of workers can be interpreted as employment shares, with $N_r + N_u = 1$.

For the rural sector, output Y_r is a function only of employment and labor productivity, A_r:

$$Y_r = A_r N_r \tag{1}$$

A_r captures everything that might determine rural labor productivity in meeting subsistence needs, including not only institutions and policies, but also climate and soils.

The urban product is the numeraire good. Assuming all rural output is valued at similar

[2]Numerous variations on this original model have appeared since then, including Fujita and Krugman (1995); Fujita et al. (2001); Puga (1999).

prices, profits π_r are:

$$\pi_r = pA_rN_r - wN_r, \tag{2}$$

where p is the price paid to producers, and w is the wage rate paid to labor.

For producers of urban goods, output Y_u is a function of just productivity A_u and labor N_u.

$$Y_u = A_uN_u. \tag{3}$$

In the city, profits depend on productivity and the wage rate, but also transportation costs to and from rrual areas or other cities:

$$\pi_u = (1-t)\,A_uN_u - wN_u, \tag{4}$$

where π_u represents profit and w is the wage paid to labor. In this static model, any capital accumulation or scale effects are swept into the productivity parameters that are left unspecified. The model accounts for the possible influence of physical geography in the form of transport costs t that urban firms must pay to reach people outside that city, and agroecological inputs to rural productivity, A_r, that helps meet workers' subsistence needs.

Equilibrium between the sectors hinges on both labor migration and goods tranport. When workers are mobile and firms are price takers, each sector's labor quantity N adjusts to yield wage equations, which in competitive equilibrium, are such that the price ratio p of the two goods is:

$$p = \frac{(1-t)\,A_m}{A_a}. \tag{5}$$

To close the model, we follow Matsuyama and impose a subsistence constraint for all workers. This takes the form of a miimum consumption requirement for the good produced by rural workers:

$$U\,(C_r, C_u) = \ln\,(C_r - \underline{r}) + \ln\,(C_u), \tag{6}$$

where C_r represents consumption of agricultural goods, $\underline{r}$ is the minimum food requirement for subsistence, and C_u is consumption of manufacturing. First-order conditions yield a marginal rate of substitution for rural and urban goods, which in equilibrium, equals the price ratio of the two goods:

$$\frac{C_u}{C_r - \underline{r}} = \frac{(1-t)\,A_u}{A_r}. \tag{7}$$

Since the economy is closed, quantity consumed equals quantity produced, thus:

$$\frac{Y_u}{Y_r - \underline{r}} = \frac{(1-t)\,A_u}{A_r}. \tag{8}$$

Substituting the production technologies into (8) equation yields:

$$\frac{A_u N_u}{A_r N_r - \underline{r}} = \frac{(1-t)\,A_u}{A_r}. \tag{9}$$

Rewriting N_r in terms of N_u and simplifying, we obtain:

$$\frac{N_u}{A_r\,(1-N_u) - \underline{r}} = \frac{(1-t)}{A_r}. \tag{10}$$

Solving the above equation for N_u and simplifying, we obtain:

$$N_u = \frac{1-t}{2-t}\left(1 - \frac{\underline{r}}{A_r}\right). \tag{11}$$

Comparative statics show the effect of a change in agricultural productivity A_r on the composition of labor between the two sectors.

$$\frac{\partial N_u}{\partial A_r} = \frac{\underline{r}}{A_r^2}\frac{1-t}{2-t}. \tag{12}$$

Since t is assumed to be less than one, $\partial N_u/\partial A_r > 0$. This implies that a rise in agriculture's productivity parameter causes labor to move from agriculture into manufacturing. However, workers do not begin to exit agriculture until the level of A_r equals the nutrition requirement $\underline{r}$. Beyond that point, higher rural productivity translates into greater urbanization, although at a diminishing rate as rural productivity and the urbanization rate rises.

Meanwhile, transport costs also matter to urbanization. Differentiating (11) with respect to transport costs t reveals how changes in transport costs affect the allocation of labor between sectors:

$$\frac{\partial N_u}{\partial t} = \frac{-1}{(2-t)^2}\left(1 - \frac{\underline{r}}{A_r}\right). \tag{13}$$

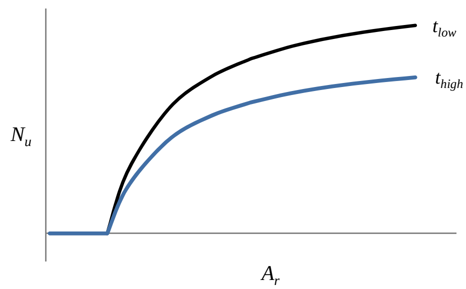

Figure 2: Urbanization and agricultural TFP

For the derivative to take a negative sign, the second term on the right hand side of the equation must be positive. This condition is met as long as rural productivity exceeds the subsistence requirement.

$$A_r > \underline{r}. \tag{14}$$

Figure 2 summarizes Equation (**??**)'s predictions regarding the effect of farm productivity, transportation, and their diminishing effects on urban activity. Both lines illustrate urbanization's response to farm productivity at a particular level of t, high and low. The figure reflects the constraint that the urban population fraction cannot be negative, and as a result, a kink appears precisely at the point where A_r reaches $\underline{r}$.

The central testable hypothesis of our model is that higher agricultural productivity and lower transport costs both facilitate urbanization for all inhabited locations where basic subsistence needs are met. A secondary hypothesis is that, as productivity rises and urbanization proceeds, additional increases in farm productivity have a diminishing effect on further urbanization.

3 Data

Our focus in this paper is on spatial differences across continents and regions, exploiting grid cell data on geographic factors that could be associated with either rural productivity or transportation costs. Since these are not time-varying, we test their link to urbanization using the historical date at which each location's urban populations passed various thresholds. This approach is consistent with some exogenous source of demographic change or knowledge accumulation that drives model parameters towards urbanization, in an unknown manner. Our goal is to explain some of the variance across grid cells in the timing of that transition.

The unit of observation is an arbitrarily-defined geographic region, which here are grid cells demarcated by lines at intervals of 0.5° latitude and 0.5° longitude. Such cells are largest at the equator, where each covers approximately 3,000 square kilometers. At the Arctic Circle, grid cells are about one-third that size. The total number of such half-degree cells in our dataset is 62,290.

