Unfavorable Land Endowment, Cooperation, and Reversal of Fortunes[*]

Anastasia Litina[†]

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Abstract

This research advances the hypothesis that reversal of fortunes in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector. In early stages of development, unfavorable land endowment enhanced the economic incentive for cooperation in the creation of agricultural infrastructure that could mitigate the adverse effect of the natural environment. Nevertheless, despite the beneficial effects of cooperation on the intensive margin of agriculture, low land productivity countries lagged behind during the agricultural stage of development. However, as cooperation, and its persistent effect on social capital, have become increasingly important in the process of urbanization and industrialization, the transition from agriculture to industry among unfavorable land endowment economies was expedited, permitting those economies that lagged behind in the agricultural stage of development, to overtake the high land productivity economies in the industrial stage of development. Exploiting exogenous sources of variations in land productivity across countries the research further explores the testable predictions of the theory. It establishes that: (i) a reversal of fortunes in the process of development can be traced to variation in land productivity across countries. Economies characterized by favorable land endowment dominated the world economy in the agricultural stage of development but were overtaken in the process of industrialization; (ii) cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could diminish the adverse effects of the environment and enhance agricultural output; (iii) lower level of land productivity in the past is associated with higher levels of contemporary social capital.

Keywords: Land productivity, Cooperation, Social Capital, Economic development, Agriculture, Industrialization

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[†] University of Luxembourg, Faculty of Law, Economics and Finance, 162a, Avenue de la Faiencerie, L - 1511 Luxembourg (e-mail: anastasia.litina@uni.lu)

1 Introduction

The origins of the remarkable transformation of the world income distribution in the past two centuries have been the focus of an intense debate in recent years. The long shadow of history on comparative economic development has been established empirically, underlying the role of variations in historical and pre-historical bio-geographical conditions, as well as the persistence effects of cultural, institutional, and human capital characteristics, in the vast inequality across the globe.

This research advances the hypothesis that reversal of fortunes in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector. In early stages of development, unfavorable land endowment enhanced the economic incentive for cooperation in the creation of agricultural infrastructure that could mitigate the adverse effect of the natural environment. Nevertheless, despite the beneficial effects of cooperation on the intensive margin of agriculture, low land productivity countries lagged behind during the agricultural stage of development. However, as cooperation, and its persistent effect on social capital, have become increasingly important in the process of urbanization and industrialization, the transition from agriculture to industry among unfavorable land endowment economies was expedited, permitting those economies that lagged behind in the agricultural stage of development, to overtake the high land productivity economies in the industrial stage of development.

The fundamental hypothesis of this research originates from the realization that the evolution of the wealth of nations has been driven in part by the trade-off between land productivity and the associated level of cooperation and social capital, in different stages of development. Social capital emerged initially as the outcome of cooperation in the agricultural sector in an effort to further enhance natural land productivity. However, cooperation in the agricultural sector was not only crucial for the development of agricultural infrastructure per se. It contributed to the emergence of social capital that has complemented the industrial sector and thus accelerated the transition from agriculture to industry.

This research suggests, therefore, that some of the observed differences in the patterns of economic development across the globe can be traced to variations in the level of cooperation and social capital, originating from differences in natural land endowment. Places with favorable natural land endowment had a reduced incentive to cooperate for the development of agricultural infrastructure. While their favorable land endowment allowed them to dominate during the agricultural era, their lower incentive for cooperation resulted in a lower level of social capital which was crucial for the development of the industrial sector. Consequently, lacking some of the necessary elements for the emergence of industrialization, they were overtaken in the transition to the industrialization era. Correspondingly, poorly endowed countries cooperated more intensely in the creation of agricultural infrastructure that could mitigate the adverse effect of low land productivity. Nevertheless, despite their efforts, they lagged behind during the agricultural stage of development due to unfavorable land endowment. The intense cooperation though, generated higher level of social capital, which ultimately allowed faster industrialization and overtaking of the high land productivity economies in the industrial stage of development.

The theory is based on an underlying mechanism comprising four phases that account for the differential development of economies and their asymmetric transition from an epoch of Malthusian stagnation to a regime of sustained economic growth. Throughout this process, natural land endowments generate differences in income per-capita, either directly through agricultural productivity or indirectly through the emergence of social capital, accounting for reversals in economic performance.

The first phase of the underlying mechanism pertains to the role of natural land endowment in generating the desirable level of cooperation in the creation of agricultural infrastructure, that could mitigate the adverse effect of the natural environment. Interventions in the agricultural sector, aiming at enhancing land productivity, require an increased amount of inputs. The need for resources committed in the production of agricultural infrastructure, implies a trade-off between the resources allocated in the production of the public good and the agricultural good. Therefore, the decision to allocate resources in the production of agricultural infrastructure hinges upon two crucial recognitions. The first is that intense investment in infrastructure is increasingly beneficial in places with unfavorable land productivity endowment. Unambiguously, places with favorable land endowment can as well benefit from investing in agricultural infrastructure, however if the decision to allocate more resources in the production of the agricultural good pays off more, they might find it optimal to invest less in infrastructure. The second recognition is, that despite the fact that individuals can certainly benefit from the development of infrastructure, it is not to their interest to commit to its production individually, unless it is the outcome of collective action that could eliminate free-riding incentives. Therefore, for the optimal level of public good to be produced, cooperation and collective action is a necessary element.[1]

Traditionally used forms of agricultural infrastructure include, among others, irrigation systems, storage facilities and drainage systems. In Egypt and Mesopotamia (4000 years ago), the so-called "passive" or "surface" irrigation was used, which exploited the annual flooding of the Nile (Adams, 1965; Butzer, 1976). In China (2000 years ago), "surface" irrigation was used, and in addition, canals were built to funnel larger volumes of water to more distant fields. In Western Europe, the first large-scale irrigation was developed by the Romans, who built aqueducts to channel water from the mountains exploiting gravity. They also built reservoirs to store the channelled water.[2] Finally, major advances in public-water systems since the Renaissance have involved the refinement of pumps and of pipe materials (Wittfogel, 1956).[3]

Other forms of intervention to enhance land productivity, entail drainage and storage infrastructure. Ancient civilizations like the Egyptians, the Greeks, and the Chinese constructed well-planned drainage systems. In later time periods, the Romans developed sophisticated drainage systems, and they were the only civilization in all of western Asia and Europe, from antiquity to the 1800s, to expand drainage infrastructure to an urban setting, by building a carefully planned

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[1] Since infrastructure is subject to economies of scale, collective action among members of a community to build communal facilities, entails large efficiency gains (Stead, 2004).

[2] Roman aqueducts were built throughout the empire, and their arches may still be seen in Greece, Italy, France, Spain, North Africa, and Asia Minor. Although the Romans are considered the greatest aqueduct builders of the ancient world, quanta systems were in use in ancient Persia, India, Egypt, and other Middle Eastern countries, hundreds of years earlier.

[3] By the late 16th century, London had a system that used five waterwheel pumps, fastened under the London Bridge to supply the city, and Paris, had a similar device at Pont Neuf, that was capable of delivering 120 gallons (454 liters) per minute.

road system with properly drained surfaces (Hill, 1984). In England, land drainage to re-claim areas adjoining the North Sea, began in the tenth century, and by the late eighteenth and nineteenth centuries, most available land had already been reclaimed by surface draining of lakes, marshes and fens. The Dutch began converting land by draining and diking around 1550. Russia inaugurated drainage works in 1710 to make St. Petersburg habitable. Similarly, much of the United States was not habitable or capable of agricultural production in its pre-development condition. Drainage in the United States occurred in two primary developmental periods, during 1870-1920 and during 1945-1960.[4] Storage technologies were also widespread.[5] Crucially, all major forms of intervention required a large-scale cooperation at the community or at the state level, and particularly in early societies, collective action and broad participation was required to undertake and construct the necessary infrastructure.[6]

The second phase of the mechanism advances the hypothesis that the emergence of social capital can be traced to the level of cooperation developed in the agricultural sector for the creation of infrastructure, that could mitigate the adverse effect of the natural environment. According to the *Social Structural Approach*, individuals exhibit different levels and types of social capital, depending on the social interactions in which they are engaged to (Bowles and Gintis, 2002). According to Henrich et al. (2001) "In situations in which large-scale cooperation increases fitness, norms that facilitate fruitful interaction (such as norms of mutual trust), will be particularly valuable and will become prevalent."[7] Putnam (2000) highlighted that social capital calls attention to the fact that civic virtue is most powerful when embedded in a network of reciprocal social relations.[8] Large scale cooperation in countries with low land productivity, in an effort to intervene in the intensive margin of agriculture and develop agricultural infrastructure, had a persistent effect on social capital that would ultimately become crucial in the process of industrialization.

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[4] Individual attempts were made prior to 1870. The first known colony-wide drainage law was enacted in New Jersey in 1772. The City of New Orleans drainage outlet, was constructed around 1794. Patterns for molding the first subsurface drains in the United States, were recorded as imported from Scotland in 1835. An estimated 110 million acres of agricultural land in the United States, benefited from artificial drainage as of 1985. At least 70 percent of this drained land is in crops, 12 percent in pasture, 16 percent in woodland, and 2 percent in miscellaneous uses.

