Malthusian Population Dynamics: Theory and Evidence*

Quamrul Ashraf† Oded Galor‡

March 26, 2008

Abstract

This paper empirically tests the existence of Malthusian population dynamics in the pre-Industrial Revolution era. The theory suggests that, during the agricultural stage of development, resource surpluses beyond the maintenance of subsistence consumption were channeled primarily into population growth. In particular, societies naturally blessed by higher land productivity would have supported larger populations, given the level of socioeconomic development. Moreover, given land productivity, societies in more advanced stages of development, as reflected by their cumulative experience with the agricultural technological paradigm since the Neolithic Revolution, would have sustained higher population densities. Using exogenous cross-country variations in the natural productivity of land and in the timing of the Neolithic Revolution, the analysis demonstrates that, in accordance with the Malthusian theory, societies that were characterized by higher land productivity and an earlier onset of agriculture had a higher population density in the time period 1-1500 CE.

Keywords: Growth, Technological Progress, Population Dynamics, Land Productivity, Neolithic Revolution, Malthusian Stagnation

JEL Classification Numbers: N10, N30, N50, O10, O40, O50

*We are indebted to Yona Rubinstein for numerous valuable discussions. We also thank David de la Croix and Oksana Leukhina for useful comments.

†Brown University, Quamrul_Ashraf@brown.edu

‡Brown University and CEPR, Oded_Galor@brown.edu

1 Introduction

The evolution of economies during the major portion of human history was marked by Malthusian stagnation. Technological progress and population growth were miniscule by modern standards and the average growth rates of income per capita in various regions of the world were possibly even slower due to the offsetting effect of population growth on the expansion of resources per capita.

In the past two centuries, in contrast, the pace of technological progress increased significantly in association with the process of industrialization. Various regions of the world departed from the Malthusian trap and initially experienced a considerable rise in the growth rates of income per capita and population. Unlike episodes of technological progress in the pre-Industrial Revolution era that failed to generate sustained economic growth, the increasing role of human capital in the production process in the second phase of industrialization ultimately prompted a demographic transition, liberating the gains in productivity from the counterbalancing effects of population growth. The decline in the growth rate of population and the associated enhancement of technological progress and human capital formation paved the way for the emergence of the modern state of sustained economic growth.

The escape from the Malthusian epoch to the state of sustained economic growth and the related phenomenon of the Great Divergence, as depicted in Figure 1, have significantly shaped the contemporary world economy.[1] The transition from Malthusian stagnation to modern growth has been the subject of intensive research in the growth literature in recent years,[2] as it has become apparent that a comprehensive understanding of the hurdles faced by less developed economies in reaching a state of sustained economic growth would be futile unless the factors that prompted the transition of the currently developed economies into a state of sustained economic growth could be identified and their implications modified to account for the differences in the growth structure of less developed economies in an interdependent world.

[1]The ratio of GDP per capita between the richest region and the poorest region in the world was only 1.1:1 in the year 1000 CE, 2:1 in the year 1500 CE, and 3:1 in the year 1820 CE. In the course of the Great Divergence the ratio of GDP per capita between the richest region and the poorest region has widened considerably from the modest 3:1 ratio in 1820, to a 5:1 ratio in 1870, a 9:1 ratio in 1913, and a 15:1 ratio in 1950, reaching a substantial 18:1 ratio in 2001.

[2]The transition from Malthusian stagnation to sustained economic growth was explored by Galor and Weil (1999, 2000), Lucas (2002), Galor and Moav (2002), Hansen and Prescott (2002), Jones (2001), Lagerlöf (2003, 2006), Doepke (2004), Fernández-Villaverde (2005), as well as others, and the association of the Great Divergence with this transition was analyzed by Galor and Mountford (2006, 2008), O'Rourke and Williamson (2005), Voigtländer and Voth (2006), and Ashraf and Galor (2007) amongst others.

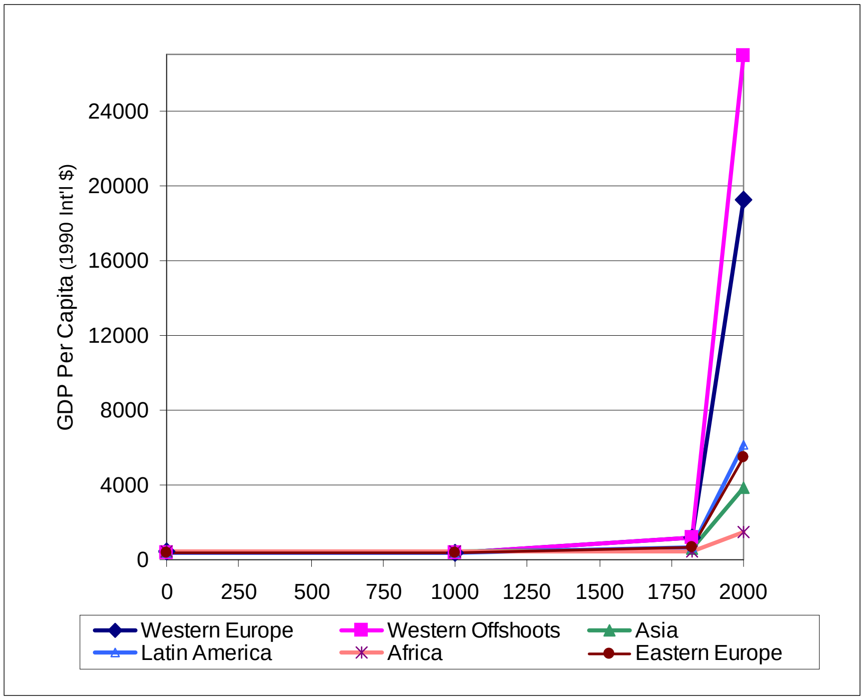


Figure 1: The Evolution of Regional Income Per Capita, 1-2000 CE
(Source: Maddison, 2003)

The forces that generated the remarkable escape from the Malthusian epoch and their significance in understanding the contemporary growth process of developed and less developed economies has raised fundamentally important questions: What accounts for the epoch of stagnation that characterized most of human history? What is the origin of the sudden spurt in growth rates of output per capita and population? Why had episodes of technological progress in the pre-industrialization era failed to generate sustained economic growth? What was the source of the dramatic reversal in the positive relationship between income per capita and population that existed throughout most of human history? What triggered the demographic transition? Would the transition to a state of sustained economic growth have been feasible without the demographic transition? What are the underlying behavioral and technological structures that can simultaneously account for these distinct phases of development and what are their implications for the contemporary growth process of developed and underdeveloped countries?

The differential timing of the escape from the Malthusian epoch that gave rise to the perplexing phenomenon of the Great Divergence in income per capita across regions of the world in the past two centuries has generated some additional intriguing research debates:

What accounts for the sudden take-off from stagnation to growth in some countries and the persistent stagnation in others? Why has the positive link between income per capita and population growth reversed its course in some economies but not in others? Why have the differences in income per capita across countries increased so markedly in the last two centuries? Has the transition to a state of sustained economic growth in advanced economies adversely affected the process of development in less-developed economies?

Unified growth theory (Galor, 2005) suggests that the transition from stagnation to growth is an inevitable by-product of the process of development. The inherent Malthusian interaction between technology and the size (Galor and Weil, 2000) and the composition (Galor and Moav, 2002; Galor and Michalopolous, 2006) of the population, accelerated the pace of technological progress, and eventually brought about an industrial demand for human capital. Human capital formation and thus further technological progress triggered a demographic transition, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita. Moreover, the theory suggests that differences in the timing of the take-off from stagnation to growth across countries contributed significantly to the Great Divergence and to the emergence of convergence clubs. According to the theory, variations in the economic performance across countries and regions (e.g., the earlier industrialization in England than in China) reflect initial differences in geographical factors and historical accidents and their manifestation in variations in institutional, demographic, and cultural characteristics, as well as trade patterns, colonial status, and public policy.

The underlying viewpoint about the operation of the world during the Malthusian epoch is based, however, on the basic premise that technological progress and resource expansion had a positive effect on population growth. Although there exists anecdotal evidence supporting this important Malthusian element, these salient characteristics of the Malthusian mechanism have not been tested empirically. A notable exception is the time series analysis of Crafts and Mills (2008), which confirms that real wages in England were stationary till the end of the 18th century and that wages had a positive effect on fertility (although no effect on mortality) till the mid-17th century.

This paper empirically tests the existence of Malthusian population dynamics in the pre-Industrial Revolution era.[3] The Malthusian theory suggests that, during the agricultural

[3] Kremer (1993), in an attempt to defend the role of the scale effect in endogenous growth models, examines a reduced-form of the co-evolution of population and technology in a Malthusian-Boserupian environment. In contrast to the current study that tests the Malthusian link (i.e., the effect of the technological environment on population density), he tests the effect of the Malthuisan-Boserupian interaction (i.e. the effect of population size on the rate of technological change and, thereby, on the rate of population growth), demonstrating that the rate of population growth in the world was proportional to the level of world population during

stage of development, resource surpluses beyond the maintenance of subsistence consumption were channeled primarily into population growth. In particular, regions that were naturally blessed by higher land productivity would have sustained larger populations, given the level of socioeconomic development. Moreover, given the natural productivity of land, societies in more advanced stages of development, as reflected by their cumulative experience with the agricultural technological paradigm since the Neolithic Revolution, would have sustained higher population densities. Using exogenous variations in the natural productivity of land and in the timing of the Neolithic Revolution, the analysis demonstrates that, in accordance with the Malthusian theory, economies that were characterized by higher land productivity and experienced an earlier onset of agriculture had a higher population density in the time period 1-1500 CE.

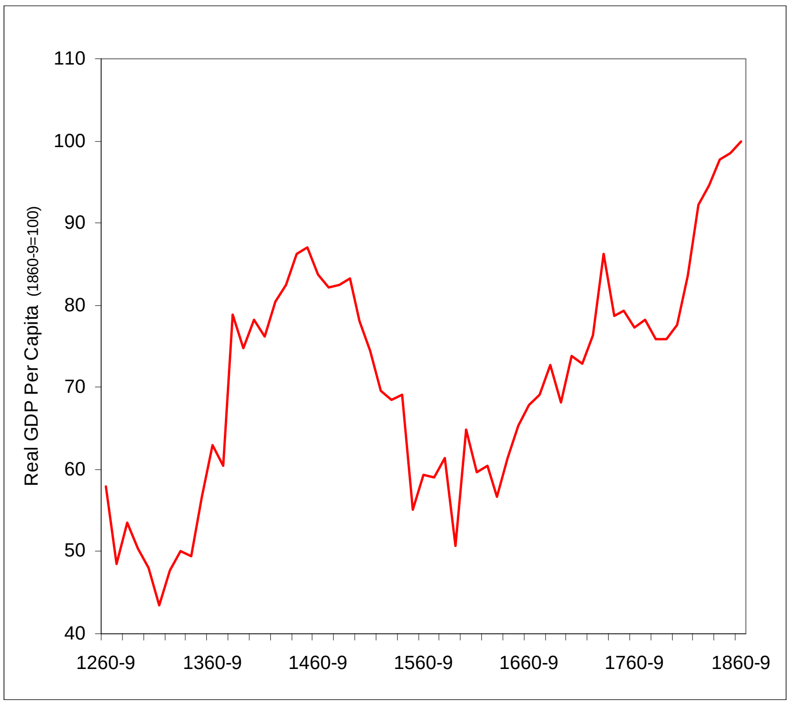


Figure 2: Fluctuations in Real GDP Per Capita in England, 1260-1870 CE
(Source: Clark, 2005)

2 Historical Evidence

According to the Malthusian theory, during the Malthusian epoch that had characterized most of human history, humans were subjected to a persistent struggle for existence. The

the pre-industrial era. The scale effect of population on agricultural technological progress was originally proposed by Boserup (1965).

rate of technological progress was insignificant by modern standards and resources generated by technological progress and land expansion were channeled primarily towards an increase in population size, with negligible long-run effects on income per capita. The positive effect of the standard of living on population growth along with diminishing labor productivity kept income per capita in the proximity of a subsistence level.[4] Periods marked by the absence of changes in the level of technology or in the availability of land, were characterized by a stable population size as well as a constant income per capita, whereas periods characterized by improvements in the technological environment or in the availability of land generated only temporary gains in income per capita, eventually leading to a larger but not richer population. Technologically superior economies ultimately had denser populations but their standard of living did not reflect the degree of their technological advancement.[5]

2.1 Income Per Capita

During the Malthusian epoch, the average growth rate of output per capita was negligible and the standard of living did not differ greatly across countries. The average level of income per capita during the first millennium fluctuated around $450 per year while the average growth rate of output per capita in the world was nearly zero. This state of Malthusian stagnation persisted until the end of the 18th century. In the 1000-1820 CE time period, the average level of income per capita in the world economy was below $670 per year and the average growth rate of the world income per capita was rather miniscule, creeping at a rate of about 0.05% per year (Maddison, 2001).[6]

This pattern of stagnation was observed across all regions of the world. As depicted in Figure 1, the average level of income per capita in Western and Eastern Europe, the Western Offshoots, Asia, Africa, and Latin America was in the range of $400-450 per year in the first millennium and the average growth rate of income per capita in each of these regions was nearly zero. This state of stagnation persisted until the end of the 18th century across all regions, with the level of income per capita in 1820 CE ranging from $418 per year in Africa, $581 in Asia, $692 in Latin America, and $683 in Eastern Europe, to $1202 in the Western Offshoots (i.e., the United States, Canada, Australia and New Zealand) and $1204 in Western Europe. Furthermore, the average growth rate of income per capita over this period ranged from 0% in the impoverished region of Africa to a sluggish rate of 0.14%

[4] The subsistence level of consumption may have been well above the minimal physiological requirements that were necessary to sustain an active human being.