Empirically, we are testing $T = f(G_r, G_u)$ where T is the transition date at which a grid cell acquired an urban population of given size, G_r are its geographic features associated with higher rural productivity in meeting subsistence needs, and G_u are its geographic features associated with facilitating urbanization through lower transport costs. To permit a causal interpretation of any correlation between T and G, we must choose geographic features that are not themselves influenced by urbanization, either directly or indirectly. The strengths and limitations of each regressor are discussed in turn below, after we present the data on urbanization itself.

3.1 Economic Transition and Urbanization

Historical data on the location and population of cities have been collected and assigned to grid cells by Klein Goldewijk (2005), and matched with estimates of the surrounding rural populations. He used a wide range of census figures, inferences and interpolation over time to construct internally consistent time series of rural and urban populations for each grid cell, from year 0 to 1600 in century intervals and 1700 to 2000 in decade intervals. From those data we compute a transition date for each cell, T, defined as the number of years since a transition event t occurs, $T = 2000 - t$.[3] Transition events t are then defined in two ways: as a threshold absolute number of urban people in that grid cell, and as a threshold urban fraction of that cell's total population.

Defining transition in terms of the absolute number of urban people, we follow Acemoglu et al. (2002), who built on Bairoch (1998) and judged urbanization to have started once a location could support over 5,000 urban inhabitants. Since grid cells closer to the equator are larger, we normalize by area and define the Bairoch rule in terms of the smallest cell

[3]We use year 2000 as the base year, since that is the last time period for which data are available.

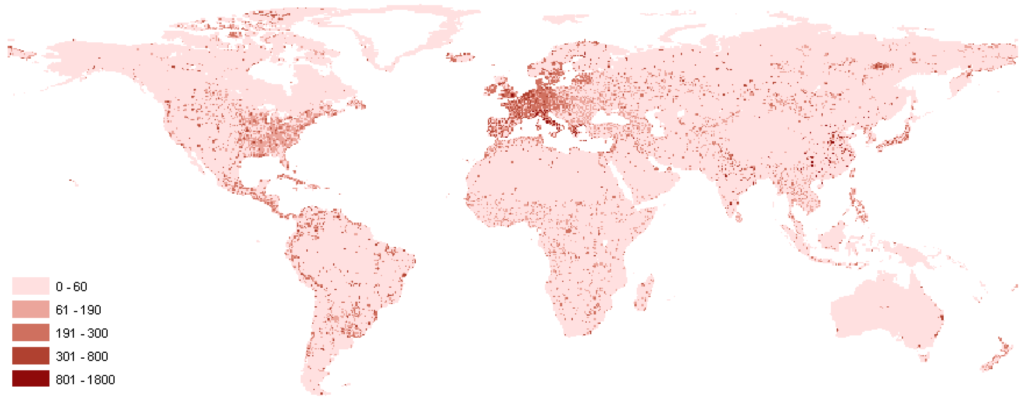

Figure 3: Number of years since transition to a $> 10\%$ urban population. Source: Authors' calculations from Klein Goldewijk (2005).

that supported an urban population greater than 5,000 in the year 2000. That cell turns out to have had a size of 881 square kilometers, so our threshold for the absolute number of urban people is actually 5.67 urban inhabitants per square kilometer.[4] This value is then applied to grid cells of other sizes, offering a consistent measure of economic activity for cross-sectional comparison purposes. For comparison, we also use a lower threshold of one person per square kilometer. At the equator, this corresponds to approximately 3,000 urban inhabitants per grid cell.

Defining transition in terms of the fraction of people who are urban, we follow Williamson (1988) and many others and consider a range of thresholds: 10%, 25%, and 50%. Figure 3 presents the geographical distribution of transition's timing at the 10% level. Maps for the other thresholds have a somewhat similar appearance, and formal summary statistics are presented in the following section.

3.2 Cultivation Suitability Index

To measure soil and climate conditions associated with rural production of subsistence goods, we start with an index of each grid cell's suitability for cultivation prepared by Ramankutty et al. (2002), which they construct from geo-referenced data on the number of growing degree days, actual and potential evapotranspiration, soil carbon density and soil

[4]This smallest of all urbanized grid cells lies above the Arctic Circle, along the northern coast of Norway. A threshold of 5,000 urban people divided by its area of 881 square kilometers yields the 5.67 urban people per square kilometer.

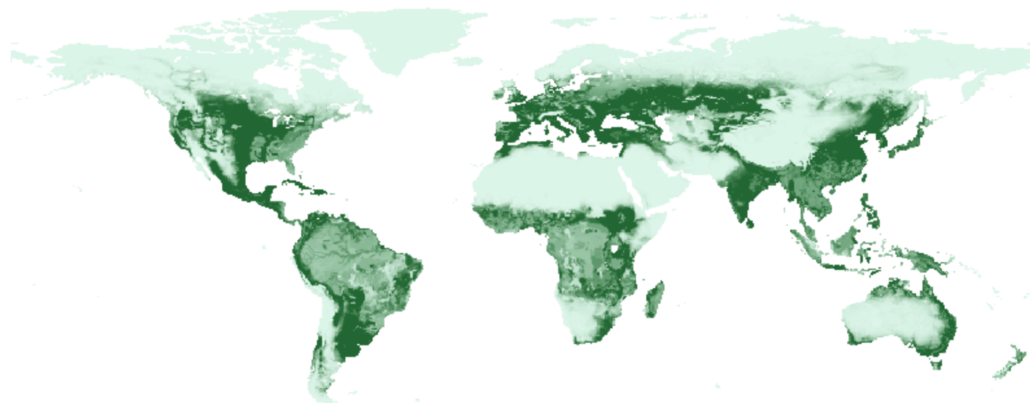

Figure 4: Worldwide distribution of land suitability for cultivation. Source: Ramankutty et al. (2002)

pH. The suitability index ranges from zero to one, and is calibrated to the probability that a particular location was actually cultivated in 1992.[5] Figure 4 presents a map of these data.

Although the Ramankutty et al. (2002) measure of cultivation suitability is constructed from purely exogenous climatic and geological features of the landscape, the selection and weights on variables in the index is potentially influenced by reverse causality from urbanization. This could arise to the extent that successful urbanization led to greater cultivation intensity of the surrounding areas. The resulting formula mighit then include variables such as availability of drinking water or drainage that reflect the needs of urban activity as much as rural productivity. In fact, however, the Ramankutty et al. (2002) index includes only standard measures of crop potential, so their only plausible channel of influence on urbanization is through farm productivity.