[5] With respect to the English agriculture before industrialization, collective action among members of the local community to build communal storage facilities, was often practiced (Stead, 2004). The role of collective storage facilities in coping with climatic conditions has been argued to be crucial on the grain banks (magasins) in 18th and 19th century Swedish parishes (Berg, 2007).

[6] Natural experiments that took place in recent years in developing countries. Bardhan (2000) for communities in rural India, Uphoff and Wijayaratna (2000) for Sri-Lanka, and Ostrom (2000) for Nepal, found evidence that after the development of irrigation infrastructure, the average yearly production for a bad year exceeded the average yearly production of a good year prior to the usage of irrigation. In all cases large scale cooperation at the community level was developed, thereby strengthening the communal ties.

[7] In the context of a cross-cultural study, Henrich et al. (2001) conducted ultimatum, public good, and dictator game experiments, with subjects from fifteen small-scale societies, exhibiting a wide variety of economic and cultural conditions. They find that, in societies where the payoff from extra-familial cooperation in economic activity is higher, subjects display significantly higher levels of cooperation in the experimental games. The authors argue that one interpretation of this result is that subjects' behavior in the experiments, reflects different norms of conduct with regard to sharing and cooperation, which, in turn, are shaped by the structures of social interaction, and modes of livelihood of the community daily life.

[8] Putnam et al. (1993) in his influential study about social capital studied the cases of Northern and Southern Italy. He argues that in Northern Italy where the structure of the society was more civic, a higher level of social capital was experienced which ultimately led to higher economic prosperity. Regions in Southern Italy were faced with a more hierarchical structure which resulted in underdevelopment of social capital that eventually led to inferior economic outcomes.

The third phase of the mechanism, relies on various transmission mechanisms, that allowed social capital to persist and be transmitted over time within societies. The need to cooperate in the agricultural sector, in order to develop the infrastructure necessary to mitigate the adverse effect of unfavorable land endowment, generated norms of mutual trust and cooperation, and allowed the emergence of social capital. Via different transmission mechanisms, social capital persisted and was transmitted over time.

Evolutionary theories, advance the "social learning" hypothesis, according to which the norms that are adopted, are determined through an evolutionary process, based on which norms yield the highest payoff in terms of survival probabilities (Boyd and Richerson, 1985, 1995). Alternative evolutionary theories, explore the role of "cultural transmission”, where socialization processes, such as social imitation and learning, result in the transmission of cultural traits across time (Bisin and Verdier, 2001).[9] Growing evidence suggests, that in fact trust and social capital, like other cultural traits, can persist for surprisingly long periods of time, primarily due to intergenerational transmission operating through genetics, imitation, or deliberate inculcation by parents.[10]

The fourth phase of the mechanism, is designed to capture the importance of social capital in promoting socioeconomic transitions to an industrialized regime. Evidence suggests, that economic activities such as commercial transactions, entrepreneurship, innovation, accumulation of human capital, credit markets and enforcement of contracts, all of which are building blocks of the industrial sector, are further enhanced and boosted in societies with high levels of social capital and trust.[11] Societies that were initially faced with unfavorable land endowments, and therefore cooperated more intensely in the agricultural sector to develop the infrastructure necessary to mitigate the adverse effect of low land productivity, naturally accumulated and transmitted higher levels of social capital across time. Given the complementarity of social capital with the emergence and the operation of the industrial sector, these countries industrialized first, thereby attaining better economic outcomes in the industrialization era. Countries with more favorable natural land endowment, had a reduced incentive to cooperate for the development of agricultural infrastructure. Limited cooperation

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[9] At the national and sub-national levels, for example, trust scores are remarkably stable over several decades (Bjornskov, 2007).

[10] Recent empirical findings document the existence of a strong correlation in the propensity to trust between parents and children (Katz and Rotter, 1969; Dohmen et al., 2011) and between second-generation immigrants and current inhabitants of the country of origin (Uslaner, 2002; Guiso et al., 2006; Algan and Cahuc, 2010).

In a recent study on the effect of culture on economic development across European regions, Tabellini (2008) finds that early political institutions have a significant impact on current trust attitudes. Regions that centuries ago had more checks and balances on the executive, are currently characterized by higher levels of trust. Guiso et al. (2008) trace current differences in social capital between the North and South of Italy, to the culture of independence fostered by the experience of the free city-states in the Middle Ages, and conclude that “at least 50% of the North- South gap in social capital is due to the lack of a free city state experience in the South”. Nunn and Wantchekon (2010) investigate the impact of the transatlantic slave trade on mistrust in contemporary Africa, finding robust evidence that “individuals whose ancestors were heavily raided during the slave trade today exhibit less trust in neighbors, relatives, and their local government”.

[11] As Arrow (1972) put it: "Virtually every commercial transaction has within itself an element of trust, certainly any transaction conducted over a period of time. It can be plausibly argued that much of the economic backwardness in the world can be explained by the lack of mutual confidence". Knack and Keefer (1997) argue that trust and civic cooperation are associated with stronger economic performance (better enforcement of contracts, innovation, credit markets, human capital accumulation). Putnam (2000) advances the hypothesis that networks of mutual obligation may encourage entrepreneurship, whereas Greif (1993) provides evidence that large networks make it more likely for a potential entrepreneur to mobilize resources to start a new enterprise and find the necessary suppliers, customers, and employees.

resulted in a lower level of accumulated and transmitted social capital, and eventually diminished the necessary elements for the emergence of an early industrialization.

The proposed mechanism is aimed to identify the intermediate phases that can account for the effect of natural land endowment on the evolution of economies, and their transition from agriculture to industry. What can be viewed initially as a drawback in economic development, namely the adverse effect of unfavorable land endowment on agricultural production, triggers a process that can ultimately lead to a reversal of fortunes with respect to economic outcomes. Low land productivity countries had an incentive to cooperate more intensely in the creation of agricultural infrastructure and the outcome of this effort, may have been initially insufficient to allow them to achieve better economic outcomes compared to highly productive places. Nevertheless, it generated a level of social capital that was sufficiently high to accelerate transition to industrialization. Critical element in this process, was the emergence of social capital as the outcome of cooperation, and its transmission across time that ultimately allowed countries to industrialize faster due to its complementarity with the industrial sector.

At early stages of development, the economy is in a Malthusian regime, where output is generated exclusively by an agricultural sector that is subject to decreasing returns to labor. Aggregate productivity in the agricultural sector, is partly determined by natural land endowments, and can be further enhanced by building up agricultural infrastructure. A fraction of the labor employed in the agricultural sector is occupied in the production of the private good, whereas the remaining fraction is occupied in the production of agricultural infrastructure aimed to enhance land productivity. Therefore, technological progress is rather gradual, and occurs via relatively small increments to the economy's stock of knowledge, which is positively affected by the size of the workforce in the agricultural sector, and by the direct effect of the infrastructure on the agricultural sector. Resources generated by technological progress, are channeled primarily towards an increase in population size, and the economy evolves along a dynamic path, characterized by growing population and total factor productivity, towards a Malthusian equilibrium where income per capita remains stagnant.

The transition from agriculture to industry in the process of development, is driven by sustained growth in the latent productivity of the industrial sector. The indirect effect of cooperation on the industrial sector, through the accumulation of social capital, drives growth in the latent industrial productivity, which ultimately leads to the transition to industry in later stages of development. Upon the adoption of industry, the economy emerges into a Post-Malthusian regime of development, where output is generated using both the agricultural and the industrial production technology. The endogenous growth of total factor productivity in industry, coupled with intersectoral labor mobility, sustains a dynamic path characterized by endogenously growing population and income per capita.

The interaction between natural land productivity, cooperation, social capital and the process of development is examined based on the significance of their coevolution in the agricultural stage of development and, also, in the timing of the take-off from agriculture to industry. In the agricultural stage, an economy characterized by a relatively higher degree of cooperation in the development of agricultural infrastructure, aimed to mitigate the adverse effect of low land productivity, is associated with a relatively inferior Malthusian steady state in terms of the economy's level of productivity per worker and the size of its working population. This inferiority, stems from the fact that the adverse effect of unfavorable land endowments is significant in the context of an economy that operates only in the agricultural sector, and therefore natural land endowments are crucial for agricultural output.

The resulting level of cooperation in the agricultural sector, as triggered by natural land productivity conditions, however, also has an effect on the timing of industrialization and, thus, on the take-off to a state of sustained economic growth. The earlier take-off from the Malthusian steady state by a society with an unfavorable natural land endowment, stems from the fact that the beneficial effect of cooperation in the agricultural sector, as perceived by the effect of the emerging social capital on the advancement of knowledge, and, therefore, on the advancement of industrial productivity relative to that in agriculture, outweighs the adverse effect of unfavorable land endowment on agricultural production.

A high level of social capital within societies, is thus associated with the phenomenon of overtaking in global economic development. Unfavorable land endowment, that generates intense cooperation in the agricultural sector, and eventually a higher level of social capital, may generate an inferior outcome in the agricultural stage of development, but it ultimately stimulates an earlier industrialization and, thus, an earlier take-off to a state of sustained economic growth. As such, natural land productivity conditions of agricultural societies can have a profound effect on their historical experience with regard to the process of economic development.