[5] Indeed, as observed by Adam Smith (1776), *"the most decisive mark of the prosperity of any country [was] the increase in the number of its inhabitants."*

[6] Maddison's estimates of income per capita are evaluated in terms of 1990 international dollars.

in the prosperous region of Western Europe.

Despite remarkable stability in the evolution of world income per capita during the Malthusian epoch from a millennial perspective, GDP per capita and real wages fluctuated significantly within regions, deviating from their sluggish long-run trend over decades and sometimes several centuries. In particular, as depicted in Figure 2, real GDP per capita in England fluctuated drastically over the majority of the past millennium. Declining during the 13th century, it increased sharply during the 14th and 15th centuries in response to the catastrophic population drop in the aftermath of the Black Death. This two-century rise in real income per capita stimulated population growth, which subsequently brought about a decline of income per capita in the 16th century, back to its level from the first half of the 14th century. Real income per capita increased once again in the 17th century and remained stable during the 18th century, prior to the take-off in the 19th century.

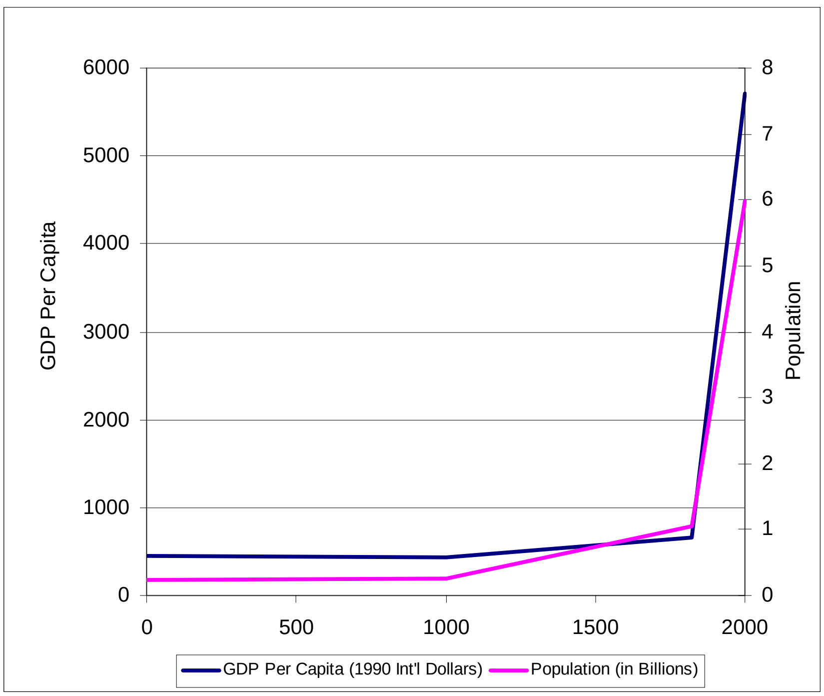


Figure 3: The Evolution of World Population and Income Per Capita, 1-2000 CE
(Source: Maddison, 2001)

2.2 Income and Population

2.2.1 Population Growth and the Level of Income

Population growth during this era exhibited the Malthusian pattern as well. As depicted in Figure 3, the slow pace of resource expansion in the first millennium was reflected in a modest increase in the population of the world from 231 million people in 1 CE to 268 million in 1000 CE, a miniscule average growth rate of 0.02% per year.[7] The more rapid (but still very slow) expansion of resources in the period 1000-1500 CE permitted the world population to increase by 63%, from 268 million in 1000 CE to 438 million in 1500 CE, a slow 0.1% average growth rate per year. Resource expansion over the period 1500-1820 CE had a more significant impact on the world population, which grew 138% from 438 million in 1500 CE to 1041 million in 1820 CE, an average pace of 0.27% per year.[8] This apparent positive effect of income per capita on the size of the population was maintained during the last two centuries as well, as the population of the world attained the remarkable level of nearly 6 billion people.

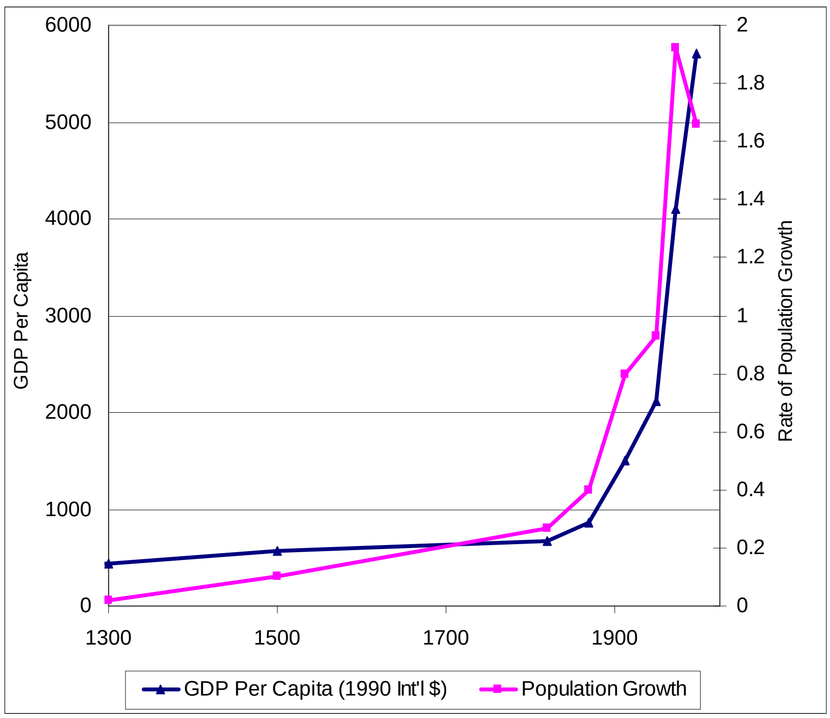


Figure 4: World Population Growth and Income Per Capita
(Source: Maddison, 2001)

Moreover, the gradual increase in income per capita during the Malthusian epoch was associated with a monotonic increase in the average rate of growth of world population, as

[7] Since output per capita grew at an average rate of 0% per year over the period 1-1000 CE, the pace of resource expansion was approximately equal to the pace of population growth, namely, 0.02% per year.

[8] Since output per capita in the world grew at an average rate of 0.05% per year in the time period 1000-1500 CE as well as in the period 1500-1820 CE, the pace of resource expansion was approximately equal to the sum of the pace of population growth and the growth of output per capita. Namely, 0.15% per year in the period, 1000-1500 CE and 0.32% per year in the period 1500-1820 CE.

depicted in Figure 4. This pattern existed both within and across countries.[9]

2.2.2 Fluctuations in Income and Population

Fluctuations in population size and real wages over this epoch also reflected the Malthusian pattern. Episodes of technological progress, land expansion, favorable climatic conditions, or major epidemics (resulting in a decline of the adult population), brought about a temporary increase in real wages and income per capita. As depicted in Figure 5, the catastrophic decline in the population of England during the Black Death (1348-1349 CE), from about 6 million to about 3.5 million people, significantly increased the land-labor ratio, tripling real wages over the subsequent 150 years. Ultimately, however, the majority of this increase in real resources per capita was channeled towards higher fertility rates, increasing the size of the population and bringing the real wage rate in the 1560s back to the proximity of its pre-plague level.[10]

[9] Lee (1997) reports a positive income elasticity of fertility and a negative income elasticity of mortality from studies examining a wide range of pre-industrial countries. Similarly, Wrigley and Schofield (1981) uncover a strong positive correlation between real wages and marriage rates in England over the period 1551-1801 CE.

[10] Reliable population data is not available for the period 1405-1525 CE. Figure 5 is depicted under the assumption maintained by Clark (2005) that the population was rather stable over this period.

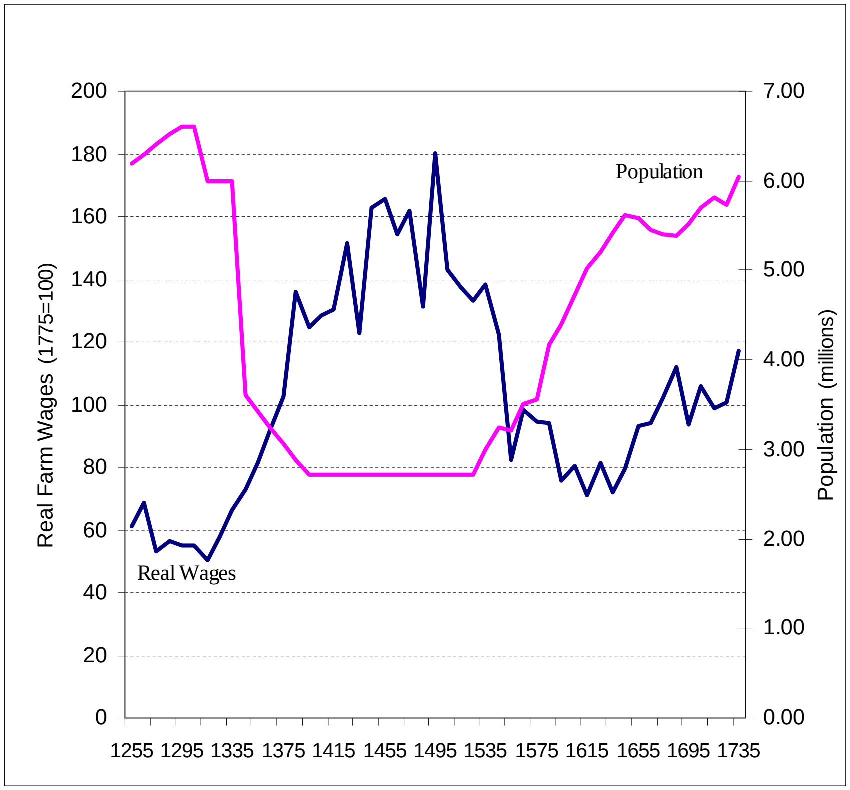


Figure 5: Population and Real Wages in England, 1250-1750 CE
(Source: Clark, 2005)

2.3 Population Density

Variations in population density across countries during the Malthusian epoch reflected primarily cross-country differences in technologies and land productivity. Due to the positive adjustment of the population to an increase in income per capita, differences in technologies or in land productivity across countries resulted in variations in population density rather than in the standard of living.[11] For instance, China's technological advancement in the period 1500-1820 CE permitted its share of world population to increase from 23.5% to 36.6%, while its income per capita at the beginning and end of this time interval remained

[11]Consistent with the Malthusian paradigm, China's sophisticated agricultural technologies allowed high per-acre yields but failed to increase the standard of living above subsistence. Likewise, the introduction of potatoes in Ireland in the middle of the 17th century generated a large increase in population over two centuries without significant improvements in the standard of living. Furthermore, the destruction of potatoes by fungus in the middle of the 19th century generated a massive decline in population due to the Great Famine and mass migration (Mokyr, 1985).

constant at roughly $600 per year.[12]

The Malthusian pattern historically persisted until the onset of the demographic transition, namely, as long as the positive relationship between income per capita and population growth was maintained. In the period 1600-1870 CE, the United Kingdom's technological advancement relative to the rest of the world more than doubled its share of world population from 1.1% to 2.5%. Similarly, during the 1820-1870 CE time period, the land abundant, technologically advanced economy of the United States experienced a 220% increase in its share of world population from 1% to 3.2%.[13]

3 The Malthusian Model

The Malthusian theory inspired by Malthus (1798)[14], suggests that the worldwide stagnation in income per capita over this epoch reflected the counterbalancing effect of population growth on the expansion of resources, in an environment characterized by diminishing returns to labor. The expansion of resources, according to Malthus, led to an increase in population growth, reflecting the natural result of the "passion between the sexes". In contrast, when population size grew beyond the capacity sustainable by available resources, it was reduced by the "preventive check" (i.e., intentional reduction of fertility) as well as by the "positive check" (i.e., the tool of nature due to malnutrition, disease, war and famine).

According to the theory, periods marked by the absence of changes in the level of technology or in the availability of land, were characterized by a stable population size as well as a constant income per capita. In contrast, episodes of technological progress, land expansion, and favorable climatic conditions, brought about temporary gains in income per capita, triggering an increase in the size of the population, which led eventually to a decline in income per capita to its long-run level. Due to the positive adjustment of population to an increase in income per capita, differences in technologies or in land productivity across countries resulted in cross-country variations in population density rather than in

[12] The Chinese population more than tripled over this period, increasing from 103 million in 1500 CE to 381 million in 1820 CE.

[13] The population of the United Kingdom nearly quadrupled over the period 1700-1870 CE, increasing from 8.6 million in 1700 CE to 31.4 million in 1870 CE. Similarly, the population of the United states increased 40-fold, from 1.0 million in 1700 CE to 40.2 million in 1870 CE, due to significant labor migration as well as high fertility rates.