Plotting the Klein Goldewijk (2005) urbanization data against the Ramankutty et al. (2002) cultivation suitability index reveals the correlation between them. Figure 5 shows urbanization rates as a function of cultivation suitability in selected years, for all cells that were actually inhabited in that year, using a local polynomial regression to compute confidence intervals around local means. The resulting lines are empirical versions of Figure 2, without controlling for transport costs or other factors, and omitting the region of uninhabited cells where subsistence needsd are not met. The curves shift upward as time passes, as

[5]Probabilities were assigned on the basis of the areal fraction of each grid cell that was observed by remote sensing to be cultivated in that year.

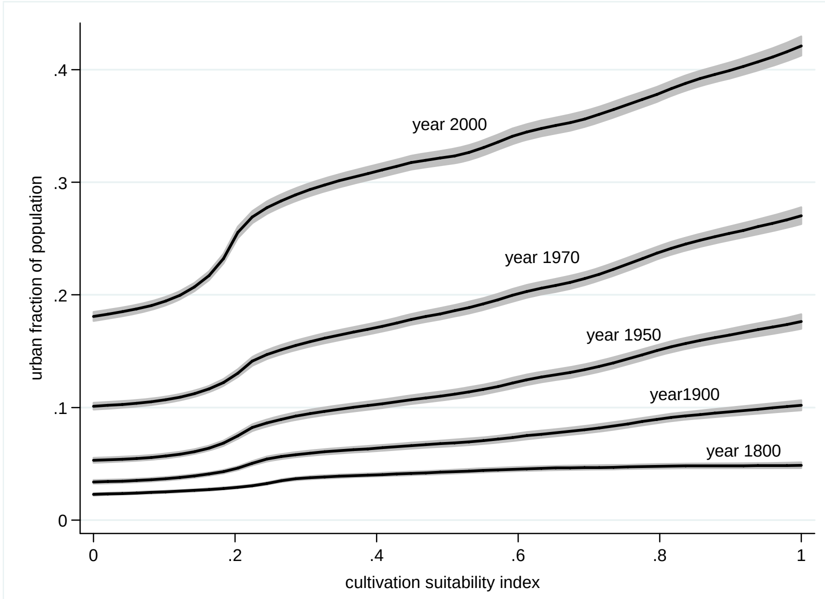

Figure 5: Local polynomial regression of urbanization on cultivation suitability. **Note:** Shaded regions show 95% percent confidence intervals around each line, fitting a zero degree polynomial, with bandwidths of 0.09, 0.09, 0.09, 0.1, and 0.12 for years 2000, 1970, 1950, 1900 and 1800 respectively, selected by rule-of-thumb using Stata's lpolyci command.

the average urbanization rate for cells at each level of cultivation suitability increases over time. For example, cells with a cultivation suitability index of 0.4 had average urbanization rates that rose to cross the 10 percent threshold around 1950 and passed 30 percent by 2000. It is this upward trend that we exploit in our cross-sectional tests, regressing the date at which each individual cell crosses various thresholds on that cell's own cultivation suitability index and other factors

3.3 Transportation Costs: Distance to Navigable Waterways

Our model suggests urbanization depends not only on farm productivity but also on low transport costs to support agglomeration. Here, the main geographic variable we use to capture historical transport costs is a grid cell's distance from a navigable waterway. Proximity to navigable waterways is captured in two variables. The first measure is distance in kilometers to the coast, calculated from the centroid of each half-degree grid cell to the nearest unbounded sea or ocean. The second measure pertains to rivers, for which the Strahler order of streams are observed in each grid cell (Vörösmatry et al., 2000). The Strahler Index

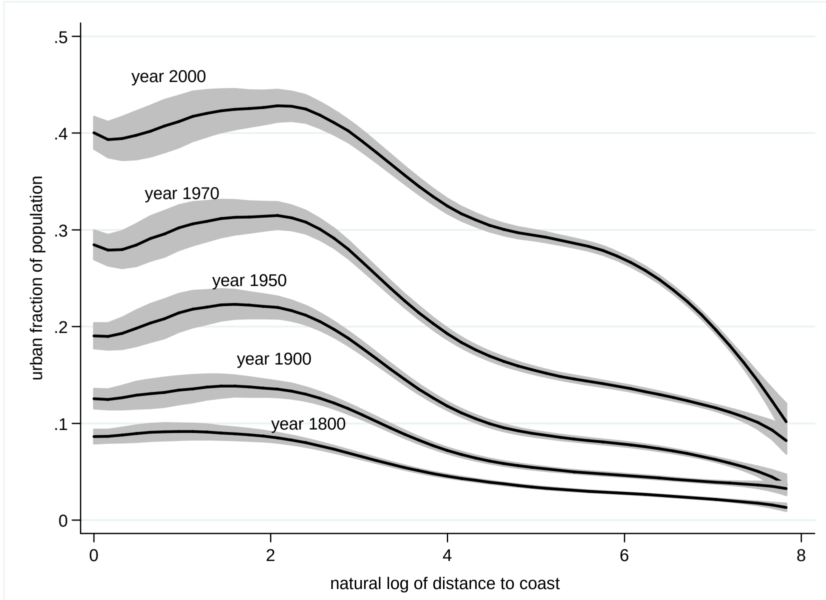

Figure 6: Local polynomial regression of urbanization on natural log of distance to coast. **Note:** Shaded regions show 95% percent confidence intervals around each line, fitting a second degree polynomial, with bandwidths of 0.34, 0.33, 0.31, 0.35, and 0.36 for years 2000, 1970, 1950, 1900 and 1800 respectively, selected by rule-of-thumb using Stata's lpolyci command.

ranges from 1 to 6, with six representing the largest river into which all tributaries flow and one representing a small stream with no tributaries. We define navigable rivers to be any stream of order four or higher.

We plot each grid cell's urbanization date, but this time against distance to coast. As in the previous figure, we limit the observations to those grid cells that were actually inhabited in each plot's year. We observe a steep decline in urbanization rates as distances to the coast grow beyond a few kilometers, and the same upward shift in these curves over time as in the previous figure. For example, cells that are about 55 km from the coast (a log value about 4) had average urbanization rates that rose to cross the 10 percent threshold between 1900 and 1950. By 1970 their average urbanization rates were about 20 percent, and by 2000 they were more than 30 percent urbanized.

3.4 Seasonal Frost and Elevation

The variables described above are complemented by data on seasonal frost, which could add to suitability in determining agricultural productivity, and elevation, which could add to distance from coasts and rivers as an influence on transport costs. For frost, we follow Masters and McMillan (2001) and use a dummy variable to capture whether or not a cell receives frost in winter, after a frost-free summer. This measure is intended to capture a potentially important aspect of temperate as opposed to tropical environments, in which post-harvest frosts help control pests and diseases until the next warm season. The prevalence of ground frost is computed from IPCC (2002), as a dummy variable equal to one for cells that receive a significant level of frost in winter, conditional on having no frost in summer. The cutoff we use is 2.11 frost-days per month, corresponding to the threshold estimated econometrically by Funke and Zuo (2003).