Exploiting exogenous sources of variations in land productivity across countries, the research further explores the testable predictions of the theory: (i) a reversal of fortunes in the process of development can be traced to variation in land productivity across countries. Economies characterized by favorable land endowment dominated the world economy in the agricultural stage of development but were overtaken in the process of industrialization; (ii) cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could diminish the adverse effects of the environment and enhance agricultural output; (iii) lower level of land productivity in the past is associated with higher levels of contemporary social capital.

Consistent with the predictions of the theory, the empirical analysis establishes that a "reversal of fortune" in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector. Low land productivity is associated with inferior economic outcomes in pre-industrial periods; however it generates more intense cooperation in the creation of agricultural infrastructure, which in turn results to higher levels of trust and social capital that persist across time, allowing these economies to achieve better current economic outcomes.

The hypothesis rests upon two fundamental building blocks. First, variations in natural land endowment led to variations in cooperation in the agricultural sector, for the development of infrastructure that could mitigate the adverse effect of the natural environment. Following this hypothesis it is postulated that countries that were faced with unfavorable land endowment cooperated more intensely in the development of infrastructure in the agricultural sector, in an effort to enhance land productivity, as opposed to countries with more favorable land endowment, that had a reduced incentive to allocate labor and cooperate in the production of the agricultural public good. The second is that intense cooperation in the agricultural sector generated higher levels of social capital, that persisted and was transmitted across time. Countries with unfavorable land endowment manifest higher levels of social capital and trust today, with trust being a crucial element of social capital.

The examination of comparative development at agricultural stages of development employs a Malthusian perspective, thereby assuming that temporary gains in income per capita were reflected to a larger but not richer population. Hence, as a proxy for prosperity in the agricultural stage of development, the research employs historical data on population density as opposed to income per capita and examines the hypothesized effect of land productivity on population densities in years 1, 1000 and 1500. As a proxy for land productivity, a measure is employed that is an index of the average suitability of land for cultivation, based on geospatial data on various ecological factors including (i) growing degree days, (ii) the ratio of potential to actual evapotranspiration, (iii) soil carbon density, and (iv) soil pH.[12]

The historical analysis reveals a negative relationship between log land productivity on log population density in the year 1500. In particular accounting for a number of geographical characteristics that could potentially affect population density in the year 1500, the timing of the Neolithic revolution, distance from technological frontier in the year 1500 as well as regional characteristics, the estimated linear coefficients associated with log land productivity, imply that a 1 percentage point increase in land productivity would increase population density by 0.43%.

To establish a "reversal of fortune" with respect to natural land endowments, the analysis employs cross country variations in land productivity, to explain the cross-country variation in log income per capita in 2000. A number of potentially confounding factors and alternative hypothesis suggested by the related literature, with respect to comparative development, are accounted for. The geography channel is controlled through a number of geographical controls that may affect economic outcomes today. The institutions hypothesis, that implies a "reversal of fortune" arising from the impact of European colonization, is accounted for through a number of controls including legal origins dummies, institutional quality controls as well as population density in the year 1500 therefore controlling for the channel suggested by Acemoglu et al. (2001). Further controls about disease environment, ethnic fractionalization and religion shares are employed. Crucially, as this research argues, it is not land productivity per se that drives the reversal of fortunes but instead what is important the portable component associated with land productivity, namely the level of cooperation developed and the social capital that emerged as the outcome of cooperation. Therefore two alternative strategies are adopted. Either the land productivity measure is adjusted to capture the portable component of natural land endowment, namely social capital, or the sample is restricted to countries with a percentage of native population above 75%. The adjustment of the land productivity index is based on the use of the migration matrix constructed by Putterman and Weil (2010), which provides estimates of the proportion of the ancestors in 1500 of one country's population today that were living within what are now the borders of that and each of the other countries. Therefore a measure of adjusted land productivity is constructed, that is the weighted average of the land productivity of the ancestral population of each country today. The variable of the percentage of

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[12] The index is based on geospatial soil pH and temperature data, as reported by Ramankutty et al. (2002) and aggregated to the country level by Michalopoulos (2011). The average of land quality is thus the average value of the index across the grid cells within a country.

native population is constructed by (Ashraf and Galor, 2011a), based on the migration matrix of Putterman and Weil (2010). In this case the approach is simpler, limiting the sample to countries that have a percentage of native population above 75%, thereby implying that the social capital that has been accumulated in the past, is still a prevalent norm among the native population.

The results from the contemporary analysis reveal a positive relationship between log adjusted land productivity and log income per capita in the year 2000. Once controlling for a number of factors, it is shown that a 1 percentage point increase in land productivity can account for a 0.27% decrease in income per capita for the unrestricted sample. Reassuringly, the highly significant and positive effect of land productivity on income per capita, persists when the analysis is conducted using the original measure for land productivity while controlling for native population being above 75%, thereby implying that the native population being the vast majority in the country carries the traits of cooperation and social capital. In the restricted sample it is shown that a 1 percentage point increase in land productivity can account for a 0.21% decrease in income per capita.

As already mentioned, the main hypothesis relies on two building blocks that must be empirically established. The first building block suggests that variations in land productivity led to variations in the level of cooperation developed in the agricultural sector, in an attempt to enhance land productivity. To capture the extent of cooperation in the agricultural sector, data on agricultural infrastructure are used as a proxy. Data about agricultural infrastructure in years prior industrialization are difficult to be constructed in a way symmetric across countries, both due to lack of data and to the fact that different forms of interventions have been historically used across countries. To address this issue the study employs data related to a major form of agricultural infrastructure, that has been commonly used in pre-industrial era, as a proxy for the level of cooperation in agricultural societies, namely the fraction of irrigated land. The primary measure that is used for cooperation in the agricultural sector is the fraction of irrigated land over the fraction of arable land in the year 1900.

The fact that data on irrigation come from year 1900 raises two potential issues. The first issue is that in the year 1900, a number of countries in the sample had already industrialized. Therefore upon industrialization and the acceleration of industrial technical progress, it is likely that agricultural infrastructure, such as irrigation, was affected as well and it would be plausible to assume that the early industrialized countries further expanded their irrigation infrastructure. In this case, what would be reflected in this empirical relationship is the effect of the stage of economic development on the expansion of irrigation. Therefore, to ensure that irrigation in the year 1900 does not reflect the stage of economic development the sample excludes countries that were members of the OECD in 1985. The choice of countries that were member of the OECD in the year 1985, despite the fact that it refers to a later date than the one under examination, i.e. irrigation in the year 1900, it captures though the countries that experienced an early transition to industrialization.

The second limitation stems from the fact that since the irrigation data are dated from the year 1900, where migration had already taken place in a number of countries, it could be argued that it is not the land productivity per se that affects the emergence of irrigation, but also some portable component associated with land productivity. If migrants carry with them the specific human and social capital associated with the development of an irrigation system, this could imply that a higher fraction of irrigated land would emerge in countries with migrants possessing this specific human capital. This argument could be countered by arguing that what this regression is aiming to capture, is the trade-off in the allocation of resources between the production of the final and the public good. Even if a group of migrants have the necessary human and social capital for the development of agricultural infrastructure, they would still have a reduced incentive to invest in infrastructure as opposed to countries with more favorable natural land endowment. Nevertheless, this particular channel is controlled in the analysis by restricting the sample of countries to the ones with a percentage of native population higher than 75%, following the same rational with the effect of land productivity on economic outcomes in the year 2000.

Consistently with the predictions of the theory, the regression of the fraction of irrigated land on land productivity establishes, that countries with unfavorable land endowment had an increased incentive to invest in agricultural infrastructure, in an effort to enhance land productivity. In particular, the analysis reveals a statistically significant and robust negative effect of the log land productivity on the fraction of irrigated land in 1900, with the coefficient implying that a 1% increase in land productivity would be associated with a 0.36% decrease in the fraction of irrigated land.

To overcome data limitations, additional measures are used as proxies for cooperation, namely: a) Communication in the year, 1 b) Transportation in the year 1, c) Medium of Exchange in the year 1.[13] The underlying assumption justifying the use of these measures is that they can be viewed as by-products of cooperation in the development of agricultural infrastructure. Agricultural societies that invested time and labor force to intervene in the intensive margin of agriculture, as a means to enhance land productivity, are the most likely candidates to have developed sophisticated means of communication and move gradually to non-mnemonic records and ultimately to written records, as the outcome of large-scale cooperation. The indirect effects of cooperation can be even more clearly indicated in the context of transportation, whereby a transition from human transportation to draft or pack animals and ultimately to vehicles could significantly facilitate the development of agricultural infrastructure. Given the resources needed to undertake an investment of this magnitude, it would be plausible to assume that more sophisticated mediums of exchange, namely domestically used articles and currency, would emerge in places that had an increase incentive to develop agricultural infrastructure. Reassuringly, adverse land productivity has a positive effect on the development of more sophisticated communication methods, transportation means and mediums of exchange in the year 1, a result robust to a number of geographical controls, distance from the nearest technological frontier in the year 1 and years since Neolithic transition.