[14] The theory was formalized recently by Kremer (1993), who models a reduced-form interaction between population and technology along a Malthusian equilibrium, and Lucas (2002), who presents a Malthusian model in which households optimize over fertility and consumption, labor is subjected to diminishing returns due to the presence of a fixed quantity of land, and the Malthusian level of income per capita is determined endogenously.

the standard of living.

3.1 The Basic Structure of the Model

Consider an overlapping-generations economy in which activity extends over infinite discrete time. In every period, the economy produces a single homogeneous good using land and labor as inputs. The supply of land is exogenous and fixed over time whereas the evolution of labor supply is governed by households' decisions in the preceding period regarding the number of their children.

3.1.1 Production

Production occurs according to a constant-returns-to-scale technology. The output produced at time t, Y_t, is:

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha}; \qquad \alpha \in (0,1), \tag{1}$$

where L_t and X is, respectively, labor and land employed in production in period t, and A measures the technological level. The technological level may capture the percentage of arable land, soil quality, climate, cultivation and irrigation methods, as well as the knowledge required for engagement in agriculture (i.e., domestication of plants and animals). Thus, AX captures the effective resources used in production.

Output per worker produced at time t, $y_t \equiv Y_t/L_t$, is therefore:

$$y_t = (AX/L_t)^{\alpha}. \tag{2}$$

3.1.2 Preferences and Budget Constraints

In each period t, a generation consisting of L_t identical individuals joins the workforce. Each individual has a single parent. Members of generation t live for two periods. In the first period of life (childhood), $t-1$, they are supported by their parents. In the second period of life (parenthood), t, they inelastically supply their labor, generating an income that is equal to the output per worker, y_t, which they allocate between their own consumption and that of their children.

Individuals generate utility from consumption and the number of their (surviving) children:[15]

[15] For simplicity parents derive utility from the expected number of surviving offspring and the parental cost of child rearing is associated only with surviving children. A more realistic cost structure would not

$$u^t = (c_t)^{1-\gamma}(n_t)^{\gamma}; \qquad \gamma \in (0,1), \tag{3}$$

where c_t is the consumption of an individual of generation t, and n_t is the number of children of individual t.

Members of generation t allocate their income between their consumption, c_t, and expenditure on children, ρn_t, where ρ is the cost of raising a child.[16] Hence, the budget constraint for a member of generation t (in the second period of life) is:

$$\rho n_t + c_t \leq y_t. \tag{4}$$

3.1.3 Optimization

Members of generation t allocate their income optimally between consumption and child rearing, so as to maximize their intertemporal utility function (3) subject to the budget constraint (4). Hence, individuals devote a fraction $(1-\gamma)$ to consumption and a fraction γ of their income to child rearing:

$$\begin{aligned} c_t &= (1-\gamma)y_t; \\ n_t &= \gamma y_t/\rho. \end{aligned} \tag{5}$$

Thus, in accordance with the Malthusian paradigm, income has a positive effect on the number of surviving children.

3.2 The Evolution of the Economy

3.2.1 Population Dynamics

The evolution of population size is determined by the number of (surviving) children per adult. Specifically, the size of the population in period $t+1$, L_{t+1}, is:

$$L_{t+1} = n_t L_t, \tag{6}$$

where n_t is the number of children per adult in generation t.

affect the qualitative features of the theory.

[16] If the cost of children is a time cost then the qualitative results will be maintained as long as individuals are subjected to a subsistence consumption constraint (Galor and Weil, 2000). If both time and goods are required to produce children, the process described will not be affected qualitatively. As the economy develops and wages increase, the time cost will rise proportionately with the increase in income, but the cost in terms of goods will decline. Hence, individuals will be able to afford more children.

Lemma 1 *The time path of population, as depicted in Figure 6, is governed by the first-order difference equation*

$$L_{t+1} = (\gamma/\rho)(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A).$$

Therefore:

- *the rate of population growth between periods t and $t+1$, g_{t+1}^L, is*

$$g_{t+1}^L \equiv (L_{t+1} - L_t)/L_t = (\gamma/\rho)(AX)^{\alpha} L_t^{-\alpha} - 1 \equiv g^L(L_t; A);$$

- *for a given level of technology, A, there exists a unique steady-state level of population size, $\bar{L}$,*

$$\bar{L} = (\gamma/\rho)^{1/\alpha}(AX) \equiv \bar{L}(A);$$

- *for a given level of technology, A, there exists a unique steady-state level of population density, $\bar{P}_d$,*

$$\bar{P}_d \equiv \bar{L}/X = (\gamma/\rho)^{1/\alpha} A \equiv \bar{P}_d(A).$$

Proof. Substituting (2) and (5) into (6) yields $L_{t+1} = (\gamma/\rho)(AX)^{\alpha} L_t^{1-\alpha}$. Hence, $\phi_L(L_t; A) > 0$ and $\phi_{LL:}(L_t; A) < 0$ so, as depicted in Figure 6, $\phi(L_t; A)$ is strictly concave in L_t with $\phi(0; A) = 0$, $\lim_{L_t \to 0} \phi_L(L_t; A) = \infty$ and $\lim_{L_t \to \infty} \phi_L(L_t; A) = 0$. Thus, for a given A, there exists a unique steady-state level of population and population density. The expressions for the levels of $\bar{L}$, $\bar{P}_d$, and g_{t+1}^L follow immediately from their definitions. □

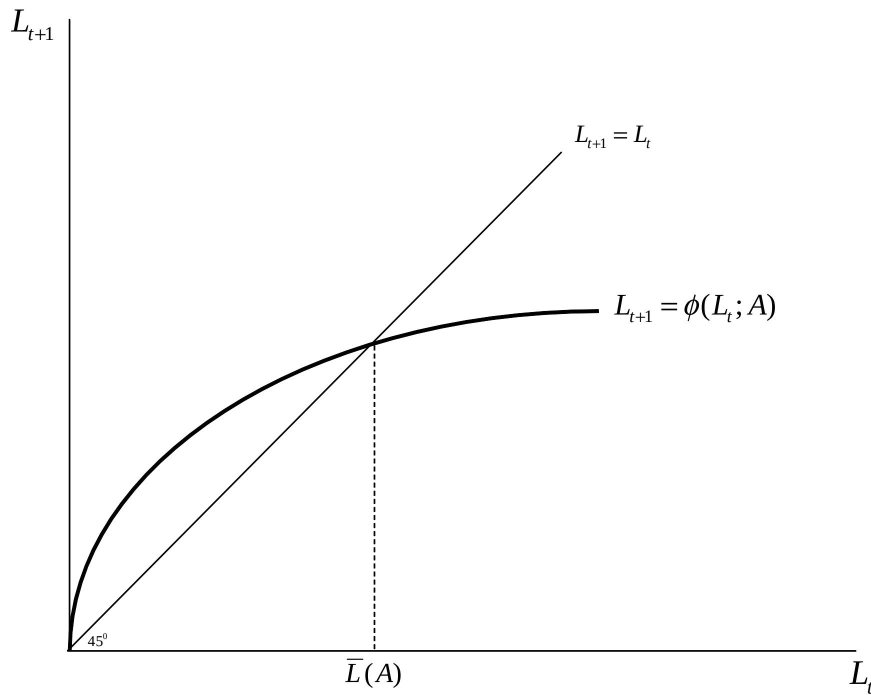


Figure 6: The Evolution of Population

Proposition 1 *1. Technological advancement:*

- *increases the steady-state levels of population,* $\bar{L}$*, and population density,* $\bar{P}_d$*, i.e.,*

$$\frac{\partial \bar{L}}{\partial A} > 0 \text{ and } \frac{\partial \bar{P}_d}{\partial A} > 0;$$

- *increases the rate of population growth between period* t *and* $t+1$*,* g^L_{t+1}*, i.e.,*

$$\frac{\partial g^L_{t+1}}{\partial A} > 0.$$

2. The positive effect of technological advancement on the rate of population growth is lower the higher is the level of the population

$$\frac{\partial^2 g^L_{t+1}}{\partial A \partial L_t} < 0.$$

Proof. Follows from differentiating the relevant expressions in Lemma 1. □

As depicted in Figure 7, if the economy is in a steady-state equilibrium, an increase in the technological level from A^l to A^h generates a transition process in which population gradually increases from its initial steady-state level, $\bar{L}^l$, to a higher one $\bar{L}^h$.

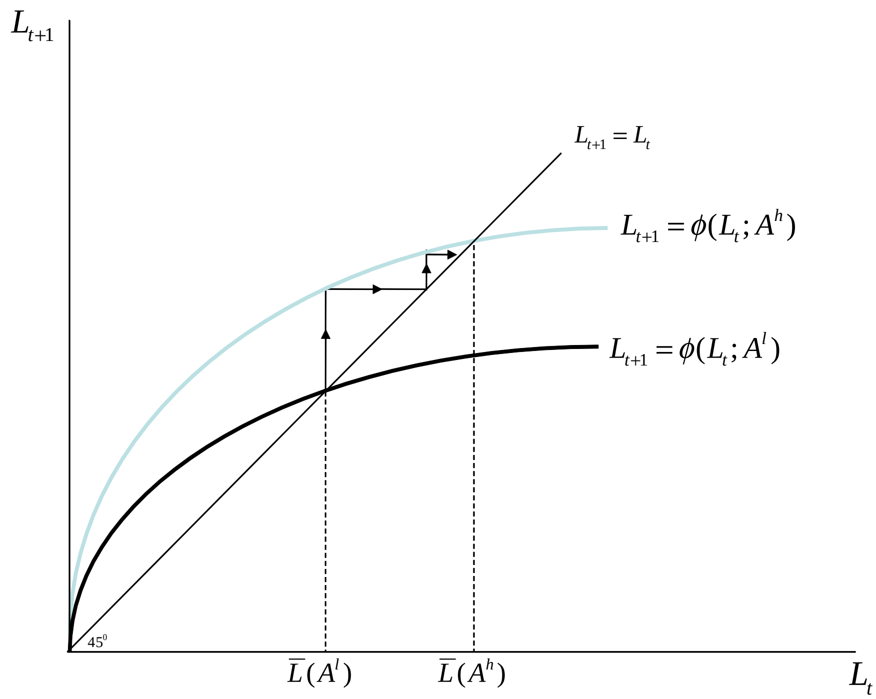


Figure 7: The Adjustment of Population due to an Advancement in the Level of Technology

Similarly, a decline in the population due to an epidemic such as the Black Death (1348-1350 CE) would temporarily reduce population, while temporarily increasing income per capita. The rise in income per capita will generate a gradual increase in population back to the steady-state level $\bar{L}$.

3.2.2 The Time Path of Income Per Worker

The evolution of income per worker is governed by the initial level of income per worker, the level of technology and the size of the population. Specifically, income per capita in period $t+1$, y_{t+1}, noting (2) and (6), is

$$y_{t+1} = [(AX)/L_{t+1}]^\alpha = [(AX)/n_t L_t]^\alpha = y_t/n_t^\alpha. \tag{7}$$

Lemma 2 *The time path of income per worker, as depicted in Figure 8, is governed by the first-order difference equation*

$$y_{t+1} = (\rho/\gamma)^{\alpha} y_t^{1-\alpha} \equiv \psi(y_t).$$

- *The growth rate of income per capita between periods t and $t+1$, g_{t+1}^y, is therefore*

$$g_{t+1}^y \equiv (y_{t+1} - y_t)/y_t = (\rho/\gamma)^{\alpha} y_t^{-\alpha} - 1 = (\rho/\gamma)^{\alpha}(AX/L_t)^{-\alpha^2} - 1 \equiv g^y(L_t; A).$$

- *Regardless of level of technology, A, there exists a unique steady-state level of income per capita, $\bar{y}$,*

$$\bar{y} = (\rho/\gamma).$$

Proof. Substituting (5) into (7) yields $y_{t+1} = (\rho/\gamma)^{\alpha} y_t^{1-\alpha}$. Hence, $\psi'(y_t) > 0$ and $\psi''(y_t) < 0$ so, as depicted in Figure 8, $\psi(y_t)$ is strictly concave in y with $\psi(0) = 0$, $\lim_{y_t \to 0} \psi'(y_t) = \infty$ and $\lim_{y_t \to \infty} \psi'(y_t) = 0$. Thus, regardless of the level of A, there exists a unique steady-state level of income per worker, $\bar{y}$. The expressions for the levels of $\bar{y}$ and g_{t+1}^y follow immediately from their definitions. $\square$

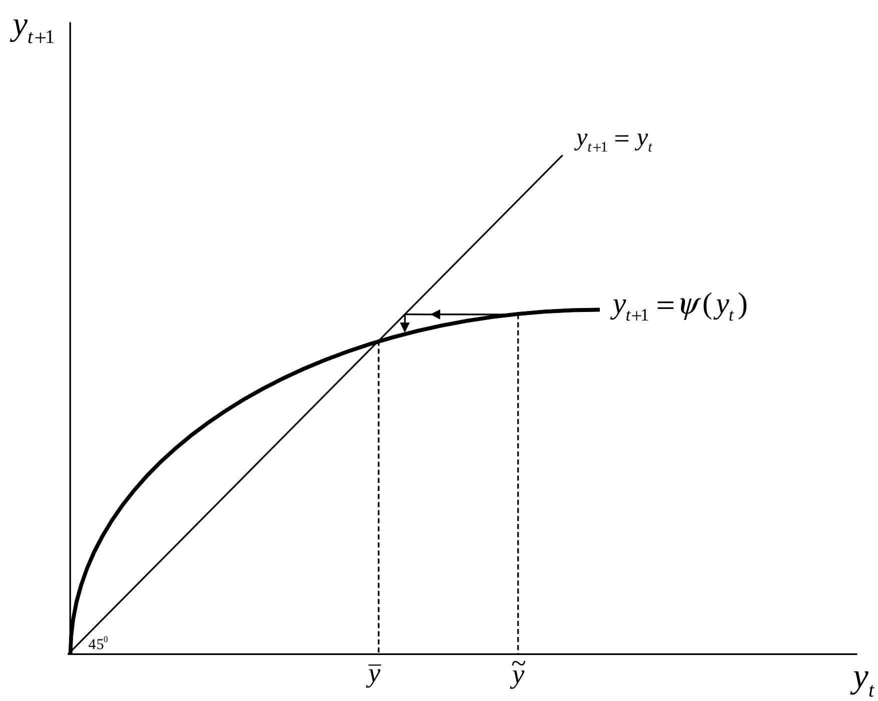


Figure 8: The Evolution of Income Per Capita

Proposition 2 *Technological advancement:*

- *increases the level of income per capita in time t, y_t, and reduces the growth rate of income per worker between period t and $t+1$, g^y_{t+1}, i.e.,*

$$\frac{\partial y_t}{\partial A} > 0 \text{ and } \frac{\partial g^y_{t+1}}{\partial A} < 0.$$

- *does not affect the steady-state levels of income per worker, $\bar{y}$,*

$$\frac{\partial \bar{y}}{\partial A} = 0.$$

Proof. Follows from differentiating the relevant expressions in Lemma 2. □

As depicted in Figure 8, if the economy is in a steady-state equilibrium, $\bar{y}$, an advancement in the technological level from A^l to A^h generates a transition process in which initially income per worker increases to a higher level $\tilde{y}$, reflecting higher labor productivity in the absence of population adjustment. However, as population increases, income per worker gradually declines to the initial steady-state equilibrium, $\bar{y}$.