Combining the cultivation-suitability index with the prevalence of winter frost gives us two plausible measures of agricultural productivity, capturing whether crops are easily grown and whether pests and diseases are easily controlled. A significant correlation between these geographic features of a grid cell and the date at which it became urbanized would be consistent with our model, and with the broader idea that farm productivity plays a causal role in economic transition. In that case, deliberate efforts to raise agricultural productivity might also facilitate urbanization, such as investments in crop improvement, soil fertility and pest control.

We use average grid cell level elevation due to Hijmans et al. (2005) to capture the ease of surface transportation, such as barriers to mobility on foot and using animals or motorized vehicles. More complex measures of topography were considered for this paper, including a grid cell's standard deviation of elevation, its average gradient, and its ruggedness, but these are all highly correlated with average elevation so we chose the simplest possible measure so as to avoid any concern about endogeneity due to ex-post selection from among a large pool of candidate variables.

3.5 Summary statistics

Our dataset consists of 62,290 grid-cell observations, summarized in Table 1 below. The dependent variables of interest are the number of years since various thresholds of urbanization were reached. Their maximum values reveal that, at the start of our data about 2000 years ago, some cells had already reached the first threshold of one urban inhabitant per square kilometer. About 200 years later the first cells reached the threshold of having 10 percent of their population in urban areas. The mean date of urbanization, however, was much more recent and many cells have not yet passed any of our five thresholds.

Table 1: Summary statistics for all variables

variable	mean	std. dev.	min	max
number of years since the urban population reached:				
1 inhabitant per sq. km.	29.640	109.622	0	2000
5.67 inhabitant per sq. km.	15.859	61.893	0	1600
10% urbanization	34.169	94.903	0	1800
25% urbanization	19.829	53.716	0	1100
50% urbanization	9.690	31.038	0	700
cultivation suitability index	0.264	0.318	0	1
distance to coast (km)	521.984	511.641	1	2514.704
presence of navigable river	0.029	0.168	0	1
presence of frost in winter	0.116	0.320	0	1
land elevation (meters)	594.458	772.698	-76.667	5717.111

Source: Authors' calculations from sources detailed in the text.
Presence of navigable river refers to a waterway of Strahler order 4 or greater.
Presence of frost in winter refers to 2.11 or more days per month of ground frost after a frost-free summer.

4 Methodology and results

Our basic specification is to regress a grid cell's date of economic transition, as measured by one of the five thresholds listed above, on our geographic variables plus country fixed effects:

$$\ln T_{i,j} = \beta_0+\beta_1 \ln cultiv_{i,j}+\beta_2 \ln coast_{i,j}+\beta_3 river_{i,j}+\beta_4 frost_{i,j}+\beta_5 \ln elevation_{i,j}+\delta_j+\epsilon_{i,j}, \tag{15}$$

where $T_{i,j}$ represents the number of years elapsed since grid cell i in country j passed the given level of urbanization; *cultiv* is the cultivation suitability index; *coast* is the distance from a grid cell's centroid to the nearest unbounded sea or ocean coast; *river* indicates the presence of a river of Strahler order 4 or greater; *frost* indicates the presence of frost in winter after a frost-free summer; and *elevation* is the average altitude of the cell's land area.

Country fixed effects are captured by the variable δ_j. Grid cells that span more than one country are assigned to the country that occupies the greatest area of the grid cell. To assure consistency we use modern country borders for this mapping, even though these borders may not have been in place at the time of each grid cell's urbanization. Absorbing fixed effects in this way makes our estimates refer only to within-country effects. Robustness tests will include regressions without these controls.

The underlying dependent variable in these regressions, $T_{i,j}$, is truncated at zero for cells that have not yet passed the threshold T. Their eventual date of transition, if any, is unknown but would imply a negative value of $T_{i,j}$ instead of the zero that is reported here. It turns out that a relatively large fraction of observations are truncated in this way. For example, for the 25% threshold there are actually 48,625 zeros out of 62,290 observations. Naïve estimation of (15) would therefore involve substantial attenuation bias, which we can address using Tobit regressions as detailed below.

4.1 Spatial diagnostics and unobserved neighborhood effects

Our analytical model and regression specification are highly stylized, omitting a wide range of variables that could lead to bias or inefficiency in estimating Equation (15) by OLS. Most fundamentally, we use a closed-economy model and only the cell's own values in the model, when we expect there to be at least some interactions between cells that influence each others' urbanization rates.

The standard statistic of spatial dependence is Moran's I, a correlation coefficient that quantifies the degree to which a given variable on a map is correlated with its values in neighboring locations (Anselin and Bera, 1998).[6] Table 2 reports the Moran's I diagnostic tests on the residuals of an OLS regression of Equation (15) for each of the five different definitions of transition. The results confirm that the errors across all models are strongly correlated in space and are not independently distributed.

To account for the spatial dependence of the errors, we consider several models estimating (15) using maximum likelihood methods to accomodate the correlation of observations within a neighborhood. The first specification, the spatial lag, captures distance-dependent

[6]To establish the extent of spatial dependence, we calculate the Moran's I statistic over increasingly large neighborhoods, measured repeatedly at increasing orders of contiguity following the queen criterion. The first order of contiguity includes the variable's value in each grid cell and the values for the eight grid cells that immediately surround it. A second order of contiguity entails a neighborhood of 24 grid cells, the third order regression has 48 cells, and so on. As the order of contiguity rises, spatial dependence eventually falls to zero. The order at which Moran's I is statistically indistinguishable from zero identifies the extent of spatial dependence. Our regressions show a high degree of spatial dependence, with significance extending to 25 orders of contiguity. Owing to computational constraints in the LM tests, however, Table 2 report the Moran's I statistic at 5 orders of contiguity. This implies a neighborhood of 121 grid cells, i.e. a geographic area with dimensions 5.5 ° latitude by 5.5 ° longitude.