Finally, the last building block pertains to the persistence of social capital across time. It is hypothesized that countries with unfavorable land endowment manifest higher levels of social capital and trust today. When data for current levels of trust, being a crucial element of social

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[13] Each of these three sectors is reported on a 3-point scale. In the communications sector, the index is assigned a value of 0 under the absence of both true writing and mnemonic or non-written records, a value of 1 under the presence of only mnemonic or non-written records, and a value of 2 under the presence of both. In the transportation sector, the index is assigned a value of 0 under the absence of both vehicles and pack or draft animals, a value of 1 under the presence of only pack or draft animals, and a value of 2 under the presence of both. In the Medium of Exchange sector, the index is assigned a value of 0 under the absence of domestically used articles and currency, a value of one under the presence of only domestically used articles and the value of 2 under the presence of both.

capital, are regressed on adjusted land productivity[14], evidence suggests a highly significant positive relationship, even when controlling for a number of factors such as geographical factor, institutions, ethnic fractionalization, disease environment, population density in the year 1500 and dummies on legal origins and major religion shares. An additional robustness check in contacted by regressing current levels of trust and social capital on the original measure of land productivity restricting the sample to countries with native population larger than 75%. Reassuringly the relationship between land productivity and trust remains unaffected. As a robustness analysis, an additional measure of social capital have been employed, namely the extent of participation in civic activities (La Porta et al., 1997).

The remainder of the paper is organized as follows: Section 2 reviews some related literature. Section 3 presents a basic model that predicts a "reversal of fortune" with respect to natural land endowments. Section 4 is presenting the empirical findings. Finally, Section 5 concludes.

2 Advances with Respect to the Related Literature

Various theories and possible explanations of comparative development have been advanced in the literature. The role of factors such as geography, institutions, colonialism, ethnolinguistic fractionalization, culture, human capital and genetic diversity have been at the center of theories attempting to account for differential take-off to a state of sustained economic growth.

The "geography hypothesis", argues that the environment can influence economic performance directly, through its effect on health, work effort and agricultural productivity (Huntington, 1915; Myrdal, 1968; Landes, 1998; Sachs and Malaney, 2002).[15] Diamond (1997), has stressed the importance of geographical conditions as determinants of the timing of the Neolithic revolution. According to his hypothesis, societies that experienced an earlier transition to agriculture, enabled their technological dominance at later stages of development, and ultimately their dominance in current economic outcomes. In a similar fashion, Sachs (2001) has highlighted the importance of technology, disease environment and transport costs, which are indirectly affected by geographical and climatic conditions. The temperate drift hypothesis claims that the newly emerged agricultural technology (e.g. crop rotation systems, high-yield crops) favored primarily temperate areas as opposed to areas in the tropics (Bloch, 1966; Mokyr, 1990; White, 1962).

Existing literature has documented that the environment can influence economic performance indirectly, by setting the conditions in which sociopolitical institutions have formed (Engerman and Sokoloff, 2000; Acemoglu et al., 2001; Easterly and Levine, 2003). According to this hypothesis differences in natural land endowments, generated differences in inequality, which eventually triggered oppressive institutions. Institutions and the significant role of property rights in fostering investment,

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[14] In the regression of trust on land productivity, the proper approach is to employ the measure of adjusted land productivity, since it is the portable component of land that is affecting current levels of trust. On the contrary, in the regression of income in year 2000, the right approach would be to employ both measures of land productivity since they can both affect current economic outcomes. Nevertheless, due to the fact that the two variable are highly correlated, the results cannot be trusted and therefore, for this particular case, only the measure of land productivity is employed, whereas at the same time restricting the sample to countries with native population higher than 75%,

[15] It has as well been stressed from a historical perspective by Jones (1981), Diamond (1997), and Pomeranz (2000), and is highlighted empirically by Gallup et al. (1999) and Olsson and Hibbs (2005).

innovation and ultimately economic growth are given historical precedence by North and Thomas (1973), Mokyr (1990), and Greif (1993), and are emphasized empirically by Hall and Jones (1999), La Porta et al. (1999), Rodrik et al. (2004), and Acemoglu et al. (2005). In related strands of the literature on institutions, Engerman and Sokoloff (2000) and Acemoglu et al. (2005), have stressed the role of colonialism. They establish that affluent places that dominated the world in agricultural stages of development, were imposed extractive institutions, which ultimately resulted in their being overtaken in the transition to industrialization. The effects of ethnolinguistic fractionalization on institutions are examined by Easterly and Levine (1997) and Alesina et al. (2003). They pertain that a high degree of ethnolinguistic fractionalization, can result in poorer institutions and consequently to inferior economic outcomes.

The cultural hypothesis, initiated by Weber (1905, 1922) and later advanced by Hall (1986) and Landes (1998, 2006) argues, that in societies where the prevailing norms and ethics enhance the "entrepreneurial spirit" and further expand the technological frontier, are the societies that flourished at industrial stages of development. Ashraf and Galor (2011c) attribute differences in the patterns of economic development, to variations in the interplay between the forces of cultural assimilation and cultural diffusion. Durante (2010) highlights the significance of trust, and argues that norms of trust can be traced to the collective action developed in pre-industrial times by farmers, in an attempt to minimize weather-related risks.

The role of human capital formation has been advanced as an alternative hypothesis, according to which the technologically driven demand for human capital, during the second phase of industrialization, led to an expansion in investment in human capital, which in turn led to an even more rapid increase in technological progress and accelerated the transition to a regime of sustained growth (Galor and Weil, 2000; Galor and Moav, 2002; Lucas, 2002; Glaeser et al., 2004; Galor, 2011). Finally, the role of genetic diversity in current economic outcomes, is explored in Ashraf and Galor (2011b), where they argue that the level of genetic diversity within a society has a hump-shaped effect on economic outcomes, reflecting the trade-off between the beneficial and the detrimental effects of diversity on productivity.

A strand of the related literature explores factors that could account for historical reversals in the economic performance of societies. Advocates of the "temperate drift hypothesis" pertain that initially, places in the tropics were more productive and therefore achieved better economic outcomes, however, the emergence of agricultural technologies favored primarily more temperate areas, thereby allowing them to achieve better economic outcomes in the long-run (Bloch, 1966; Mokyr, 1990). Acemoglu et al. (2005) attribute the "reversal of fortunes" of colonized areas to an "institutional reversal", that occurred due to colonization, thereby emphasizing the significance of institutions in the process of economic development. Ashraf and Galor (2011c), establish that societies that were geographically isolated, and thus manifested lower cultural diversity, managed to operate more closely to their production possibility frontier, which allowed them to achieve better economic outcomes at early stages of development. However, the lack of cultural diffusion reduced their ability to adapt to a new technological paradigm, which ultimately delayed their industrialization as opposed to countries that were more culturally diffused.

The theory advanced in this study with the aim to account for the observed reversal of fortunes, underlines the effect of natural geographical conditions on the process of development, but differs significantly from the existing geography hypothesis in many respects.[16] The proposed hypothesis suggests that geographical conditions, and particularly land productivity endowments, had a differential impact on economic outcomes across time, operating via social capital, that emerged as the outcome of cooperation in the agricultural sector, in an effort to mitigate unfavorable land endowment. In agricultural stages of development, countries with unfavorable land endowments were surpassed in terms of economic outcomes by high land productivity places. In an effort to boost land productivity though, they cooperated more intensely in the development of agricultural infrastructure, which eventually allowed them to achieve a higher level of social capital, thereby allowing them to industrialize first and dominate the world in terms of current economic outcomes. Overall the effect of geography over economic outcomes, differed across time, and what was once perceived as a drawback in the process of economic development, namely unfavorable land endowment, eventually became an engine of sustained growth operating through the emergence of social capital.

The proposed theory differs from the institutional hypothesis in two respects. Whereas the institutional hypothesis argues on the impact of sociopolitical institutions on economic growth, and attributes the "reversal of fortunes" of colonized areas to an "institutional reversal", the hypothesis advanced by this research is that reversal of fortunes in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector and the emerging social capital. The second major departure from the institutional hypothesis stems from the fact that the suggested reversal extends beyond colonized areas and can be applicable for a larger subset of countries.[17]

Whereas the scope of this research is primarily intended to provide an alternative explanation for the reversal of fortunes in a number of countries, the mechanism employed provides an alternative explanation as well for the emergence of social capital. It is suggested that the emergence of social capital can be traced to the level of cooperation developed in the agricultural sector for the creation of infrastructure that could enhance land productivity. The idea that large scale cooperation can strengthen social ties and create social capital is not new in the literature (Bowles and Gintis, 2002; Henrich et al., 2001). Interestingly, this literature advances the hypothesis that a large scale community driven development is a crucial element towards the creation of social capital, and ultimately of effective institutions that will be successful in building infrastructure and providing elementary public goods. A number of natural experiments that encourage collective action at the community level have highlighted that this strategy is the right approach towards the creation of social capital and effective networks (Bardhan, 2000; Uphoff and Wijayaratna, 2000; Ostrom, 2000).