Similarly, a decline in the population due to an epidemic such as the Black Death (1348-1350 CE) would temporarily reduce population to $\tilde{L}$, while temporarily increasing income per capita to $\tilde{y}$. The rise in income per worker will generate a gradual increase in population back to the steady-state level $\bar{L}$, and therefore a gradual decline in income per worker back to $\bar{y}$.

3.3 Testable Predictions

The Malthusian theory generates the following testable predictions:

1. A higher productivity of land leads in the long-run to a larger population, without altering the long run level of income per capita.

2. Countries characterized by a superior land productivity would have higher populations density, but their standard of living, in the long run, would not reflect the degree of their technological advancement.

3. Countries that experienced a universal technological advancement (e.g., the Neolithic Revolution) earlier would have, in a given time period,

(a) larger population density;

(b) lower rate of population growth.

In the absence of reliable and extensive data on income per capita in the Malthusian epoch, the theoretical predictions will be tested in two dimensions, comprising (i) the effect of measures of land productivity (e.g., the arable percentage of land, the suitability of land for agriculture, etc.) on population density in the pre-industrial era (specifically, the years 1 CE, 1000 CE and 1500 CE), and (ii) the effect of an earlier onset of the Neolithic Revolution on population density and rates of population growth.

4 Cross-Country Evidence

The Malthusian theory suggests that, during the agricultural stage of development, social surpluses beyond the maintenance of subsistence consumption were channelled primarily into population growth. As such, at any point in time, population density in a given region would have largely reflected its carrying capacity, determined by the effective resource constraints that were binding at that point in time. The Malthusian theory can therefore be tested in two dimensions. The first dimension pertains to the assertion that population density during the Malthusian epoch was largely constrained by the availability of *natural* resources. The second dimension concerns the role of socioeconomic development in augmenting total factor productivity and, thereby, in expanding *effective* resources over time.

In particular, since resource constraints were slacker for regions naturally blessed by a higher agricultural productivity of land, they would have sustained larger populations, given the level of socioeconomic development. Moreover, conditional on land productivity, societies in more advanced stages of development, as reflected by their cumulative experience with the agricultural technological paradigm since the Neolithic Revolution, would have sustained higher population densities.

The Malthusian theory predicts that regional variation in population density in the long-run would ultimately reflect variations in land productivity and biogeographic attributes. For a given socioeconomic environment, greater land productivity, manifested in a higher arable percentage of land, better soil quality, and a favorable climate, would enable society to sustain a larger population. Further, for a given land productivity, auspicious biogeographic factors, such as proximity to waterways, absolute latitude, and a greater availability of domesticable plant and animal species, would enhance population density via trade and the implementation and diffusion of agricultural technologies.

Beyond the Malthusian predictions for population density, the theory also suggests that, at a given point in time, societies should have been gravitating towards their respective Malthusian steady states, determined by their respective land productivities and their levels of socioeconomic development at that point in time. In particular, conditional on the natural productivity of land for agriculture and the level of socioeconomic development, a society with a higher population density in a given period would have exhibited, consistently with convergence, a relatively slower rate of population growth.

Favorable biogeographic factors led to an earlier onset of the Neolithic Revolution and facilitated the subsequent diffusion of agricultural techniques. The transition of societies in the Neolithic from primitive hunting and gathering techniques to the more technologically advanced agricultural mode of production initiated a cumulative process of socioeconomic development. It gave some societies a developmental headstart, conferred by their superior production technology that enabled the rise of a non-food-producing class whose members were crucial for the advancement of written language and science, and for the formation of cities, technology-based military powers and nation states (Diamond, 1997).[17] The current analysis therefore employs the number of years elapsed since the Neolithic Revolution as a metric of the level of socioeconomic development in an agricultural society during the Malthusian era.

To establish the testable predictions of the Malthusian theory empirically, the analysis at hand exploits cross-country variation in land productivity and in the number of years elapsed since the onset of the Neolithic Revolution to explain cross-country variation in population density in the years 1500 CE, 1000 CE and 1 CE.[18] The analysis additionally exploits variations in the aforementioned independent variables as well as in initial population densities to explain cross-country variation in the average rate of population growth over the 1-1000 CE and the 1000-1500 CE time horizons.

[17]See Weisdorf (2005) as well. In the context of the Malthusian model presented earlier, the Neolithic Revolution should be viewed as a large positive shock to the level of technology, A, followed by a long series of aftershocks, thereby preventing populations from approaching their Malthusian steady-state within a few generations. These aftershocks may be historically interpreted as discrete steps comprising the process of socioeconomic development such as urbanization, the emergence of land ownership and property rights institutions, advancements in communication via written language, scientific discoveries, etc. As will become evident, the empirical findings suggest that conditional convergence in the evolution of population takes place, suggesting therefore that the social gains from this subsequent process of development were eventually characterized by diminishing returns over time.

[18]Historical population estimates are obtained from McEvedy and Jones (1978) while data on the timing of the Neolithic Revolution is from Putterman (2006). The measure of land productivity employed is the first principal component of the arable percentage of land from the World Development Indicators and an index gauging the overall suitability of land for agriculture, based on soil quality and temperature, from Michalopoulos (2008). See the appendix for additional details and statistics.

Consistent with the predictions of the theory, the regression results demonstrate highly statistically significant positive effects of land productivity and an earlier onset of the Neolithic Revolution on population density in each historical period. Furthermore, in line with the conditional convergence hypothesis implied by the Malthusian theory, the findings also reveal statistically significant negative effects of initial population density on the average rate of population growth in the two time horizons. These results are shown to be robust to controls for other geographical factors such as access to waterways, which historically played a major role in augmenting productivity by facilitating trade and the diffusion of technologies, and to different cuts of the relevant regression samples that eliminate the influence of potential outliers.[19]

Formally, the baseline specification adopted to examine the Malthusian predictions regarding the effects of land productivity and the level of socioeconomic development on population density is:

$$\ln P_i = \beta_0 + \beta_1 \ln T_i + \beta_2 \ln X_i + \beta_3^{'} \Gamma_i + \beta_4^{'} D_i + \varepsilon_i, \tag{8}$$

where P_i is the population density of country i in a given year; T_i is the number of years elapsed since the onset of agriculture in country i; X_i is a measure of land productivity for country i based on the arable percentage of land area and an index of agricultural suitability; Γ_i is a vector of geographical controls for country i including absolute latitude and variables gauging access to waterways; D_i is a vector of continental dummies; and ε_i is a country-specific disturbance term for population density.

The baseline specification adopted to examine the conditional convergence hypothesis for population growth rates, on the other hand, is:[20]

$$g_i^L = \gamma_0 + \gamma_1 P_i + \gamma_2 T_i + \gamma_3 X_i + \gamma_4^{'} \Gamma_i + \gamma_5^{'} D_i + \upsilon_i, \tag{9}$$

where g_i^L is the average rate of growth of population in country i between years t and $t + \tau$; P_i is the population density of country i in year t; and υ_i is a country-specific disturbance term for the rate of population growth.

[19] The variables employed to gauge access to waterways are obtained from the CID research datasets online and include the mean within-country distance to the nearest coast or sea-navigable river and the percentage of total land located within 100 km of the nearest coast or sea-navigable river. See the appendix for additional details and statistics.

[20] The use of logged variables in the population density regressions but not in those examining growth rates is simply based on choosing the specification yielding the higher R-squared coefficient.

4.1 Population Density in 1500 CE

The results from regressions explaining log population density in the year 1500 CE are presented in Table 1. In particular, a number of specifications comprising different subsets of the explanatory variables in equation (8) are estimated to examine the independent and combined effects of the transition timing and land productivity channels, while controlling for other geographical factors and continental fixed effects.

Table 1: Comparative Development in 1500 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	IV
	Dependent Variable is Log Population Density in 1500 CE					
Log Years since Neolithic Transition	0.827 (0.299)***		1.024 (0.223)***	1.087 (0.184)***	1.389 (0.224)***	2.077 (0.391)***
Log Land Productivity		0.584 (0.068)***	0.638 (0.057)***	0.576 (0.052)***	0.573 (0.095)***	0.571 (0.082)***
Log Absolute Latitude		-0.426 (0.124)***	-0.354 (0.104)***	-0.314 (0.103)***	-0.278 (0.131)**	-0.248 (0.117)**
Mean Distance to Nearest Coast or River				-0.392 (0.142)***	0.220 (0.346)	0.250 (0.333)
% Land within 100 km of Coast or River				0.899 (0.282)***	1.185 (0.377)***	1.350 (0.380)***
Continent Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	148	148	148	147	96	96
R-squared	0.40	0.60	0.66	0.73	0.73	0.70
First-stage F-statistic	-	-	-	-	-	14.65
Overid. p-value	-	-	-	-	-	0.44

Notes: (i) log land productivity is the first principal component of the log of the arable percentage of land and the log of an agricultural suitability index; (ii) the IV regression employs the numbers of prehistoric domesticable species of plants and animals as instruments for log transition timing; (iii) the statistic for the first-stage F-test of these instruments is significant at the 1% level; (iv) the p-value for the overidentifying restrictions test corresponds to Hansen's J statistic, distributed in this case as chi-square with one degree of freedom; (v) a single continent dummy is used to represent the Americas, which is natural given the historical period examined; (vi) regressions (5)-(6) do not employ the Oceania dummy due to a single observation for this continent in the IV data restricted sample; (vii) robust standard errors are reported in parentheses; (viii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Figure 9a: Transition Timing and Population Density in 1500 CE — Conditional on Land Productivity, Geographical Factors and Continental Fixed Effects

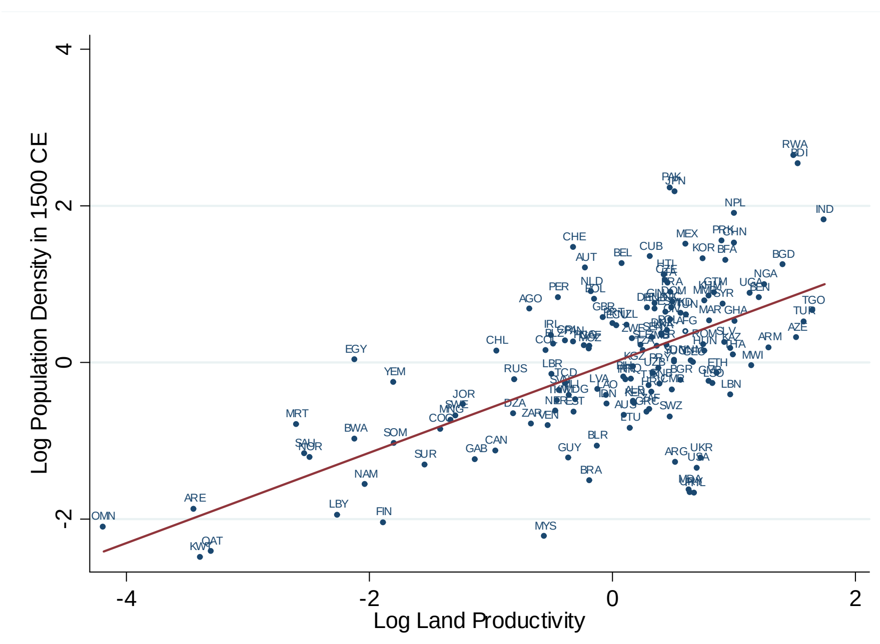


Figure 9b: Land Productivity and Population Density in 1500 CE — Conditional on Transition Timing, Geographical Factors and Continental Fixed Effects

Consistent with the predictions of the Malthusian theory, Column 1 reveals the positive relationship between log years since transition and log population density in the year 1500 CE, controlling for continental fixed effects. Specifically, the estimated OLS coefficient implies that a 1% increase in the number of years elapsed since the transition to agriculture increases population density in 1500 CE by 0.83%, an effect that is statistically significant at the 1% level. Moreover, based on the R-squared coefficient of the regression, the transition timing channel appears to explain 40% of the variation in log population density in 1500 CE along with the dummies capturing unobserved continental characteristics.