Table 2: Diagnostics for spatial dependence and model specification, transition and geography

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
Moran's I	0.402	0.179	0.207	0.172	0.123
LM lag	126,015.90	55,539.830	75,567.14	55,901.37	31,176.22
LM error	134,991.50	83,057.517	110,694.01	76,783.24	39,390.28

Note: Moran's I statistics are significant at the $p < 0.001$ level.

spillover effects by which urbanization at each location is influenced by urbanization among its neighbors. That is:

$$y = \rho W y + \beta X + \epsilon \tag{16}$$

where ρ represents the coefficient on the neighbors of the left hand side variable y, and Wy denotes the neighbors of y. W is a square matrix of spatial weights that reflect the distances over which these spillovers occur.

An alternative specification, the spatial error, captures any sort of spatial dependence in the error term.

$$\begin{aligned} y &= \beta X + \mu \\ \mu &= \lambda W \mu + \epsilon \end{aligned} \tag{17}$$

Lagrange multiplier tests can distinguish which specification best characterizes the data Anselin and Bera (1998). Table 2 above reports these values, the highest of which indicates the best specification. Based on these results, the spatial error model is the most appropriate specification and run the model specified in (15) with spatial dependence modeled in the error term.

The following tables present the results of three model specifications: simple OLS, Tobit, and spatial error.

The results reject the hypothesis that economic transition is not correlated with our geographic variables. We find strong significance for all of our variables, as predicted by the model. Grid cells whose land is more suitable for cultivation and are exposed to frost

Table 3: Transition date and geography, OLS

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
cultiv	0.329***	0.229***	0.303***	0.246***	0.158***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)
coast	–0.130***	–0.253***	–0.131***	–0.149***	–0.148***
	(0.008)	(0.007)	(0.009)	(0.008)	(0.007)
river	0.570***	0.493***	0.913***	0.809***	0.647***
	(0.056)	(0.048)	(0.063)	(0.059)	(0.050)
frost	0.847***	0.686***	0.821***	0.736***	0.544***
	(0.035)	(0.030)	(0.039)	(0.037)	(0.031)
elevation	–0.089***	–0.084***	–0.097***	–0.045***	–0.008***
	(0.009)	(0.008)	(0.011)	(0.010)	(0.008)
constant	2.116***	0.991***	1.878***	0.552***	-0.735***
	(0.155)	(0.133)	(0.175)	(0.162)	(0.39)
R^2	0.355	0.354	0.274	0.248	0.196

Note: $n = 62,290$
Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
All regressions use country fixed effects (not shown).

Table 4: Transition date and geography, Tobit

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
cultiv	1.732***	1.769***	1.187***	1.152***	1.157***
	(0.021)	(0.027)	(0.017)	(0.019)	(0.026)
coast	–0.480***	–0.743***	–0.499***	–0.638***	–0.882***
	(0.028)	(0.033)	(0.025)	(0.028)	(0.036)
river	1.699***	2.121***	2.134***	2.361***	2.856***
	(0.177)	(0.212)	(0.165)	(0.185)	(0.237)
frost	1.884***	2.195***	1.787***	1.873***	2.070***
	(0.112)	(0.137)	(0.110)	(0.124)	(0.160)
elevation	–0.109***	–0.151***	–0.150***	–0.036	0.080*
	(0.034)	(0.040)	(0.031)	(0.035)	(0.046)
constant	4.180***	2.880***	2.769***	–0.721***	–8.464***
	(0.490)	(0.605)	(0.496)	(0.612)	(1.225)
Log Likelihood	–68649.34	–50441.88	–85622.93	–73977.96	–53210
Pseudo R^2	0.153	0.176	0.099	0.096	0.099

Note: $n = 62,290$
Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
All regressions use country fixed effects (not shown).

Table 5: Transition date and geography, Tobit Marginal Effects

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
cultiv	0.388***	0.309***	0.330***	0.280***	0.217***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)
coast	–0.107***	–0.130***	–0.139***	–0.155***	–0.166***
	(0.006)	(0.006)	(0.007)	(0.009)	(0.007)
river	0.414***	0.406***	0.659***	0.639***	0.599***
	(0.047)	(0.04)	(0.056)	(0.055)	(0.055)
frost	0.456***	0.414***	0.534***	0.488***	0.415***
	(0.029)	(0.029)	(0.035)	(0.035)	(0.034)
elevation	–0.024***	–0.026***	–0.042***	–0.009	–0.015*
	(0.008)	(0.007)	(0.009)	(0.009)	(0.009)

Note: $n = 62,290$
Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
For now, only Model (2) reflects country dummies.

Table 6: Transition date and geography, spatial error with country dummies

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
cultiv	0.315***	0.231***	0.300***	0.254***	0.176***
	(0.078)	(0.007)	(0.008)	(0.008)	(0.007)
coast	–0.044***	–0.074***	–0.050***	–0.088***	–0.097***
	(0.011)	(0.010)	(0.011)	(0.010)	(0.009)
river	0.635***	0.516***	0.630***	0.617***	0.522***
	(0.051)	(0.045)	(0.050)	(0.048)	(0.043)
frost	0.226***	0.262***	0.210***	0.211***	0.237***
	(0.039)	(0.034)	(0.039)	(0.037)	(0.033)
elevation	–0.168***	–0.155***	–0.139***	–0.094***	–0.074***
	(0.013)	(0.011)	(0.013)	(0.012)	(0.012)
λ	0.900***	0.882***	0.897***	0.872***	0.815***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.008)

Note: $n = 62,290$
Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
No constant appears in this specification since, due to computational constraints, the regressions were run on variables demeaned by their country-level averages.

Table 7: Transition date and geography, spatial error without country dummies

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
cultiv	0.012***	0.010***	0.016***	0.014***	0.008**
	(0.004)	(0.005)	(0.005)	(0.005)	(0.004)
coast	–0.042***	–0.053***	–0.049***	–0.101***	–0.126***
	(0.011)	(0.010)	(0.013)	(0.012)	(0.011)
river	0.707***	0.563***	1.032***	0.925***	0.739***
	(0.051)	(0.045)	(0.058)	(0.054)	(0.049)
frost	0.195***	0.251***	0.112**	0.109**	0.137***
	(0.040)	(0.035)	(0.049)	(0.043)	(0.038)
elevation	–0.212***	–0.202***	–0.267	–0.195***	–0.138***
	(0.013)	(0.012)	(0.015)	(0.014)	(0.013)
constant	0.842***	0.247*	1.556***	0.927***	0.136
	(0.157)	(0.129)	(0.159)	(0.132)	(0.096)
λ	0.951***	0.946***	0.941***	0.929***	0.902***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)

Note: $n = 62,290$
Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

in winter urbanized earlier in history, as did cells that are closer to the seacoast, have a navigable river, and are lower in average altitude. These effects are for each cell's own characteristics only. Neighbors' characteristics are also significant, as shown by the λ values in the last row of the table.