Broadening the scope of the related literature this research argues that in agricultural stages of development, cooperation in the agricultural sector to increase natural land productivity, was the optimal survival strategy at the time. The more intense the optimal cooperation, the higher the

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[16] As Acemoglu et al. (2001) highlight, the "geography hypothesis" is not consistent with a reversal of fortunes, since neither is there any evidence that geography triggered industrialization directly nor did the geographical conditions that allowed certain countries to dominate in the agricultural era significantly changed over time.

[17] Whereas the institutional hypothesis can account for colonizes counties in North and South America, it cannot account for countries within the European continent or the overtaking of Asia by Europe in the transition to industrialization (Landes, 1998).

level of social capital obtained, which ultimately accelerated the industrialization process in these countries. Therefore, it is argued that what is currently advocated as a growth boosting strategy in developing countries, has spontaneously taken place centuries ago within the context of perhaps the most extended large scale natural experiment, namely the development of agricultural infrastructure in an effort to mitigate the adverse effect of natural environment.

3 The Basic Structure of the Model

Consider a perfectly competitive overlapping-generations economy in the process of development where economic activity extends over infinite discrete time.

3.1 Production

In every period, a single homogenous good is being produced either in an agricultural sector or in both an agricultural and an industrial sector, with the inputs being labor and land. Each household is supplying inelastically one unit of labor in every time period, whereas the aggregate supply of labor evolves over time at the endogenously determined rate of population growth. The supply of land is determined exogenously and remains constant over time.[18] In early stages of development, the economy operates exclusively in the agricultural sector, whereas the industrial sector is not economically viable. However, since productivity grows faster in the industrial sector, it ultimately becomes economically viable and therefore, in later stages of development, the economy operates in both sectors.

3.1.1 Production in the Agricultural and Industrial Sectors

The output produced in the agricultural sector in period t, Y_t^A, is determined by land, X_t, and labor employed in the agricultural sector, L_t^A, as well as by aggregate agricultural productivity. Aggregate agricultural productivity comprises three components: the natural level of land productivity, $\xi > 0$, acquired productivity (based on learning by doing), A_t^A, and public infrastructure, G_t.

The production is governed by a Cobb-Douglas, constant-returns-to-scale production technology such that

$$Y_t^A = \left[\xi A_t^A + G_t\right]^a X^a \left[L_t^A\right]^{1-a}; \qquad a \in (0,1). \tag{1}$$

For simplicity the amount of land is normalized such that $X = 1$.

Public infrastructure, G_t, is produced by a fraction z_t of the labor force employed in the agricultural sector. The remaining fraction $(1 - z_t)$ is employed in the production of the final output. Hence the production of agricultural output is

$$Y_t^A = \left[\xi A_t^A + z_t \theta_t L_t\right]^a X^a \left[(1 - z_t)\,\theta_t L_t\right]^{1-a}, \tag{2}$$

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[18] For the emergence of a stable Malthusian equilibrium in the agricultural stage of development, diminishing returns to labor implied by the presence of a fixed factor are essential.

where θ_t is the faction of labor employed in the agricultural sector and L_t denotes the total labor force of the economy in every time period t.

Aggregate productivity in the agricultural sector, $\left[\xi A_t^A + G_t\right]$, is aimed to capture the trade-off between allocating labor in the production of the final good and the production of the public good. Places that are faced with favorable land endowment, may find it optimal to allocate more resources to the production of the final good, whereas unfavorably endowed places, may find it optimal to invest more in infrastructure as a means to further enhance land productivity.[19]

The output of the industrial sector in period t, Y_t^I, is determined by a linear, constant-returns-to-scale production technology such that

$$Y_t^I = A_t^I L_t^I = A_t^I (1-\theta_t) L_t \tag{3}$$

where L_t^I is the labor employed in the industrial sector. $(1-\theta_t)$ is the fraction of labor employed in the industrial sector in period t, and A_t^I is the level of industrial productivity in period t.

The total labor force in period t, L_t, is allocated between the two sectors. Therefore,

$$L_t^A + L_t^I = L_t, \tag{4}$$

where $L_t > 0$ in every period t.

As will become evident, in early stages of development, the productivity of the industrial sector, A_t^I, is low relative to that of agricultural sector, and therefore output is produced using exclusively the agricultural technology. However, in later stages of development, A_t^I rises sufficiently relative to the productivity of agricultural sector, and ultimately the industrial technology becomes economically viable.

3.1.2 Collective Action in the Production of the Agricultural Infrastructure

Labor in the agricultural sector is allocated between two different activities. A fraction of the labor, $1-z_t$, is employed in the production of the final good, whereas the remaining fraction, z_t, is employed in the production of agricultural infrastructure that is aimed to further enhance land productivity. The decision over what fraction of the labor is allocated to the production of each good, is made at the community level before production takes place. The objective of the community is to maximize output in the agricultural sector.

The community faces a trade-off in the decision to allocate labor to the production of agricultural infrastructure. More labor in the production of agricultural infrastructure implies increases in land productivity, which may increase production of the final good, despite the reduction in labor employment in the production of the final good.

Optimization Members of the community in every time period t, choose the fraction of labor employed in the agricultural sector that will be allocated in the production of the public good, so as to maximize agricultural output, i.e.,

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[19] Different formulations of the prodcution function, e.g. $Y_t^A = A_t^A \left[\xi + G_t\right]^a X^a \left[L_t^A\right]^{1-a}$ would yield qualitatively similar results under certain assumption, nevertheless they would complicate the model to the level of intractability.

$$\{z_t\} = \arg\max Y_t^A. \tag{5}$$

Hence, noting (1),

$$z_t = a - \frac{(1-a)\xi A_t^A}{\theta_t L_t}. \tag{6}$$

Interestingly, the optimal fraction of labor allocated to the development of agricultural infrastructure is a decreasing function of natural land productivity, ξ, as well as of acquired agricultural productivity, A_t, thereby implying that countries with more favorable land endowment have a reduced incentive to invest in infrastructure and therefore, choose to allocate more labor to the direct production of the final good. Conversely, unfavorably endowed countries, choose to commit more resources to the development of agricultural infrastructure, as a means to further enhance natural land productivity.[20]

3.1.3 Factor Prices and Aggregate Labor Allocation

The markets for labor and the production of the final good are perfectly competitive. Workers in the agricultural sector receive their average product, given that there are no property rights to land, and therefore the return to land is zero. Given (2), the inverse demand for labor in the agricultural sector is

$$w_t^A \equiv \frac{Y_t^A}{\theta_t L_t} = \left[\frac{\xi A_t^A}{\theta_t L_t} + z_t\right]^a (1-z_t)^{1-a} = \frac{a^a(1-a)^{(1-a)}\left(\xi A_t^A + \theta_t L_t\right)}{\theta_t L_t}, \tag{7}$$

where w_t^A is the wage rate of agricultural labor in period t.

The inverse demand for labor in the industrial sector, given (3), is

$$w_t^I = A_t^I, \tag{8}$$

where w_t^I is the wage rate of industrial labor in period t.

From (7) and (8) it is evident that as employment increases in the agricultural sector, the inverse demand for labor increases without bound, whereby productivity in the industrial sector is finite. It is therefore implied that the agricultural sector will be operative in every period, whereas the industrial sector will be operative if and only if labor productivity in this sector exceeds the marginal productivity of labor in the agricultural sector, assuming that the entire labor force is employed in the agricultural sector. Once the two sectors become operative, the perfect labor mobility assumption implies an equalization of wages across sectors.

The following lemma and its associated corollary, respectively, establish conditions on the level of industrial productivity and, equivalently, on the size of the working population for the viability of the industrial sector.

Lemma 1 *(The Industrial Productivity Threshold for the Economic Viability of the Industrial Sector) There exists a threshold level of industrial productivity, $\hat{A}_t^I$, such that the industrial sector is*

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[20] Further restrictions must be imposed on the A_0^A, L_0 that ensure that $z_t \geq 0$.

economically viable in period t if and only if

$$A_t^I \geq \frac{a^a(1-a)^{(1-a)}\left(\xi A_t^A + L_t\right)}{L_t} \equiv \hat{A}^I\left(\xi, A_t^A, L_t\right) \equiv \hat{A}_t^I.$$

Proof. Follows from (7)-(8) and the perfect mobility of labor between sectors. It establishes that workers will start being employed in the industrial sector if their productivity in that sector, A_t^I, is equal to or exceeds the marginal productivity in the agricultural sector, $a^a(1-a)^{(1-a)}\left(\xi A_t^A + L_t\right)/L_t$, under the assumption that the entire labor force, L_t, is employed in the agricultural sector (i.e. $\theta_t = 1$). $\square$

Corollary 1 *(The Population Threshold for the Economic Viability of the Industrial Sector) Given* $A_t^I > 0$*, there exists a unique threshold size of the working population,* $\hat{L}_t$*, such that the industrial sector is economically viable in period t if and only if*

$$L_t \geq \frac{a^a(1-a)^{(1-a)}\xi A_t^A}{A_t^I - a^a(1-a)^{(1-a)}} = \hat{L}\left(A_t^A, A_t^I\right) \equiv \hat{L}_t.$$

To ensure the emergence of the industrial sector, additional restrictions must be imposed on the initial value of industrial productivity, i.e. $A_0^I > a^a(1-a)^{(1-a)}$.