The effect of the land productivity channel, controlling for absolute latitude and continental fixed effects, is reported in Column 2. In line with theoretical predictions, a 1% increase in land productivity raises population density in 1500 CE by 0.58%, an effect that is also significant at the 1% level. Interestingly, in contrast to the relationship between absolute latitude and contemporary income per capita, the estimated elasticity of population density in 1500 CE with respect to absolute latitude suggests that economic development during the Malthusian stage was on average higher at latitudinal bands closer to the equator. The R-squared of the regression indicates that, along with continental fixed effects and absolute latitude, the land productivity channel explains 60% of the cross-country variation in log population density in 1500 CE.

Column 3 presents the results from examining the combined explanatory power of the previous two regressions. The estimated coefficients on the transition timing and land productivity variables remain highly statistically significant and continue to retain their expected signs, while increasing slightly in magnitude in comparison to their estimates in earlier columns. Furthermore, transition timing and land productivity together explain 66% of the variation in log population density in 1500 CE, along with absolute latitude and continental fixed effects.

The explanatory power of the regression in Column 3 improves by an additional 7% once controls for access to waterways are accounted for in Column 4, which constitutes the baseline regression specification for population density in 1500 CE. In comparison to the estimates reported in Column 3, the effects of the transition timing and land productivity variables remain reassuringly stable in both magnitude and statistical significance when subjected to the additional geographic controls. Moreover, the estimated coefficients on the additional geographic controls indicate significant effects consistent with the assertion that better access to waterways has been historically beneficial for economic development by fostering urbanization, international trade and technology diffusion. To interpret the baseline effects of the variables of interest, a 1% increase in the number of years elapsed since the

Neolithic Revolution raises population density in 1500 CE by 1.02%, conditional on land productivity, absolute latitude, waterway access and continental fixed effects. Similarly, a 1% increase in land productivity is associated, *ceteris paribus*, with a 0.64% increase in population density in 1500 CE. These conditional effects are depicted on the scatter plots in Figures 9a-b respectively.

The analysis now turns to address issues regarding causality, particularly with respect to the transition timing variable. Specifically, while variations in land productivity and other geographical characteristics are inarguably exogenous to the cross-country variation in population density, the onset of the Neolithic Revolution and the outcome variable of interest may in fact be endogenously determined. For instance, the experience of an earlier transition to agriculture may have been caused by a larger proportion of "higher ability" individuals in society, which also fostered population density through other channels of socioeconomic development. Thus, although reverse causality is not a source of concern, given that the vast majority of countries experienced the Neolithic Revolution by the common era, OLS estimates of the effect of the time elapsed since the transition to agriculture may indeed suffer from omitted variable bias, reflecting spurious correlations with the outcome variable being examined.

To demonstrate the causal effect of the timing of the Neolithic transition on population density in the common era, the investigation appeals to Diamond's (1997) hypothesis on the role of exogenous geographic and biogeographic endowments in determining the timing of the Neolithic Revolution. Accordingly, the emergence and subsequent diffusion of agricultural practices were primarily driven by geographic conditions such as climate, continental size and orientation, as well as by biogeographic factors such as the availability of wild plant and animal species amenable to domestication. However, while geographic factors certainly continued to play a direct role in economic development after the onset of agriculture, it is postulated that the prehistorical biogeographic endowments did not influence population density in the common era other than through the timing of the Neolithic Revolution. The analysis consequently adopts the numbers of prehistorical domesticable species of wild plants and animals as instruments to establish the causal effect of transition timing on population density.[21]

[21] The numbers of prehistorical domesticable species of wild plants and animals are obtained from the dataset of Olsson and Hibbs (2005). It should be noted that an argument could be made for the endogeneity of these biogeographic variables whereby hunter-gatherer populations with "higher ability" individuals settled in regions with a greater availability of domesticable plants and animals. This argument, however, is rather implausible given (i) the vast distance between territories that contained domesticable species, (ii) the highly imperfect flow of information in such a primitive stage of development, and (iii) the evidence that the mobility of hunter-gatherer populations was typically limited to small geographical areas. In addition, even if the

The final two columns in Table 1 report the results associated with a subsample of countries for which data is available on the biogeographic instruments. To allow meaningful comparisons between IV and OLS coefficient estimates, Column 5 repeats the baseline OLS regression analysis on this particular subsample of countries, revealing that the coefficients on the explanatory variables of interest remain largely stable in terms of both magnitude and significance when compared to those estimated using the baseline sample. This is a reassuring indicator that any additional sampling bias introduced by the restricted sample, particularly with respect to the transition timing and land productivity variables, is negligible. Consistent with this assertion, the explanatory powers of the baseline and restricted sample regressions are identical.

Column 6 presents the IV regression results from estimating the baseline specification with log years since transition instrumented by the numbers of prehistorical domesticable species of plants and animals. The estimated causal effect of transition timing on population density not only retains statistical significance at the 1% level but is substantially stronger in comparison to the estimate in Column 5. This pattern is consistent with attenuation bias afflicting the OLS coefficient as a result of measurement error in the transition timing variable. Moreover, omitted variable bias that might have been caused by the latent "higher ability" channel discussed earlier appears to be negligible since the IV coefficient on the transition timing variable would have otherwise been weaker than the OLS estimate.[22] To interpret the causal impact of the Neolithic transition, a 1% increase in years elapsed since the onset of agriculture causes, *ceteris paribus*, a 2.08% increase in population density in the year 1500 CE.

The coefficient on land productivity, which maintains stability in both magnitude and statistical significance across the OLS and IV regressions, indicates that a 1% increase in the agricultural productivity of land raises population density by 0.57%, conditional on transition timing, other geographical factors and continental fixed effects. Finally, it is reassuring to observe the rather large F-statistic in the first-stage regression, verifying the significance and explanatory power of the biogeographic instruments for the timing of the Neolithic Revolution. In addition, the high p-value associated with the test for

selection of "higher ability" hunter-gatherers occurred into regions that eventually proved agriculturally favorable, it is unlikely that the skills that were more productive for hunting and gathering activities were also more conducive to agriculture. As will become evident, the potential endogeneity of the biogeographic variables is rejected by the overidentifying restrictions test in all IV regressions examined.

[22] It should be stressed that the "higher ability" channel is being raised in the discussion as one example of any number unidentified channels and, as such, the direction of omitted variable bias is obviously *a priori* ambiguous. Hence, the comparatively higher IV coefficient on the transition timing variable should be taken at face value without necessarily prescribing to any one particular interpretation.

overidentifying restrictions asserts that the instruments employed are indeed valid in that they do not exert any independent influence on population density in 1500 CE other than through the transition timing channel.

Table 2: Comparative Development in 1000 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	IV
	Dependent Variable is Log Population Density in 1000 CE					
Log Years since Neolithic Transition	1.227 (0.293)***		1.434 (0.243)***	1.480 (0.205)***	1.803 (0.251)***	2.933 (0.504)***
Log Land Productivity		0.467 (0.079)***	0.550 (0.063)***	0.497 (0.056)***	0.535 (0.098)***	0.549 (0.092)***
Log Absolute Latitude		-0.377 (0.148)**	-0.283 (0.117)**	-0.229 (0.111)**	-0.147 (0.127)	-0.095 (0.116)
Mean Distance to Nearest Coast or River				-0.528 (0.153)***	0.147 (0.338)	0.225 (0.354)
% Land within 100 km of Coast or River				0.716 (0.323)**	1.050 (0.421)**	1.358 (0.465)***
Continent Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	143	143	143	142	94	94
R-squared	0.38	0.46	0.59	0.67	0.69	0.62
First-stage F-statistic	-	-	-	-	-	15.10
Overid. p-value	-	-	-	-	-	0.28

Notes: (i) log land productivity is the first principal component of the log of the arable percentage of land and the log of an agricultural suitability index; (ii) the IV regression employs the numbers of prehistoric domesticable species of plants and animals as instruments for log transition timing; (iii) the statistic for the first-stage F-test of these instruments is significant at the 1% level; (iv) the p-value for the overidentifying restrictions test corresponds to Hansen's J statistic, distributed in this case as chi-square with one degree of freedom; (v) a single continent dummy is used to represent the Americas, which is natural given the historical period examined; (vi) regressions (5)-(6) do not employ the Oceania dummy due to a single observation for this continent in the IV data restricted sample; (vii) robust standard errors are reported in parentheses; (viii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

4.2 Population Density in Earlier Historical Periods

The results from replicating the previous analysis for log population density in the years 1000 CE and 1 CE are presented in Tables 2 and 3 respectively. As before, the independent and combined explanatory powers of the transition timing and land productivity channels are examined while controlling for other geographical factors and unobserved continental characteristics.

Table 3: Comparative Development in 1 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	IV
	Dependent Variable is Log Population Density in 1 CE					
Log Years since Neolithic Transition	1.560 (0.326)***		1.903 (0.312)***	1.930 (0.272)***	2.561 (0.369)***	3.459 (0.437)***
Log Land Productivity		0.404 (0.106)***	0.556 (0.081)***	0.394 (0.067)***	0.421 (0.094)***	0.479 (0.089)***
Log Absolute Latitude		-0.080 (0.161)	-0.030 (0.120)	0.057 (0.101)	0.116 (0.121)	0.113 (0.113)
Mean Distance to Nearest Coast or River				-0.685 (0.155)***	-0.418 (0.273)	-0.320 (0.306)
% Land within 100 km of Coast or River				0.857 (0.351)**	1.108 (0.412)***	1.360 (0.488)***
Continent Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	128	128	128	128	83	83
R-squared	0.47	0.41	0.59	0.69	0.75	0.72
First-stage F-statistic	-	-	-	-	-	10.85
Overid. p-value	-	-	-	-	-	0.59

Notes: (i) log land productivity is the first principal component of the log of the arable percentage of land and the log of an agricultural suitability index; (ii) the IV regression employs the numbers of prehistoric domesticable species of plants and animals as instruments for log transition timing; (iii) the statistic for the first-stage F-test of these instruments is significant at the 1% level; (iv) the p-value for the overidentifying restrictions test corresponds to Hansen's J statistic, distributed in this case as chi-square with one degree of freedom; (v) a single continent dummy is used to represent the Americas, which is natural given the historical period examined; (vi) regressions (5)-(6) do not employ the Oceania dummy due to a single observation for this continent in the IV data restricted sample; (vii) robust standard errors are reported in parentheses; (viii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

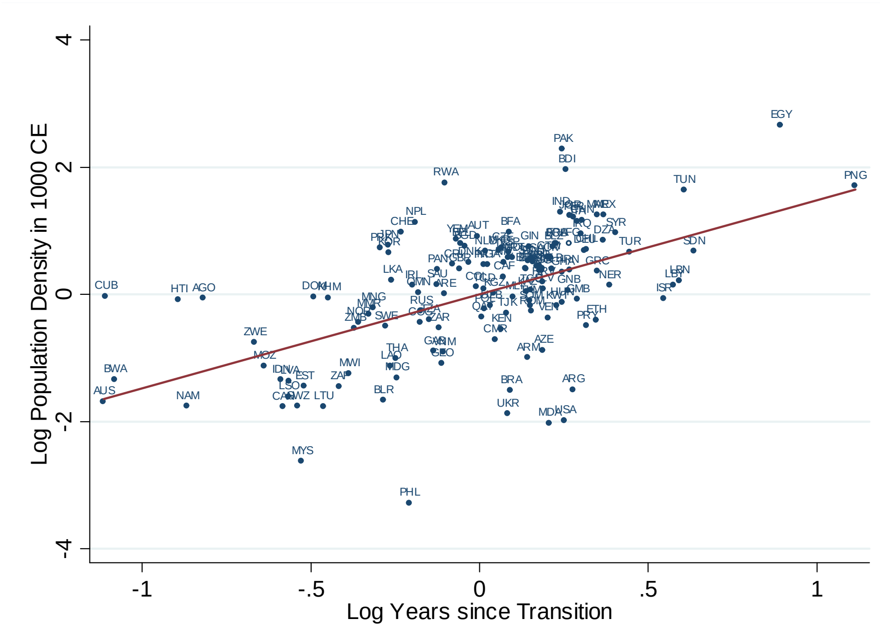


Figure 10a: Transition Timing and Population Density in 1000 CE — Conditional on Land Productivity, Geographical Factors and Continental Fixed Effects