Results reported above correspond to within-country differences, after controlling for country fixed effects. Those country effects are themselves potentially of interest, since they capture impacts of social, institutional and policy factors beyond the simple distance-dependent neighborhood effects absorbed in λ. Country fixed effects are presented in Figure 7. Clearly some of the variance is systematically absorbed by country dummies, which show earlier-than-average urbanization primarily in Northwest Europe, but also the rest of Europe, Scandinavia and the Near East, plus the U.S., Argentina and New Zealand.

An interesting feature of our results is that, as the threshold for transition rises, the magnitude of the coefficient on cultivation suitability declines. Rivers and elevation also decline in importance. In contrast, proximity to the coast registers increasingly larger effects. One interpretation of these results is that the initial growth of urban settlements depend more on an area's agriculture potential, topography, and fresh water access, while

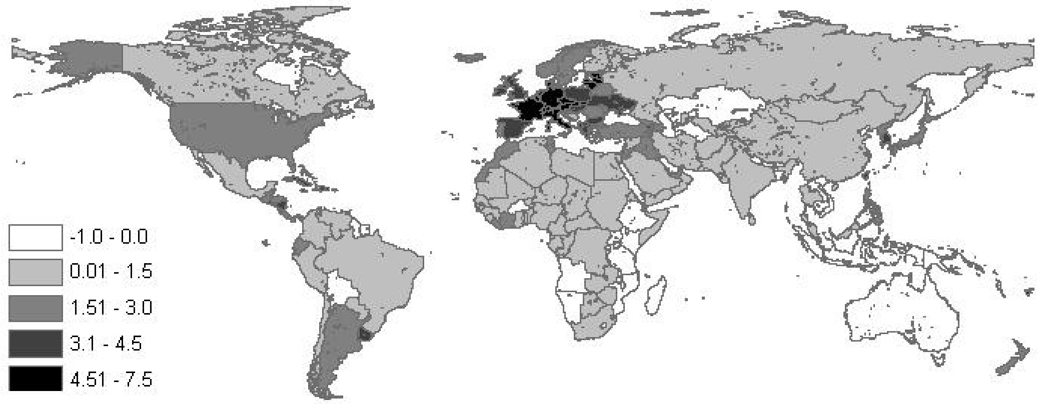

Figure 7: Country effects from the spatial error model (25% urbanization)

their subsequent growth at high levels of urbanization depend more on trade access.

4.2 Transition and modern national income

We have shown that geography can impact the date at which a location urbanizes and ultimately transitions. Recall Figure 1 in which incomes are plotted over time for different regions. To show how these time paths might owe something to geography, we plot the time series of the average urbanization rate for all grid cells that eventually achieved at least 10% urbanization by the year 2000, divided into two samples. One sample's path is the average of all grid cells whose cultivation suitability index is above the median value, 0.391, and the other is the average of all grid cells whose cultivation suitability index is below that value. Figure 8 illustrates the idea that locations with higher agricultural land quality may have, on average, urbanized earlier than areas with lower agricultural land quality.

Since urbanization plausibly links geography to modern income, we ask whether the historic date of a country's urbanization matters to income today. Following Olsson and Hibbs (2005) and Putterman (2008), the implicit hypothesis is that the earlier a country was able to urbanize, the higher its present-day income can be. Figure 9 illustrates this possibility, plotting a country's real per capita income on the number of years since any of its grid cells first reached 25% urbanization.[7] There is a strong correlation, and the outliers are themselves of interest: below the regression line are several countries such as China,

[7]We use the country's first cell to urbanize, rather than the average date of a country's cells, to capture the start of a country's transition wherever it may occur.

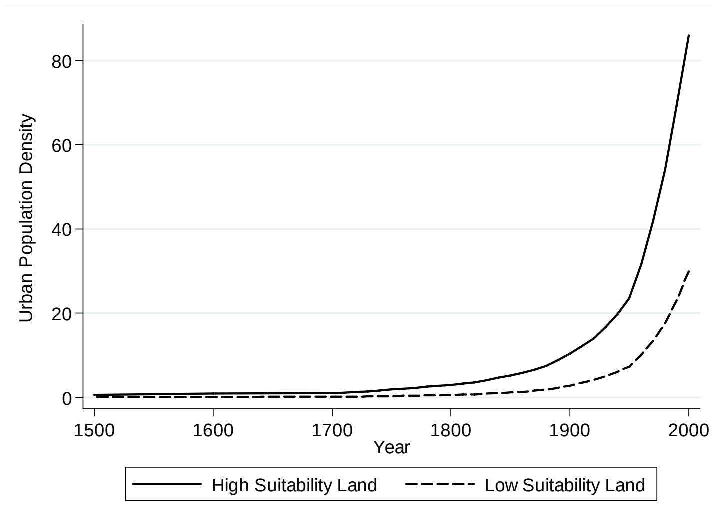

Figure 8: Urban density growth and cultivation suitability

India and Italy which had early urbanized centers but persistent poverty in hinterland areas. Countries above the line include Luxembourg, Qatar, and Singapore all of which urbanized late but are geographically small and had no lagging hinterland.

We test this relationship more formally in a regression framework, again accounting for spatial dependence due to distance-dependent but otherwise unobserved neighborhood effects. The dependent variable is always per-capita national income at PPP prices in 2000, regressed on the number of years since at least one of that country's cells passed our urbanization thresholds.

$$\ln(income_i) = \beta_{0i} + \beta_{1i} trans_i + \epsilon_i, \tag{18}$$

where $income_i$ is country i's income in year 2000, as taken from Penn World Tables (Heston et al., 2006) and variable $trans_i$ represents country i's transition date. Table 8 reports the results of the spatial diagnostics. From the results of the LM tests, the spatial lag specification is the most appropriate spatial process model. This implies an additional variable on the right side to represent the incomes of a country's neighbors; its coefficient is represented with a ρ. Table 9 presents the results of the estimation.[8] For the spatial lag model, the marginal effects for each location are $\partial y/\partial x = (I - \rho W)^{-1} \beta$. Table 10 presents

[8] In choosing the spatial extent for the distance-based weights matrix for this regression, we use the minimum distance necessary for all countries in the sample to have at least one neighbor.