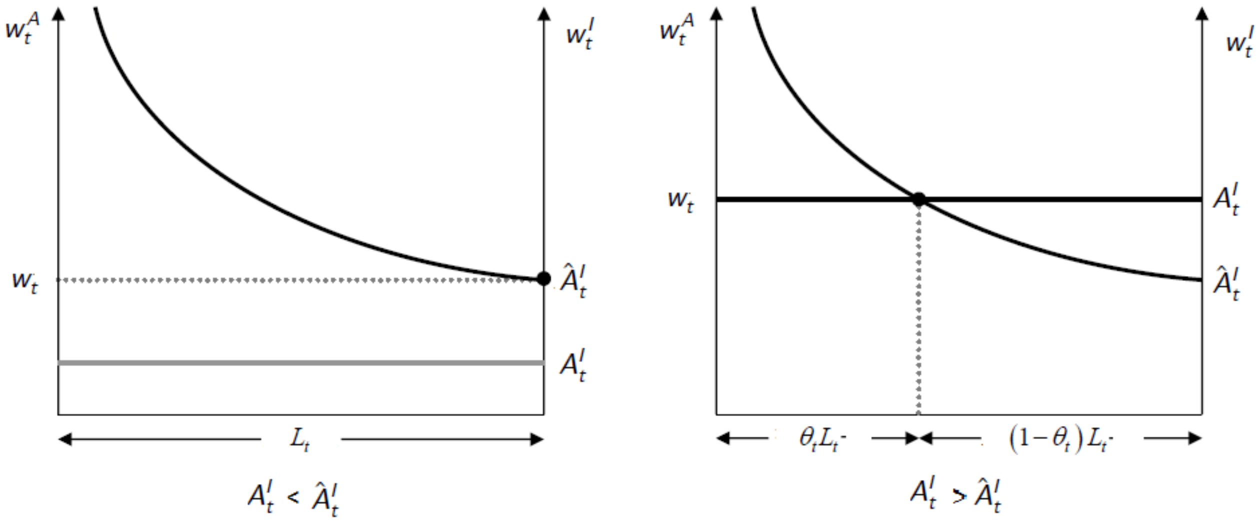
$\theta_t \in (0,1]$ denotes the fraction of the economy's labor force employed in the agricultural sector in period t, i.e., $\theta_t \equiv L_t^A/L_t$. As follows from Lemma 1 and depicted in Figure 1.a, if $A_t^I < \hat{A}_t^I$, then only the agricultural sector is active and therefore the entire labor force will be employed in this sector. Therefore wage rate in the economy, w_t, will be the associated wage rate in the agricultural sector, w_t^I. However, as depicted in Figure 1.b, if $A_t^I \geq \hat{A}_t^I$, then the industrial sector will become operative, thereby implying that the perfect mobility of workers between sectors will assure that $w_t = w_t^A = w_t^I$. Hence, the equilibrium allocation of labor between the agricultural and industrial sectors in period t, as described by θ_t, is given by

$$\theta_t \equiv L_t^R/L_t = \begin{cases} 1 & \text{if} \quad A_t^I < \hat{A}_t^I \\ \\ \frac{a^a(1-a)^{(1-a)}\xi A_t^A}{A_t^I - a^a(1-a)^{(1-a)}}\frac{1}{L_t} & \text{if} \quad A^I \geq \hat{A}_t^I, \end{cases} \tag{9}$$

and, as follows from (7) and (8), the equilibrium wage rate in the economy in period t, w_t, is

$$w_t = \begin{cases} w_t^A = \frac{a^a(1-a)^{(1-a)}\left(\xi A_t^A + L_t\right)}{L_t} & \text{if} \quad A_t^I < \hat{A}_t^I \\ \\ w_t^I = A_t^I & \text{if} \quad A_t^I \geq \hat{A}_t^I. \end{cases} \tag{10}$$

Figure 1: The Labor Market Equilibrium



Only Sector A Active

Both Sectors A and I Active

Consistent with the historical path of economic development, where agriculture unequivocally precedes industry, it is assumed that the industrial sector is not economically viable in period 0. Using the restrictions imposed by Lemma 1

$$a^a(1-a)^{(1-a)} < A_0^I < \frac{a^a(1-a)^{(1-a)}\left(\xi A_0^A + L_0\right)}{L_0}. \tag{A1}$$

3.2 Individuals

In every period t, a generation comprising a continuum of L_t economically identical individuals, enters the labor force. Reproduction occurs asexually and, therefore, each individual has a single parent. Each member of generation t lives for two periods. In the first period of life (childhood), $t-1$, individuals are raised by their parents who face a fixed cost of child-rearing for every child in the household.[21] In the second period of life (parenthood), t, individuals are endowed with one unit of time, which they allocate entirely to labor force participation.

3.2.1 Preferences and Constraints

The preferences of members of generation t (those born in period $t-1$) are defined over consumption as well as the number of their children. They are represented by the utility function

$$u_t = (c_t)^\gamma (n_t)^{1-\gamma}; \qquad \gamma \in (0,1), \tag{11}$$

where c_t is consumption, and n_t is the number of children of individual t. The individual's utility function is therefore strictly monotonically increasing and strictly quasi-concave, satisfying the

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[21] It is assumed that each child is associated with a fixed cost that can be interpreted as purchasing child-rearing services. Imposing a time cost would not qualitatively change the predictions of the model, as long as technological progress reduces the amount of time required to raise a child.

conventional boundary conditions, which ensure the existence of an interior solution to the utility maximization problem.

Let $\tau > 0$ be the cost (in terms of the consumption good) faced by a member of generation t for raising a child. Income from labor force participation is allocated between expenditure on children (at a real cost of τ per child) and consumption. Hence, the budget constraint faced by a member of generation t is

$$c_t + \tau n_t \leq w_t, \tag{12}$$

where w_t is the labor income of individual t as given by (10).

3.2.2 Optimization

Members of generation t choose the number of their children and, therefore, their own consumption so as to maximize their utility subject to the budget constraint. Substituting (12) into (11), the optimization problem for a member of generation t reduces to

$$n_t = \arg\max \left\{ (w_t - \tau n_t)^{\gamma} (n_t)^{1-\gamma} \right\}. \tag{13}$$

The optimal number of children for a member of generation t is an increasing function of individual t's income, an outcome consistent with one of the fundamental features of a Malthusian environment. Specifically,

$$n_t = \frac{1-\gamma}{\tau} w_t, \tag{14}$$

which, following (10), yields

$$n_t = \begin{cases} \frac{1-\gamma}{\tau} \frac{a^a (1-a)^{(1-a)} \left(\xi A_t^A + L_t\right)}{L_t} & \text{if} \quad A_t^I < \hat{A}_t^I \\ \\ \frac{1-\gamma}{\tau} A_t^I & \text{if} \quad A_t^I \geq \hat{A}_t^I. \end{cases} \tag{15}$$

4 The Time Paths of the Macroeconomic Variables

The time paths of the macroeconomic variables are governed by the dynamics of acquired factor productivity in both the agricultural and the industrial sector, A_t^A and A_t^I, as well as the evolution of the size of the working population, L_t. The evolution of industrial productivity and the size of the working population are in turn governed by the amount of labor allocated to the production of agricultural infrastructure and therefore by natural land endowment. [22]

4.1 The Dynamics of Sectoral Productivity

The level of the acquired productivity in the agricultural and industrial sectors, A_t^A and A_t^I, is affected by the productivity level in the previous time period as well as by technological progress, which reflects the incorporation of new knowledge into existing technologies. Industrial productivity is further enhanced by the level of social capital on industrial specific knowledge creation.

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[22] The structure of the dynamical system is inspired by Ashraf and Galor (2011c).

In each time period, a fraction of the workforce that is employed in the agricultural sector is allocated to the construction of the public good. The newly created infrastructure has two effects on the economy as a whole. A short run and a long run effect. In the short run, it boosts agricultural production directly, by mitigating the adverse effect of unfavorable natural land endowment.[23] In the long run, the cooperation in the production of agricultural infrastructure, contributes to societal social capital that ultimately benefits the process of industrialization.[24]

4.1.1 Industrial Productivity

Industrial productivity is being enhanced by two distinct components. The first component reflects improvements in industrial technology, driven by the new knowledge added by the population employed in the industrial sector. The second component can be viewed as the social component, namely the acquired level of social capital (as emerging from cooperation in the agricultural sector), and its beneficial effect on industrial specific new knowledge.[25]

The evolution of productivity in the industrial sector between periods t and $t+1$ is determined by

$$A^I_{t+1} = A^I_t + (1 + z_t\theta_t)L_t A^I_t \quad \equiv A^I\left(A^A_t, L_t, A^I_t\right) \ , \tag{16}$$

where the initial level of industrial productivity, $A^I_0 > a^a(1-a)^{(1-a)}$, is given.

In particular, A^I_t reflects past productivity in the industrial sector, in time t. The application of new knowledge, stimulated by population size, $L_t A^I_t$, captures the advancement in productivity due to the application of new knowledge to the existing level of productivity.