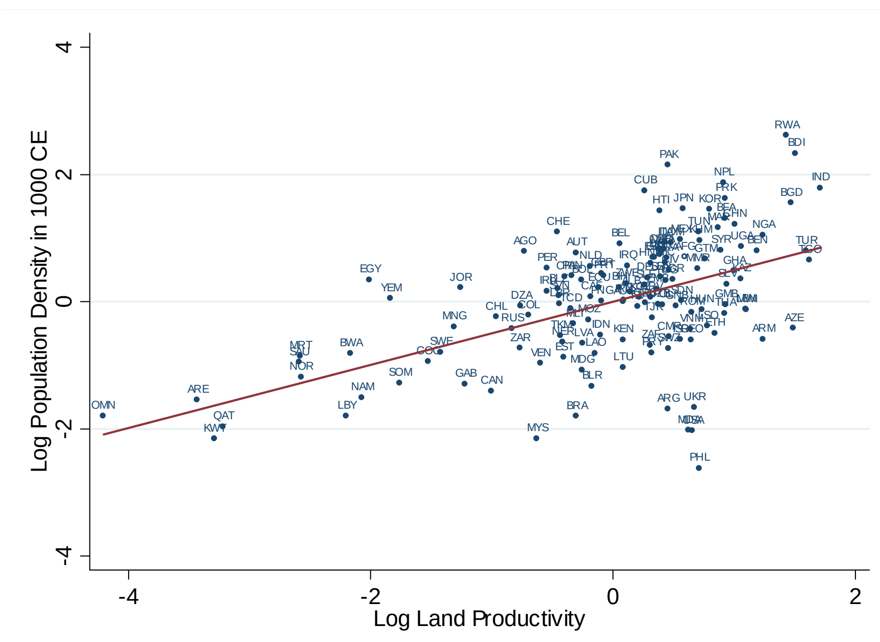


Figure 10b: Land Productivity and Population Density in 1000 CE — Conditional on Transition Timing, Geographical Factors and Continental Fixed Effects

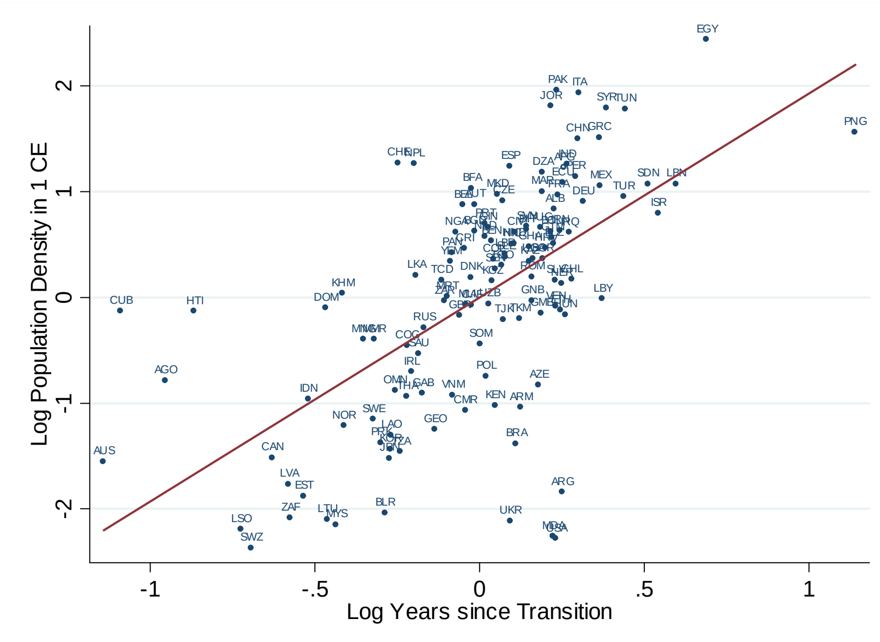


Figure 11a: Transition Timing and Population Density in 1 CE — Conditional on Land Productivity, Geographical Factors and Continental Fixed Effects

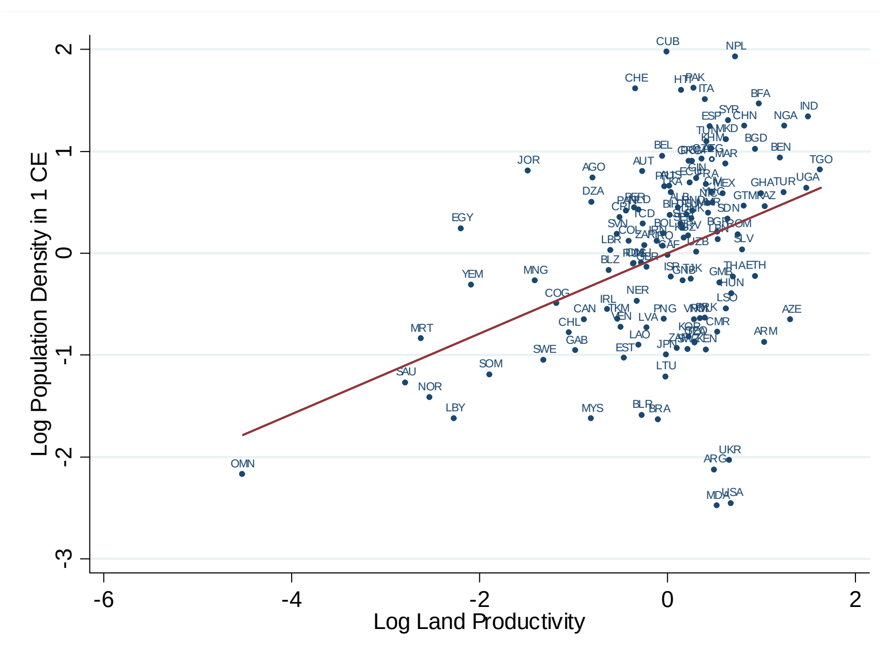


Figure 11b: Land Productivity and Population Density in 1 CE — Conditional on Transition Timing, Geographical Factors and Continental Fixed Effects

In line with the empirical predictions of the Malthusian theory, the findings reveal highly statistically significant positive effects of land productivity and an earlier transition to agriculture on population density in these earlier historical periods as well. Moreover, the positive impact on economic development of geographical factors capturing better access to waterways is also confirmed for these earlier periods, as is the inverse relationship between absolute latitude and population density, particularly for the 1000 CE analysis.

The stability patterns exhibited by the magnitude and significance of the coefficients on the explanatory variables of interest in Tables 2-3 are strikingly similar to those observed earlier in the 1500 CE analysis. Thus, for instance, while statistical significance remains unaffected across specifications, the independent effects of Neolithic transition timing and land productivity from the first two columns in each table increase slightly in magnitude when both channels are examined concurrently in Column 3, and remain stable thereafter when subjected to the additional geographic controls in the baseline regression specification of the fourth column. This is a reassuring indicator that the variance-covariance characteristics of the regression samples employed for the different periods are not fundamentally different from one another, despite differences in sample size due to the greater unavailability of population density data in the earlier historical periods. The qualitative similarity of the results across periods also suggests that the empirical findings are indeed more plausibly associated with the Malthusian theory as opposed to being consistently generated by spurious correlations between population density and the explanatory variables of interest across the different historical periods.

To interpret the baseline effects of interest in each historical period, a 1% increase in the number of years elapsed since the Neolithic Revolution raises population density in the years 1000 CE and 1 CE by 1.48% and 1.90% respectively, conditional on the productivity of land, absolute latitude, access to waterways and continental fixed effects. Similarly, a 1% increase in land productivity is associated with, *ceteris paribus*, a 0.50% increase in population density in 1000 CE and a 0.39% increase in population density in 1 CE. These conditional effects are depicted on the scatter plots in Figures 10a-b for the 1000 CE analysis and in Figures 11a-b for the 1 CE analysis.

For the 1000 CE analysis, the additional sampling bias on OLS estimates introduced by moving to the IV-restricted subsample in Column 5 is similar to that observed in Table 1, whereas the bias appears somewhat larger for the analysis in 1 CE. This is attributable to the smaller size of the subsample in the latter analysis. The subsequent IV regressions in Column 6, however, once again reflect the pattern that the causal effect of transition timing on population density in each period is stronger than its corresponding reduced-form effect, while the effect of land productivity remains rather stable across the OLS and IV specifications. In addition, the strength and validity of the numbers of domesticable plant and animal species as instruments continue to be confirmed by their joint significance in the first-stage regressions and by the results of the overidentifying restrictions tests. The similarity of these findings with those obtained in the 1500 CE analysis reinforces the validity of these instruments and, thereby, lends further credence to the causal effect of the timing of the Neolithic transition on population density.

Finally, turning attention to the differences in coefficient estimates obtained for the three periods, it is interesting to note that, while the positive effect of land productivity on population density remains rather stable, that of the number of years elapsed since the onset of agriculture declines over time.[23] For instance, comparing the IV coefficient estimates on the transition timing variable across Tables 1-3, the positive causal impact of the Neolithic Revolution on population density diminishes by 0.53 percentage points over the 1-1000 CE time horizon and by 0.85 percentage points over the subsequent 500-year period. This pattern is consistently reflected by all regression specifications examining the effect of the transition timing variable, lending support to the assertion that the process of socioeconomic development initiated by the technological breakthrough of the Neolithic Revolution conferred social gains characterized by diminishing returns over time.[24] In line with this assertion, the number of years elapsed since the Neolithic Revolution should be expected to confer a negative effect on the rate of population growth during the 1-1500 CE time period, a prediction that is indeed verified by the population growth rate regressions discussed below.[25]

[23] Another interesting pattern concerns the increasing strength and significance of the inverse relationship between population density and absolute latitude over time. This finding may in part reflect the assertion that technological diffusion during the Malthusian epoch, constrained largely amongst societies residing under similar geographical conditions, was complementary with the overall level of agricultural development. The importance of absolute latitude therefore increases at more advanced stages of development.

[24] This may seem contradictory to the finding that the baseline estimate of the elasticity of population density with respect to the years elapsed since the Neolithic transition is greater than unity in each period examined, suggesting the presence of increasing returns instead. However, it is important to bear in mind that the function relating population in two consecutive periods in the Malthusian model can indeed generate elasticities greater than unity for sufficiently low initial population levels even though the function itself is strictly concave. In addition, it should be noted that the cross-sectional effect, in a given period, of the years elapsed since the Neolithic transition is dependent on the distribution of the variable itself. Thus, given that its distribution is not uniform, cross-sectional elasticities larger than unity are not entirely surprising as they predominantly reflect the cumulative gains enjoyed by early-movers into agriculture over a large expanse of time before late-movers experienced the transition.

[25] The assertion that the process of economic development initiated by the Neolithic Revolution was characterized by diminishing returns over time implies that, given a sufficiently large lag following the transition, societies should be expected to converge towards a Malthusian steady-state conditional only on the productivity of land. Hence, the cross-sectional relationship between population density and the number

4.3 Long-Run Population Dynamics

Table 4 presents the results of regressions examining the Malthusian prediction of conditional convergence in the 1-1000 CE and 1000-1500 CE horizons. In particular, specifications spanning different subsets of the explanatory variables in equation (9) are estimated and the robustness of the regression results is verified in subsamples eliminating the influence of potential outliers.

Columns 1 and 4 establish conditional convergence in population across countries during the 1-1000 CE and 1000-1500 CE time horizons respectively, employing data from the full sample of countries available for each period. Specifically, a statistically significant negative effect of initial population density on the rate of population growth is revealed for each of the historical time spans examined. The estimated OLS coefficients indicate that, conditional on land productivity and the timing of the Neolithic transition, a 1 person increase per square km in the years 1 CE and 1000 CE is associated with a 7.9 percentage point and a 3.4 percentage point decrease in the average rate of population growth in the 1-1000 CE and 1000-1500 CE time horizons respectively. Moreover, the finding that the effect of initial population density on the rate of population growth is smaller in absolute value for the latter period suggests that societies were indeed closer to their conditional Malthusian steady states in the year 1000 CE than in 1 CE.

The result that societies were closer to their conditional Malthusian steady states by 1000 CE goes hand in hand with the assertion that steady states themselves began to gradually settle down as a result of diminishing social gains over time from the process of development initiated by the Neolithic Revolution. In accordance with this assertion, the number of years elapsed since the Neolithic transition not only has a significant negative effect on population growth in each time span, but its effect is smaller in absolute value in the latter horizon. Specifically, a 1 year increase in time elapsed since the Neolithic transition is associated with a 0.43 percentage point lower rate of population growth in the 1-1000 CE time span and a 0.19 percentage point lower rate in the 1000-1500 CE time span, conditional

---

of years elapsed since the Neolithic transition should be expected to exhibit some concavity. This prediction was tested using the following specification:

$$\ln P_i = \alpha_0 + \alpha_1 T_i + \alpha_2 T_i^2 + \alpha_3 \ln X_i + \alpha_4^{'} \Gamma_i + \alpha_5^{'} D_i + \varepsilon_i.$$

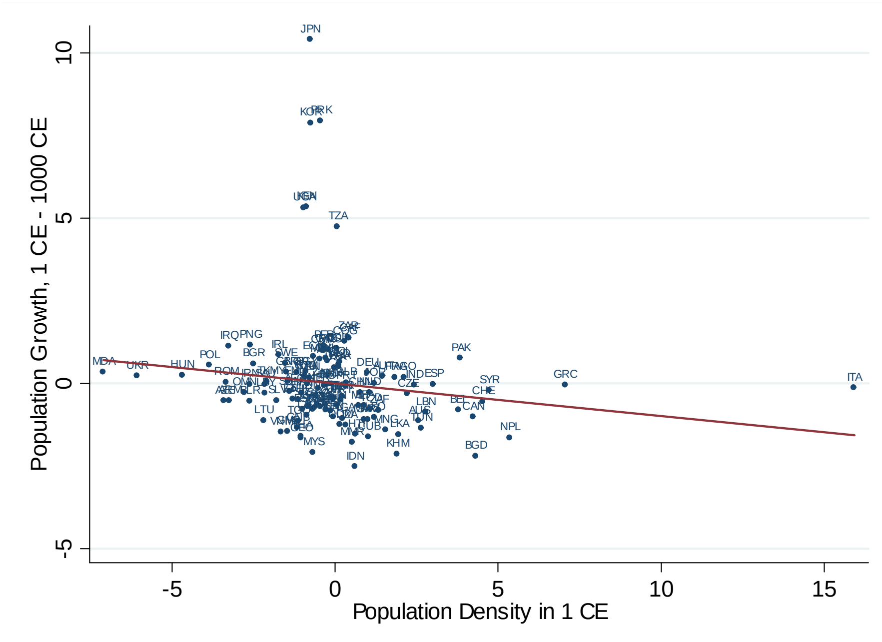
Consistent with the aforementioned prediction, the OLS regression for 1500 CE yields $\alpha_1 = 0.630$ [0.133] and $\alpha_2 = -0.033$ [0.011] with the standard errors (in brackets) indicating that both estimates are statistically significant at the 1% level. Moreover, in line with the prediction that a concave relationship should not necessarily be observed in an earlier period, the regression for 1 CE yields $\alpha_1 = 0.755$ [0.172] and $\alpha_2 = -0.020$ [0.013] with the standard errors indicating that the first-order (linear) effect is statistically significant at the 1% level whereas the second-order (quadratic) effect is insignificant.

on initial population density and land productivity. Interestingly, the productivity of land confers significant positive effects on population growth in the two time spans, suggesting upward pressures on conditional Malthusian steady states over time, although the smaller magnitude of its effect in the latter time span is once again consistent with the finding that regions were relatively closer to their steady states in the year 1000 CE.