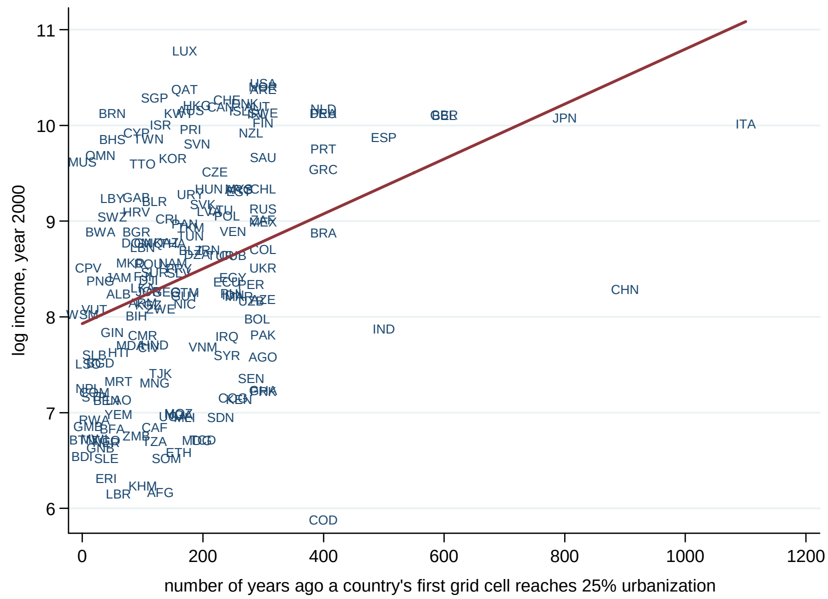

Figure 9: Country-level income in year 2000 and country's first transition date (25% urbanization). **Note:** Fitted equation is $\ln(income_i) = 7.93 + 0.003 transition_i$, $R^2 = 0.14$, $n = 169$.

the average of the marginal effects, calculated for each individual observation.

Table 8: Diagnostics for spatial dependence and model specification, income and transition

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
Moran's I	0.296	0.275	0.276	0.240	0.255
LM lag	97.66	89.95	90.46	77.93	82.28
LM error	89.41	77.08	77.82	58.84	66.29

Note: Moran's I statistics are significant at the $p < 0.001$ level.

Across all urbanization criteria, the historical transition date is a statistically significant correlate of incomes today, when controlling for neighborhood effects. From the table of marginal effects, reaching the 25% urbanization threshold one year earlier raises a country's per capita income by nearly 0.6%, and reaching the 50% urbanization one year earlier raises a country's per capita income by nearly one percent. For regions where significant levels of urbanization have yet to be achieved, this effect can explain economically important differences in present day income. The results presented here confirm that a country's income is correlated with having had an earlier start of urbanization, demonstrating the importance of our earlier finding that geographic variation in the start of urbanization is correlated with a grid cell's agro-ecological characteristics and transport opportunities.

Table 9: Income and transition date

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
trans	0.0003*	0.0009***	0.0007***	0.0015***	0.0023***
	(0.00019)	(0.0003)	(0.0003)	(0.0004)	(0.0007)
constant	1.80***	1.88***	1.83***	1.95***	1.94***
	(0.55)	(0.57)	(0.57)	(0.603)	(0.59)
ρ	0.777***	0.76***	0.76***	0.740***	0.746
	(0.063)	(0.066)	(0.066)	(0.070)	(0.069)

Note: $n = 169$
*** p<0.01, ** p<0.05, * p<0.1
Standard errors in parentheses

Table 10: Average of Individual Marginal Effects from Spatial Lag Estimation

	(1) 1 inhabitant per sq. km.	(2) 5.67 inhabitants per sq. km.	(3) 10% urban	(4) 25% urban	(5) 50% urban
trans	0.0015	0.0037	0.0031	0.0058	0.0090

5 Conclusion

A growing body of research is concerned with the role of physical geography in shaping historical events associated with modern economic outcomes. This paper focuses on one of the most important and highly visible of such events, namely the formation and growth of cities. We motivate our work with a model in which the extent of urban employment depends on the productivity of agriculture around that city, and transport costs between the city and its surroundings.

We test the model with new data from Klein Goldewijk (2005) on urban and rural populations around the world over the past 2000 years, from which we derive the date at which each of the world's 62,290 half-degree grid cells passed various thresholds of urbanization. Most of the world's grid cells have never urbanized by any measure, but over time an increasing fraction of cells pass our thresholds of one and then above five urban people per square kilometer, or the thresholds of ten, twenty-five and then fifty percent of the population living in urban areas.

Our central finding is that, controlling for country fixed effects and unobserved neighborhood characteristics, cells urbanize earlier when their land is more suitable for cultivation or is exposed to seasonal frost, using the Ramankutty et al. (2002) index of cultivation suitability (based on growing degree days, actual and potential evapotranspiration, soil carbon density and soil pH) and the data on frost in winter (after a frost-free summer) following Masters and McMillan (2001). We also find that cells urbanize earlier when they are closer to the seacoast, have a navigable river, or have lower average elevations. We go on to show that countries with earlier urbanization now have higher incomes, again controlling for unobserved neighborhood characteristics.

References

Acemoglu, D., S. Johnson, and J. Robinson (2001). The colonial origins of comparative development: An empirical investigation. *American Economic Review 91*, 1369–1401.

Acemoglu, D., S. Johnson, and J. Robinson (2002). Reversal of fortune: Geography and institutions in the making of the modern world income distribution. *Quarterly Journal of Economics 117*, 1231–1294.

Allen, R. C. (2008). The nitrogen hypothesis and the English agricultural revolution: A biological analysis. *The Journal of Economic History 68*(01), 182–210.

Anselin, L. and A. K. Bera (1998). Spatial dependence in linear regression models with an introduction to spatial econometrics. In A. Ullah and D. E. A. Giles (Eds.), *Handbook of Applied Economic Statistics*, Handbook of Applied Economic Statistics, Chapter 11, pp. 237–290. Marcel Dekker, Inc.

Bairoch, P. (1998). *Cities and economic development: From the dawn of history to the present.* The University of Chicago Press.

Banerjee, A. and L. Iyer (2005). History, institutions, and economic performance: The legacy of colonial land tenure systems in India. *American Economic Review 95*(4), 1190–1214.

Birdsall, N. (1988). Economic approaches to population growth. In H. Chenery and T. Srinivasan (Eds.), *Handbook of Development Economics*, Volume 1 of *Handbook of Development Economics*, Chapter 12, pp. 477–542. Elsevier.

Chorley, G. P. H. (1981). The agricultural revolution in northern Europe, 1750-1880: Nitrogen, legumes, and crop productivity. *The Economic History Review 34*(1), 71–93.