$z_t\theta_t$ is the fraction of the population employed in the production of agricultural infrastructure and therefore $z_t\theta_t L_t$ captures the externalities from cooperation in the agricultural sector over the total population.[26] The beneficial effect of cooperation in the agricultural sector, on the industrial productivity, is captured by $z_t\theta_t L_t A^I_t$.

At any point in time, the beneficial effect of cooperation on the industrial sector through the creation and accumulation of social capital and ultimately through its effect on the creation of industrial specific knowledge, is being reflected on the level of past productivity, A^I_t. What was initiated as cooperation at time t, is embodied as social capital in period $t+1$.

4.1.2 Agricultural Productivity

Similarly, the evolution of productivity in the agricultural sector between periods t and $t+1$ is determined by

$$A^A_{t+1} = \beta A^A_t + \theta_t(L_t)^\lambda (A^A_t)^b \quad \equiv A^A\left(A^A_t, L_t\right) \ , \tag{17}$$

where the natural level of agricultural productivity, $A^A_0 > 0$, is given.

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[23] For simplicity it is assumed that agricultural infrastructure fully depreciates within a period.

[24] It is plausibly assumed that when the community decides to construct agricultural infrastructure, it cannot internalize the externality of the emerging social capital in the latent industrial sector.

[25] Higher levels of social capital are associated with higher innovation and entrepreneurship, via reducing the associated risks and providing the necessary network (Putnam, 2000; Greif, 1993)

[26] One can assume that each extended household allocates labor to both the industrial and the agricultural sector. Hence the entire society is exposed to the externalities of cooperation.

A_t^A is the productivity of the agricultural sector in time t. $\beta \in (0,1)$ captures the erosion in agricultural productivity due to imperfect transmission from one generation to the other.[27] θ_t is the fraction of people employed in agriculture and therefore the term $\theta_t(L_t)^{\lambda}(A_t^A)^b$ is capturing a "learning by doing effect".

In particular it is further assumed that

$$b > 0, \lambda > 0 \quad \text{and} \quad \lambda + b < 1,$$

thereby implying both diminishing returns to population driven knowledge creation, and a "fishing out" effect, namely the negative effect of past discoveries on making discoveries today. In addition, it is assumed a larger degree of complementarity between the advancement of the knowledge frontier and the existing stock of sector-specific productivity in the industrial sector.

It is assumed that agricultural infrastructure is fully depreciating within one period, therefore productivity in the agricultural sector is not affected by the level of agricultural infrastructure.[28]

4.2 The Dynamics of Population Size

The size of the labor force in any period is determined by the size of the preceding generation and its fertility rate. As follows from (15), the adult population size evolves over time according to

$$L_{t+1} = n_t L_t = \begin{cases} \frac{1-\gamma}{\tau} a^a (1-a)^{(1-a)} \left(\xi A_t^A + L_t\right) & \equiv L^A\left(A_t^R, L_t\right) \quad \text{if} \quad L_t < \hat{L}_t \\ \\ \frac{1-\gamma}{\tau} A_t^I L_t & \equiv L^I\left(A_t^I, L_t\right) \quad \text{if} \quad L_t \geq \hat{L}_t, \end{cases} \tag{18}$$

where the initial size of the adult population, $L_0 > 0$, is given.

In the agricultural stage of development the dynamics of the population are governed by acquired productivity in the agricultural sector as well as the size of the adult population, whereas when both sectors become active, population dynamics are determined by the level of the productivity in the industrial sector and the size of the adult population. Interestingly, natural land endowment directly positively influences population dynamics while being in the agricultural stage of development, whereas after industrialization it positively influences population dynamics, but only indirectly through its effect on industrial productivity.

5 The Process of Development

This section focuses on the role of natural land endowment in determining the characteristics of the Malthusian equilibrium and the timing of the take-off from an epoch of Malthusian stagnation to a state of sustained economic growth. The analysis demonstrates that countries with unfavorable

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[27] It is assumed that erosion takes place in the agricultural sector, since agricultural technology reflects mostly human embodied knowledge and therefore imperfect transmission, as opposed to the industrial knowledge. The assumption that there is no erosion in the industrial sector is a simplification aimed to capture this particular aspect. Nevertheless the results would hold under any parameterization that would capture this aspect.

[28] If contemporary infrastructure is long lasting and society would internalize its future effects on agricultural output, the qualitative analysis will remain intact, however it would complicate the model to the level of intractability.

natural land endowment are being dominated by more favorably endowed countries in the Malthusian regime. Hence, in an effort to mitigate the adverse effect of land, they cooperate more intensely in the production of agricultural infrastructure, which ultimately results to the emergence of higher levels of social capital. Due to the complementarity of social capital with the industrial sector, these countries industrialize faster, and therefore, escape Malthusian stagnation to enter a state of sustained economic growth.

The process of economic development, given the natural land endowment ξ, is fully determined by a sequence $\left\{A_t^A, A_t^I, L_t; \xi\right\}_{t=0}^{\infty}$ that governs the evolution of the acquired productivity in the agricultural sector, A_t^A, the productivity in the industrial sector, A_t^I, and the size of adult population, L_t. Specifically, noting (16), (17), and (18), the dynamic path of the economy is given by

$$\begin{cases} L_{t+1} = n_t L_t = \begin{cases} \frac{1-\gamma}{\tau} a^a (1-a)^{(1-a)} \left(\xi A_t^A + L_t\right) & \equiv L^A\left(A_t^R, L_t\right) \quad \text{if} \quad L_t < \hat{L}_t \\ \\ \frac{1-\gamma}{\tau} A_t^I L_t & \equiv L^I\left(A_t^I, L_t\right) \quad \text{if} \quad L_t \geq \hat{L}_t, \end{cases} \\ \\ A_{t+1}^A = \beta A_t^A + \theta_t (L_t)^{\lambda} (A_t^A)^b = A^A\left(A_t^A, L_t\right) \\ \\ A_{t+1}^I = A_t^I (1 + (1 + z_t \theta_t) L_t) = A^I\left(A_t^A, A_t^I, L_t\right) \end{cases} \tag{19}$$

where, consistent with the process of development, the initial conditions, $\left(A_0^A, A_0^I, L_0\right)$, are set to satisfy assumption (A1).

5.1 The Dynamical System

To analyze the evolution of the economy from the agricultural to the industrial regime, a series of phase diagrams is employed, that is describing the evolution of the system within the Malthusian epoch, as well as the endogenous transition to industrialization. The analysis underlines the role of natural land endowment and of cooperation for the development of infrastructure in agricultural sector, in determining the characteristics of the Malthusian equilibrium and the timing of the economy's take-off to the industrialization era.[29]

The phase diagrams, depicted in Figures 2-3, describe the evolution of the system in the $\left(A_t^A, L_t\right)$ plane, conditional on the level of A_t^I. The evolution of A_t^I generates a phase transition of the dynamical system and brings about a qualitative change that is associated with industrialization and the take-off to a state of sustained economic growth.

Three geometric elements are crucial for building the phase diagrams and are instrumental for the determination of motion within the system: the Conditional Malthusian Frontier, which separates the regions in which the economy is exclusively operating in the agricultural sector from those where it operates in both the industrial and the agricultural sector; the AA locus, which denotes the set of

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[29] The analysis is focusing on the transition from a Malthusian regime to an industrialization regime and the forces that led to a faster industrialization. The forces that eventually led to the demographic transition and the emergence of the modern growth regime are not being explored in the context of this research. The underlying assumption behind this approach is the historical observation that a "reversal of fortunes" has been observed initially with respect to the timing of industrialization. The model could be expanded to account for the current growth regime however this extension would just increase the complexity of the model without adding any new insights.

all pairs $\left(A_t^A, L_t\right)$ for which the acquired productivity in the agricultural sector is constant; and the LL locus, which denotes the set of all pairs for which the size of the workforce is constant, conditional on the latency of the industrial sector.

5.1.1 The Conditional Malthusian Frontier

The Conditional Malthusian Frontier is a geometric locus, in $\left(A_t^A, L_t\right)$ space, that separates the regions where the economy operates exclusively on the agricultural sector from those where it operates in both sectors. Once the economy's trajectory crosses this frontier, the industrial sector becomes operative.

Let the Conditional Malthusian Frontier be the set of all pairs $\left(A_t^A, L_t\right)$ such that, for a given level of industrial productivity, A_t^I, the entrepreneurs in the economy are indifferent as to whether to operate the industrial sector or not. Following Corollary 1, the Conditional Malthusian Frontier, $MM_{|A_t^I}$, as depicted in Figures 2-3, is

$$MM_{|A_t^I} \equiv \left\{ \left(A_t^A, L_t\right) : L_t = \hat{L}\left(A_t^A, A_t^I\right) \right\}. \tag{20}$$

Lemma 2 *(The Properties of the Conditional Malthusian Frontier) If* $\left(A_t^A, L_t\right) \in MM_{|A_t^I}$*, then along the* $MM_{|A_t^I}$ *frontier,*

$$L_t = \frac{a^a(1-a)^{(1-a)}\xi A_t^A}{A_t^I - a^a(1-a)^{(1-a)}} \equiv \hat{L}\left(A_t^A, A_t^I\right),$$

where $\partial \hat{L}\left(A_t^A, A_t^I\right)/\partial A_t^A > 0$*, and* $\partial \hat{L}\left(A_t^A, A_t^I\right)/\partial A_t^I < 0$*.*

Proof. Follows immediately from (20), Corollary 1, and differentiation. □

The Conditional Malthusian Frontier is therefore an upward sloping ray from the origin in $\left(A_t^A, L_t\right)$ space. From Corollary 1, it becomes evident that the region strictly below the frontier denotes that production takes place exclusively in the agricultural sector whereas the region (weakly) above the frontier, denotes that the economy operates both in the industrial and the agricultural sector. As A_t^I increases in the process of development, the Conditional Malthusian Frontier rotates clockwise in $\left(A_t^A, L_t\right)$ space.