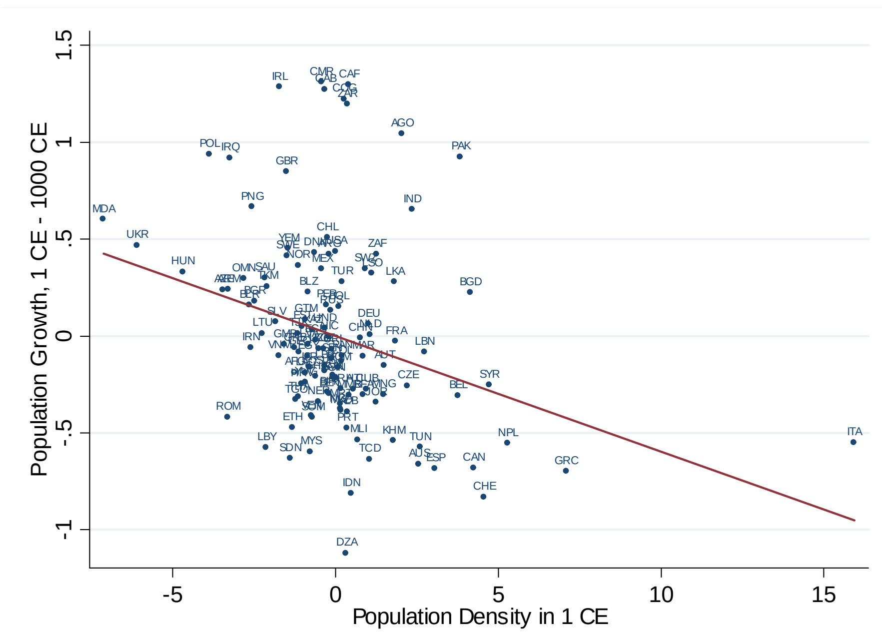
Table 4: Long-Run Population Dynamics

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS Full Sample	OLS Full Sample	OLS No Outliers	OLS Full Sample	OLS Full Sample	OLS No Outliers
	Average Rate of Population Growth, 1 CE - 1000 CE			Average Rate of Population Growth, 1000 CE - 1500 CE		
Population Density in 1 CE	-0.079 (0.035)**	-0.099 (0.042)**	-0.060 (0.015)***			
Population Density in 1000 CE				-0.034 (0.019)*	-0.035 (0.020)*	-0.026 (0.013)**
Years since Neolithic Transition	-0.429 (0.161)***	-0.395 (0.143)***	-0.148 (0.035)***	-0.186 (0.043)***	-0.185 (0.043)***	-0.174 (0.024)***
Land Productivity	0.335 (0.143)**	0.227 (0.126)*	0.049 (0.043)	0.121 (0.059)**	0.110 (0.054)**	0.103 (0.044)**
Absolute Latitude		0.002 (0.023)	-0.017 (0.006)***		0.001 (0.005)	-0.001 (0.004)
Mean Distance to Nearest Coast or River		-0.296 (0.403)	-0.009 (0.120)		-0.049 (0.132)	-0.042 (0.103)
% Land within 100 km of Coast or River		0.630 (0.734)	-0.145 (0.153)		0.049 (0.255)	-0.358 (0.162)**
Continent Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	128	128	122	143	142	137
R-squared	0.25	0.27	0.57	0.38	0.38	0.52

Notes: (i) land productivity is the first principal component of the arable percentage of land and an agricultural suitability index; (ii) in regression (3) the outlying countries omitted from the sample are Japan, Kenya, North and South Korea, Tanzania and Uganda; (iii) the outliers omitted from the sample in regression (6) are Israel, Japan, Madagascar, Mozambique and the Philippines; (iv) a single continent dummy is used to represent the Americas, which is natural given the historical period examined; (v) robust standard errors are reported in parentheses; (vi) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

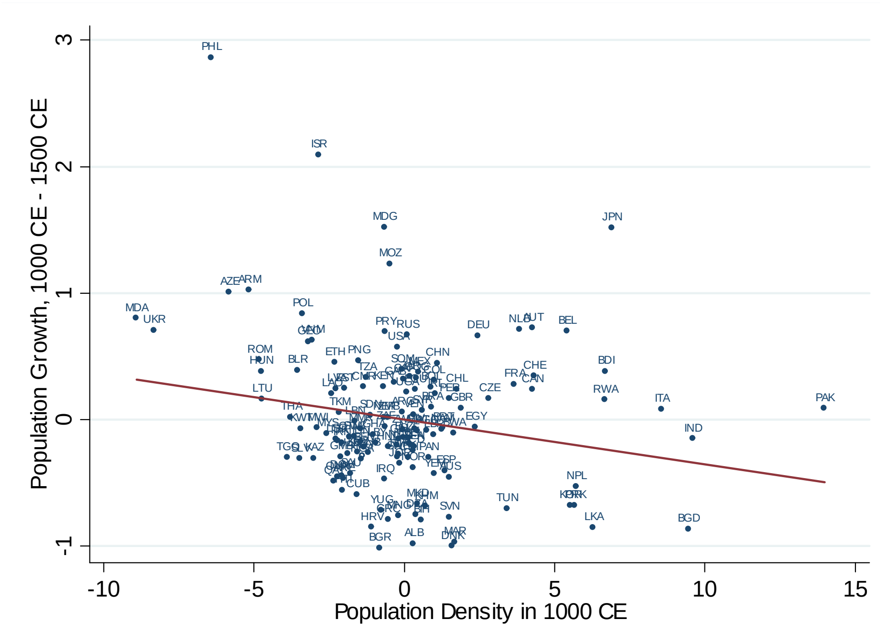


Panel (i) - Full Sample

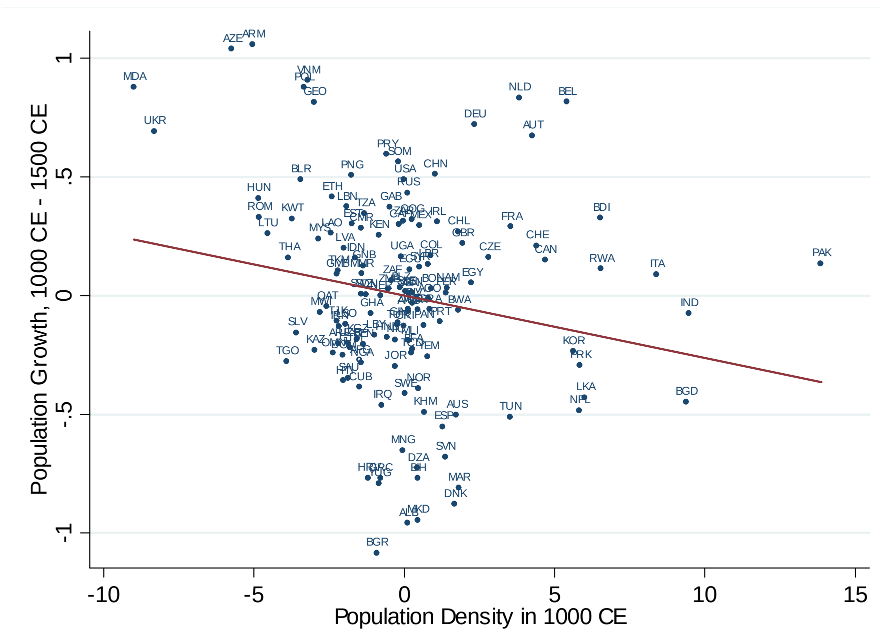


Panel (ii) - Sample Excluding Outliers

Figure 12a: Initial Density and Population Growth, 1-1000 CE — Conditional on Transition Timing, Geographical Factors and Continental Fixed Effects



Panel (i) - Full Sample



Panel (ii) - Sample Excluding Outliers

Figure 12b: Initial Density and Population Growth, 1000-1500 CE — Conditional on Transition Timing, Geographical Factors and Continental Fixed Effects

Columns 2 and 5 augment the analyses of their preceding columns with controls for additional geographical factors, constituting the baseline specifications for explaining population growth rates in the two time horizons.[26] Despite the importance of latitude and access to waterways in determining population levels, the explanatory power of these variables appears to be negligible for population growth rates, suggesting that the beneficial effects of trade and technological diffusion, as captured by these variables, remained fixed over time at least during the 1500-year period examined in this study.[27] Consistent with this finding, the estimated effects of initial conditions, transition timing and land productivity on population growth rates remain largely stable in comparison to those presented in the preceding columns, albeit less so for the 1-1000 CE time span. More importantly, the baseline coefficients in the two time spans continue to reflect the pattern that the effects of these variables are smaller in absolute value during the later time horizon. To interpret the baseline estimates on the initial conditions, a 1 person increase per square km in the years 1 CE and 1000 CE is associated with a 9.9 percentage point and a 3.5 percentage point decrease in the average rate of population growth during the 1-1000 CE and the 1000-1500 CE time horizons respectively. These relationships are respectively depicted on the scatter plots presented in panel (i) of Figures 12a and 12b. The scatter plots, however, immediately reveal the existence of possibly influential outliers.

To ensure that the results from earlier columns confirming the convergence hypothesis were not being driven by the influence of outliers, the baseline regressions for population growth in each time span were estimated using samples eliminating these outliers.[28] The results from these regressions are presented in Columns 3 and 6, and are depicted on the scatter plots in panel (ii) of Figures 12a and 12b. Reassuringly, the results continue to confer strong support for the convergence hypothesis with highly statistically significant

[26] It is interesting to note that in (unreported) IV regressions examining population growth rates, where the years elapsed since the Neolithic transition is instrumented by biogeographic endowments, the transition timing variable captures the explanatory power and significance of initial population density. This result is not entirely surprising given that the exogenous factors governing the timing of the Neolithic Revolution are indeed the "ultimate" initial conditions for subsequent Malthusian population dynamics.

[27] This appears to be at odds with the argument presented in Footnote 23. However, as will become evident shortly, once the influence of outliers is accounted for, absolute latitude is found to confer a significant negative effect on the rate of population growth in the 1-1000 CE time span but not on that in the 1000-1500 CE time span. This finding is entirely consistent with complementarity between technological diffusion and the level of socioeconomic development once the diminishing social gains assertion is also taken into consideration.

[28] Sample outliers were identified by examining partial scatter plots for each explanatory variable in the baseline specification and selecting those observations that were consistently located at a disproportionately large distance from the partial (covariate-adjusted) regression lines. The outliers identified in the population growth rate analysis for 1-1000 CE were Japan, Kenya, North and South Korea, Tanzania and Uganda. The outliers in the 1000-1500 CE analysis, on the other hand, were Israel, Japan, Madagascar, Mozambique and the Philippines.

negative effects of initial population densities on population growth rates in both historical time horizons. Moreover, the assertion that the marginal social gains originating from the Neolithic Revolution diminished over time is also confirmed by the statistically significant negative coefficient on the transition timing variable in each analysis. Unlike the earlier results, however, the effect of the years elapsed since the Neolithic transition on population growth is larger in absolute value for the 1000-1500 CE time span in comparison to the 1-1000 CE time span, suggesting the possibility of a jump in social gains at some point during the later period. Nevertheless, the fact that the relationship between initial population density and the rate of population growth is weaker in the 1000-1500 CE time horizon continues to imply that on average societies were indeed closer to their conditional Malthusian steady states in the year 1000 CE than in 1 CE.

5 Concluding Remarks

This paper provides an empirical test for the existence of Malthusian population dynamics in the pre-Industrial Revolution era. The Malthusian theory suggests that, during the agricultural stage of development, social surpluses beyond the maintenance of subsistence consumption were channelled primarily into population growth with negligible long-run effects on income per capita. As such, at any point in time, population density in a given region would have largely reflected its carrying capacity, determined by the effective resource constraints that were binding at that point in time.