Clark, G. (1992). The economics of exhaustion, the postan thesis, and the agricultural revolution. *The Journal of Economic History 52*(1), 61–84.

Clark, G. and A. Clark (2001). Common rights to land in England, 1475-1839. *The Journal of Economic History 61*(4), 1009–1036.

Comin, D., W. Easterly, and E. Gong (2006, October). Was the wealth of nations determined in 1000 b.c.? Working Paper 12657, National Bureau of Economic Research.

Diamond, J. M. (1997). *Guns, germs and steel: the fates of human societies.* Jonathan Cape, London.

Easterly, W. and R. Levine (2003). Tropics, germs, and crops: how endowments influence economic development. *Journal of Monetary Economics 50*(1), 3 – 39.

Fujita, M. and P. Krugman (1995). When is the economy monocentric?: von Thunen and Chamberlin unified. *Regional Science and Urban Economics 25*(4), 505 – 528. Recent Advances in Urban Economics and Land Use: A Special Issue in Honour of Hiroyuki Yamada.

Fujita, M., P. Krugman, and A. J. Venables (2001). *The Spatial Economy: Cities, Regions, and International Trade.* MIT Press Books. The MIT Press.

Funke, M. and J. Zuo (2003, August). Annual hard frosts, scale effects and economic development: A case not closed. Quantitative Macroeconomics Working Papers 20308, Hamburg University, Department of Economics.

Gallup, J. L., J. D. Sachs, and A. D. Mellinger (1999). Geography and economic development. *International Regional Science Review 22*(2), 179–232.

Galor, O. and D. N. Weil (2000). Population, technology, and growth: From Malthusian stagnation to the demographic transition and beyond. *The American Economic Review 90*(4), 806–828.

Gollin, D., S. Parente, and R. Rogerson (2002). The role of agriculture in development. *The American Economic Review 92*(2), 160–164.

Hansen, G. D. and E. C. Prescott (2002). Malthus to Solow. *The American Economic Review 92*(4), 1205–1217.

Heston, A., R. Summers, and B. Aten (2006). Penn world table. Technical report.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology 25*(15), 1965–1978.

IPCC (2002). *The IPCC Data Distribution Centre: Downloading Scenarios and Climate Data from the DDC.*

Johnston, B. F. and J. W. Mellor (1961). The role of agriculture in economic development. *The American Economic Review 51*(4), 566–593.

Klein Goldewijk, K. (2005). Three centuries of global population growth: A spatial referenced population (density) database for 1700-2000. *Population and Environment 26*(4), 343–367.

Kögel, T. and A. Prskawetz (2001). Agricultural productivity growth and escape from the malthusian trap. *Journal of Economic Growth 6*(4), 337–357.

Krugman, P. (1991). Increasing returns and economic geography. *The Journal of Political Economy 99*(3), 483–499.

Kuznets, S. (1973). Modern economic growth: Findings and reflections. *The American Economic Review 63*(3), 247–258.

Lucas, R. E. (2000). Some macroeconomics for the 21st century. *The Journal of Economic Perspectives 14*(1), 159–168.

Maddison, A., O. for Economic Co-operation, and Development. (2001). *The world economy: a millennial perspective / by Angus Maddison.* Development Centre of the Organisation for Economic Co-operation and Development, Paris :.

Mankiw, N. G., D. Romer, and D. N. Weil (1992). A contribution to the empirics of economic growth. *The Quarterly Journal of Economics 107*(2), 407–437.

Masters, W. A. and M. S. McMillan (2001). Climate and scale in economic growth. *Journal of Economic Growth 6*(3), 167–186.

Matsuyama, K. (1992). Agricultural productivity, comparative advantage, and economic growth. *Journal of Economic Theory 58*(2), 317 – 334.

McCloskey, D. N. (1972). The enclosure of open fields: Preface to a study of its impact on the efficiency of English agriculture in the eighteenth century. *The Journal of Economic History 32*(1), 15–35.

Michalopoulos, S. (2008). The origins of ethnolinguistic diversity: Theory and evidence.

Murata, Y. (2008, August). Engel's law, Petty's law, and agglomeration. *Journal of Development Economics 87*(1), 161–177.

Ngai, L. R. (2004). Barriers and the transition to modern growth. *Journal of Monetary Economics 51*(7), 1353 – 1383.

Nordhaus, W. D. (2006). Geography and macroeconomics: New data and new findings. *Proceedings of the National Academy of Sciences of the United States of America 103*(10), 3510–3517.

North, D. C. (1990). *Institutions, institutional change, and economic performance.* Cambridge University Press, Cambridge.

Nunn, N. (2008). The long-term effects of Africa's slave trades. *Quarterly Journal of Economics 123*(1), 139–176.

Nunn, N. (2009). The importance of history for economic development. *Annual Review of Economics 1*(1).

Nunn, N. and D. Puga (2007). Ruggedness: The blessing of bad geography in Africa. CEPR Discussion Papers 6253, C.E.P.R. Discussion Papers.

Olsson, O. and D. A. Hibbs (2005). Biogeography and long-run economic development. *European Economic Review 49*(4), 909 – 938.

Puga, D. (1999, February). The rise and fall of regional inequalities. *European Economic Review 43*(2), 303–334.

Putterman, L. (2008). Agriculture, diffusion and development: Ripple effects of the neolithic revolution. *Economica 75*(300), 729 – 748.

Ramankutty, N., J. A. Foley, J. Norman, and K. McSweeney (2002). The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. *Global Ecology and Biogeography 11*(5), 377–392.

Sachs, J. D. (2003). Institutions don't rule: Direct effects of geography on per capita income. Working Paper 9490, National Bureau of Economic Research.

Sokoloff, K. L. and S. L. Engerman (2000). History lessons: Institutions, factors endowments, and paths of development in the new world. *The Journal of Economic Perspectives 14*(3), 217–232.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics 70*(1), 65–94.

Strulik, H. and J. Weisdorf (2008). Population, food, and knowledge: a simple unified growth theory. *Journal of Economic Growth 13*(3), 195–216.

Vörösmatry, C. J., B. M. Fekete, M. Meybeck, and R. Lammers (2000). Global system of rivers: Its role in organizing continental land mass and defining land-to-ocean linkages. *Global Biogeochemical Cycles 14*, 599–622.

Williamson, J. G. (1988). Migration and urbanization. In H. Chenery and T. Srinivasan (Eds.), *Handbook of Development Economics*, Volume 1 of *Handbook of Development Economics*, Chapter 11, pp. 425–465. Elsevier.