In the absence of reliable and extensive data on income per capita from the Malthusian epoch, the theory is tested in two dimensions. The first dimension pertains to the assertion that population density in the Malthusian epoch was largely constrained by the availability of *natural* resources. The second dimension concerns the role of socioeconomic development in augmenting total factor productivity and, thereby, in expanding *effective* resources over time. In particular, since resource constraints were slacker for regions naturally blessed by a higher agricultural productivity of land, they would have sustained larger populations, given the level of socioeconomic development. On the other hand, given land productivity, societies in more advanced stages of development, as reflected by their cumulative experience with the agricultural technological paradigm since the Neolithic Revolution, would have sustained higher population densities.

The Malthusian theory predicts that regional variation in population density in the long-run would ultimately reflect variations in land productivity and biogeographic attributes. For a given socioeconomic environment, greater land productivity, manifested in a higher arable percentage of land, better soil quality, and a favorable climate, would enable society to sustain a larger population. Further, for a given land productivity, auspicious biogeographic factors, such as proximity to waterways, absolute latitude, and a greater availability of domesticable plant and animal species, would enhance population density via trade and the implementation and diffusion of agricultural technologies.

Consistent with the predictions of the Malthusian theory, statistically significant positive effects of land productivity and an earlier onset of the Neolithic Revolution are uncovered for population density in the years 1500 CE, 1000 CE and 1 CE. These results are shown to remain robust to controls for other geographical factors such as absolute latitude and access to waterways, which historically played a major role in facilitating trade and technological diffusion, and to biogeographic instrumental variables, employed to establish causality. Moreover, in accordance with the Malthusian prediction of conditional convergence, the empirical findings also reveal statistically significant negative effects of initial population density on the average rate of population growth in the 1-1000 CE and the 1000-1500 CE time horizons, conditional on land productivity and time elapsed since the Neolithic Revolution. Finally, the empirical evidence appears to support the assertion that the social gains from the process of development initiated by the Neolithic Revolution were characterized by diminishing returns over time. Consistent with this assertion, the findings reveal that societies were successfully gravitating towards a limiting conditional Malthusian steady state over the years 1-1500 CE.

Data Appendix

Population Density in 1, 1000, and 1500 CE: Population density in a given year is calculated as population in that year, as reported by McEvedy and Jones (1978), divided by land area, as reported by the World Development Indicators online database. The cross-sectional unit of observation in McEvedy and Jones (1978) is a region delineated by its international borders in 1975. Historical population estimates are provided for regions corresponding to either individual countries or, in some cases, to sets comprised of 2-3 neighboring countries (e.g., India, Pakistan and Bangladesh). In the latter case, a set-specific population density figure is calculated based on total land area and the figure is then assigned to each of the component countries in the set. The same methodology is also employed to obtain population density for countries that exist today but were part of a larger political unit (e.g., the former Yugoslavia) in 1975.

Population Growth Rate, 1-1000 CE and 1000-1500 CE: The average rate of population growth in a given time interval is calculated as the percentage increase in population between the starting and ending years of the time interval, using the population density data described above.

Years since Neolithic Transition: The time elapsed (in thousands of years) since the Neolithic transition to agriculture, as reported by Putterman (2006).

Land Productivity: Land productivity is calculated as the first principal component of the arable percentage of land, as reported by the World Development Indicators database, and an agricultural suitability index of land, based on soil pH levels and temperature, as reported by Michalopoulos (2008). The variation in land productivity captures 78% of the combined variation in the two variables. The variable labelled as log land productivity in tables reporting regression results is the first principal component of the logs of the aforementioned variables, capturing 83% of their combined variation.

Absolute Latitude: The absolute value of the latitude of a country's centroid, as reported by the CIA World Factbook available online.

Mean Distance to Nearest Coast or River: The expected distance (in thousands of km) from any GIS grid point within a country to the nearest ice-free coastline or sea-navigable river, as reported in the physical geography dataset available online from the Center for International Development.

Land within 100 km of Coast or River: The percentage of a country's land area located within 100 km of the nearest ice-free coastline or sea-navigable river, as reported in the physical geography dataset available online from the Center for International Development.

Plants and Animals (used as instruments for Years since Transition): The number of domesticable species of plants and animals, respectively, that were prehistorically native to the continent or landmass to which a country belongs. These variables are obtained from the dataset of Olsson and Hibbs (2005).

	Obs.	Mean	Std. Dev.	Min.	Max.
Log Population Density in 1500 CE	148	0.88	1.49	-3.82	3.84
Log Population Density in 1000 CE	143	0.46	1.44	-4.51	2.99
Log Population Density in 1 CE	128	-0.07	1.54	-4.51	3.17
Log Years since Neolithic Transition	148	8.34	0.59	5.99	9.26
Log Land Productivity	148	0.07	1.21	-4.34	1.66
Log Absolute Latitude	148	2.99	0.97	-0.69	4.16
Mean Distance to Coast or River	147	0.35	0.46	0.01	2.39
Land w/in 100 km of Coast or River	147	0.44	0.37	0.00	1.00

Table A1: Summary Statistics of the Sample used in Density Regressions

	Obs.	Mean	Std. Dev.	Min.	Max.
Population Growth 1000-1500 CE	143	0.78	0.71	-0.50	4.00
Population Growth 1-1000 CE	128	1.30	2.08	-0.50	14.00
Population Density in 1000 CE	143	3.57	4.33	0.01	19.87
Population Density in 1 CE	128	2.54	3.66	0.01	23.80
Years since Neolithic Transition	143	4.96	2.42	0.40	10.50
Land Productivity	143	0.06	1.25	-1.83	3.39
Absolute Latitude	143	27.05	16.76	0.50	62.00
Mean Distance to Coast or River	142	0.36	0.46	0.01	2.39
Land w/in 100 km of Coast or River	142	0.44	0.37	0.00	1.00

Table A2: Summary Statistics of the Sample used in Growth Regressions

	1	2	3	4	5	6	7	8
Log Population Density in 1500 CE	1.00							
Log Population Density in 1000 CE	0.96	1.00						
Log Population Density in 1 CE	0.88	0.94	1.00					
Log Years since Neolithic Transition	0.51	0.57	0.65	1.00				
Log Land Productivity	0.52	0.43	0.39	0.00	1.00			
Log Absolute Latitude	0.11	0.10	0.30	0.32	0.13	1.00		
Mean Distance to Coast or River	-0.31	-0.34	-0.38	-0.03	-0.23	-0.06	1.00	
Land w/in 100 km of Coast or River	0.39	0.37	0.40	0.12	0.33	0.26	-0.67	1.00

Table A3: Pairwise Correlations in the Sample used in Density Regressions

	1	2	3	4	5	6	7	8	9
Population Growth 1000-1500 CE	1.00								
Population Growth 1-1000 CE	0.22	1.00							
Population Density in 1000 CE	-0.04	0.12	1.00						
Population Density in 1 CE	-0.08	-0.28	0.78	1.00					
Years since Neolithic Transition	-0.18	-0.28	0.43	0.61	1.00				
Land Productivity	0.26	0.04	0.50	0.37	0.08	1.00			
Absolute Latitude	0.24	-0.18	0.24	0.33	0.47	0.23	1.00		
Mean Distance to Coast or River	-0.10	-0.02	-0.23	-0.26	-0.05	-0.38	0.02	1.00	
Land w/in 100 km of Coast or River	0.21	0.02	0.29	0.31	0.14	0.51	0.26	-0.67	1.00

Table A4: Pairwise Correlations in the Sample used in Growth Regressions

References

[1] ASHRAF, Q., and O. GALOR (2007): "Cultural Assimilation, Cultural Diffusion and the Origin of the Wealth of Nations," Working Paper, Brown University.

[2] BOSERUP, E. (1965): *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*. Allen & Unwin, London, UK.

[3] CRAFTS, N., and T. C. MILLS (2008): "From Malthus to Solow: How did the Malthusian Economy Really Evolve?," *Journal of Macroeconomics* (forthcoming).

[4] CLARK, G. (2005): "The Condition of the Working Class in England, 1209-2004," *Journal of Political Economy*, 113(6), 1307–1340.

[5] DIAMOND, J. (1997): *Guns, Germs and Steel: The Fates of Human Societies*. W. W. Norton & Co., New York, NY.

[6] DOEPKE, M. (2004): "Accounting for Fertility Decline During the Transition to Growth," *Journal of Economic Growth*, 9(3), 347–383.

[7] FERNÁNDEZ-VILLAVERDE, J. (2005): "Was Malthus Right? Economic Growth and Population Dynamics," Working Paper, University of Pennsylvania.

[8] GALOR, O. (2005): "From Stagnation to Growth: Unified Growth Theory," in *Handbook of Economic Growth*, Vol IA, ed. by P. Aghion, and S. N. Durlauf. Elsevier North-Holland, Amsterdam, The Netherlands.

[9] GALOR, O., and S. MICHALOPOULOS (2006): "The Evolution of Entrepreneurial Spirit and the Process of Development," Working Paper, Brown University.

[10] GALOR, O., and O. MOAV (2002): "Natural Selection and the Origin of Economic Growth," *Quarterly Journal of Economics*, 117(4), 1133–1191.

[11] GALOR, O., and A. MOUNTFORD (2006): "Trade and the Great Divergence: The Family Connection," *American Economic Review*, 96(2), 299–303.

[12] GALOR, O., and A. MOUNTFORD (2008): "Trading Population for Productivity: Theory and Evidence," Working Paper, Brown University.

[13] GALOR, O., and D. N. WEIL (1999): "From Malthusian Stagnation to Modern Growth," *American Economic Review*, 89(2), 150–154.

[14] GALOR, O., and D. N. WEIL (2000): "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90(4), 806–828.

[15] HANSEN, G. D., and E. C. PRESCOTT (2002): "Malthus to Solow," *American Economic Review*, 92(4), 1205–1217.

[16] JONES, C. I., (2001): "Was an Industrial Revolution Inevitable? Economic Growth Over the Very Long Run," *Advances in Macroeconomics*, 1(2), 1–43.

[17] KREMER, M. (1993): "Population Growth and Technological Change: One Million B.C. to 1990," *Quarterly Journal of Economics*, 108(3), 681–716.

[18] LAGERLÖF, N.-P. (2003): "From Malthus to Modern Growth: Can Epidemics Explain the Three Regimes?," *International Economic Review*, 44(2), 755–777.

[19] LAGERLÖF, N.-P. (2006): "The Galor-Weil Model Revisited: A Quantitative Exercise," *Review of Economic Dynamics*, 9(1), 116–142.

[20] LEE, R. D. (1997): "Population Dynamics: Equilibrium, Disequilibrium, and Consequences of Fluctuations," in *Handbook of Population and Family Economics*, Vol IB, ed. by M. R. Rosenzweig, and O. Stark. Elsevier North-Holland, Amsterdam, The Netherlands.

[21] LUCAS, Jr., R. E. (2002): "The Industrial Revolution: Past and Future," in *Lectures on Economic Growth*, ed. by R. E. Lucas, Jr. Harvard University Press, Cambridge, MA.

[22] MADDISON, A. (2001): *The World Economy: A Millennial Perspective*. OECD, Paris.

[23] MADDISON, A. (2003): *The World Economy: Historical Statistics*. CD-ROM. OECD, Paris.

[24] MALTHUS, T. R. (1798): *An Essay on the Principle of Population*. J. Johnson, in St. Paul's Church-Yard, London, UK.

[25] McEVEDY, C., and R. JONES (1978): *Atlas of World Population History*. Penguin Books Ltd., New York, NY.

[26] MICHALOPOULOS, S. (2008): "Ethnolinguistic Diversity: Origins and Implications," Mimeo, Brown University.

[27] MOKYR, J. (1985): *Why Ireland Starved: A Quantitative and Analytical History of the Irish Economy, 1800-1850*. Allen & Unwin, London, UK.

[28] OLSSON, O., and D. A. HIBBS, Jr. (2005): "Biogeography and Long-Run Economic Development," *European Economic Review*, 49(4), 909–938.

[29] O'ROURKE, K. H., and J. G. WILLIAMSON (2005): "From Malthus to Ohlin: Trade, Industrialisation and Distribution Since 1500," *Journal of Economic Growth*, 10(1), 5–34.

[30] PUTTERMAN, L. (2006): "Agriculture, Diffusion, and Development: Ripple Effects of the Neolithic Revolution," Working Paper, Brown University.

[31] SMITH, A. (1776): *An Inquiry into the Nature and Causes of the Wealth of Nations.* ed. by E. Cannan, 1904. Methuen & Co., Ltd., London, UK.

[32] VOIGTLÄNDER, N., and H.-J. VOTH (2006): "Why England? Demographic Factors, Structural Change and Physical Capital Accumulation During the Industrial Revolution," *Journal of Economic Growth*, 11(4), 319–361.

[33] WEISDORF, J. L. (2005): "From Foraging To Farming: Explaining The Neolithic Revolution," *Journal of Economic Surveys*, 19(4), 561–586.

[34] WRIGLEY, E. A., and R. S. SCHOFIELD (1981): *The Population History of England 1541–1871: A Reconstruction*. Cambridge University Press, Cambridge, UK.