Lemma 3 *(The Dynamics of Population Size with respect to the Conditional Malthusian Frontier) Given* $A_t^A > 0$ *and* $A_t^I > 0$*, for all* $L_t \geq \hat{L}\left(A_t^A, A_t^I\right)$*,*

$$L_{t+1} - L_t \gtreqless 0 \quad \Leftrightarrow \quad A_t^I \gtreqless \tfrac{\tau}{1-\gamma} \Leftrightarrow \hat{L}\left(A_t^A, A_t^I\right) \gtreqless L^{LL}\left(A_t^A\right)$$

Proof. Follows immediately from (18). □

Hence, if the industrial sector is operational, (i.e., if the economy is in the region above the $MM_{|A_t^I}$ frontier in $\left(A_t^A, L_t\right)$ space), the evolution of the size of the workforce depends on the level of A_t^I relative to a critical level, $\tau/\left(1-\gamma\right)$. In particular, when industrial productivity is below the threshold, $\tau/\left(1-\gamma\right)$, the wage rate in the economy is not sufficiently high to sustain fertility beyond replacement, thereby implying that the size of the workforce declines in size over time. Conversely if A_t^I is above the critical threshold, then the wage rate is sufficiently high to sustain fertility above the replacement level and hence the workforce increases in size over time.

5.1.2 The AA Locus

Let the AA locus be the set of all pairs $\left(A_t^A, L_t\right)$ such that the level of agricultural productivity, A_t^A, is in a steady state:

$$AA \equiv \left\{\left(A_t^A, L_t\right) : A_{t+1}^A - A_t^A = 0\right\}. \tag{21}$$

Lemma 4 *(The Properties of the AA Locus) If $\left(A_t^A, L_t\right) \in AA$, then along the AA locus,*

$$L_t = \left(\frac{1-\beta}{\left(A_t^A\right)^{b-1}\theta_t}\right)^{1/\lambda} \equiv L^{AA}\left(A_t^A\right),$$

where $\partial L^{AA}\left(A_t^A\right)/\partial A^A > 0$ and $\partial^2 L^{AA}\left(A_t^A;\omega\right)/\left(\partial A_t^A\right)^2 > 0$.

Proof. Noting (21), the functional form of $L^{AA}\left(A_t^A\right)$ is obtained by algebraically manipulating (17) under $A_{t+1}^A = A_t^A$. The remainder follows directly from differentiation. □

Corollary 2 *(The Dynamics of Agricultural Productivity with respect to the AA Locus) Given $A_t^A > 0$,*

$$A_{t+1}^A - A_t^A \gtreqqless 0 \quad \textit{if and only if} \quad L_t \gtreqqless L^{AA}\left(A_t^A\right)$$

Hence, the AA locus, as depicted in Figures 2-3, is a strictly convex, upward sloping curve from the origin in $\left(A_t^A, L_t\right)$ space. A_t^A grows over time above the AA locus, due to the fact that there is a sufficiently large cohort of adults that ensure the advancement of the knowledge frontier that can overcome the erosion effect of imperfect intergenerational transmission of knowledge on A_t^A. Respectively, below the AA locus, the advancement of the knowledge frontier is not sufficient to overcome the eroding effects of imperfect intergenerational transmission on A_t^A, and therefore, productivity diminishes over time.

5.1.3 The LL Locus

Let the LL locus be the set of all pairs $\left(A_t^A, L_t\right)$ such that, conditional on the latency of the industrial sector, the size of the adult population, L_t, is in a steady state:

$$LL \equiv \left\{\left(A_t^A, L_t\right) : L_{t+1} - L_t = 0 \mid L_t < \hat{L}\left(A_t^A, A_t^I\right)\right\}. \tag{22}$$

Lemma 5 *(The Properties of the LL Locus) If $\left(A_t^A, L_t\right) \in LL$, then along the LL locus,*

$$L_t = \frac{(1-\gamma)a^a(1-a)^{1-a}\xi A_t^A}{\tau-(1-\gamma)a^a(1-a)^{1-a}} \equiv L^{LL}\left(A_t^A\right),$$

where $\tau > (1-\gamma)a^a(1-a)^{1-a}$, $dL_t^{LL}/dA_t^A > 0$, and $d^2L_t^{LL}/\left(dA_t^A\right)^2 = 0$.

Proof. Noting (22), the functional form of $L^{LL}\left(A_t^A\right)$ is obtained from the algebraic manipulation of (18) under $L_{t+1} = L_t$. The remainder follows immediately from differentiation. $\square$

Corollary 3 *(The Dynamics of Population Size with respect to the LL Locus) Given $A_t^A > 0$ and $A_t^I > 0$, for all $L_t < \hat{L}\left(A_t^A, A_t^I\right)$,*

$$L_{t+1} - L_t \lesseqgtr 0 \quad \textit{if and only if} \quad L_t \gtreqless L^{LL}\left(A_t^A\right)$$

Hence, the LL locus, as depicted in Figures 2-3, is an upward sloping ray from the origin in $\left(A_t^A, L_t\right)$ space. L_t grows over time below the LL locus due to the fact that since population is sufficiently low, it allows for a high wage rate which permits fertility to be above replacement. Reversely, L_t declines over time above the LL locus, since the population is higher than the steady state, thereby implying a sufficiently low wage rate that sustains fertility below the replacement level. The position of the LL locus, in $\left(A_t^A, L_t\right)$ space, relative to the Conditional Malthusian Frontier, $MM_{|A_t^I}$, is established in the following lemma.

Lemma 6 *(The Position of the LL Locus relative to the Conditional Malthusian Frontier) Given $A_t^I > 0$, for all A_t^A such that $\left(A_t^A, \hat{L}\left(A_t^A, A_t^I\right)\right) \in MM_{|A_t^I}$ and $\left(A_t^A, L^{LL}\left(A_t^A\right)\right) \in LL$,*

$$\hat{L}\left(A_t^A, A_t^I\right) \gtreqless L^{LL}\left(A_t^A\right) \quad \textit{if and only if} \quad A_t^I \lesseqgtr \tfrac{\tau + \gamma a^a (1-a)^{1-a}}{(1-\gamma)}.$$

Proof. Follows from comparing the functional forms of $\hat{L}\left(A_t^A, A_t^I\right)$ and $L^{LL}\left(A_t^A\right)$ as specified in Corollary 1 and Lemma 5 respectively. $\square$

Thus, for $A_t^I < \tau + \gamma a^a (1-a)^{1-a}/(1-\gamma)$, the Conditional Malthusian Frontier, $MM_{|A_t^I}$, is located above the LL locus. In the process of development though, $MM_{|A_t^I}$ rotates clockwise driven by the growth of A_t^I and ultimately the two loci coincide when $A_t^I = \tau + \gamma a^a (1-a)^{1-a}/(1-\gamma)$. After this point, for $A_t^I > \tau + \gamma a^a (1-a)^{1-a}/(1-\gamma)$ the Conditional Malthusian Frontier, $MM_{|A_t^I}$, drops below the LL locus.

So far it has become evident that growth in the latent industrial sector productivity, A_t^I, has an influence on the global dynamics of the size of the workforce, which in turn reflects a transition of the system from the Malthusian to the Post-Malthusian regime. The following lemma is summarizing the dynamics of the workforce.

Lemma 7 *(The Dynamics of the Workforce with respect to the LL Locus and the Conditional Malthusian Frontier) Given $A_t^I > 0$, for all $A_t^A > 0$,*

1. *If $A_t^I < \frac{\tau + \gamma a^a (1-a)^{1-a}}{(1-\gamma)}$, then*

   the Conditional Malthusian Frontier is above the LL locus, i.e.,

$$\hat{L}\left(A_t^A, A_t^I\right) > L^{LL}\left(A_t^A\right),$$

and

$$L_{t+1} - L_t \begin{cases} < 0 & \textit{if} \quad L_t > L^{LL}\left(A_t^A\right) \\ = 0 & \textit{if} \quad L_t = L^{LL}\left(A_t^A\right) \\ > 0 & \textit{if} \quad L_t < L^{LL}\left(A_t^A\right); \end{cases}$$

2. If $A_t^M > \frac{\tau + \gamma a^a (1-a)^{1-a}}{(1-\gamma)}$, *then*

the Conditional Malthusian Frontier is below the LL locus, i.e.,

$$\hat{L}\left(A_t^A, A_t^I\right) < L^{LL}\left(A_t^A\right),$$

and, for all L_t,

$$L_{t+1} - L_t > 0.$$

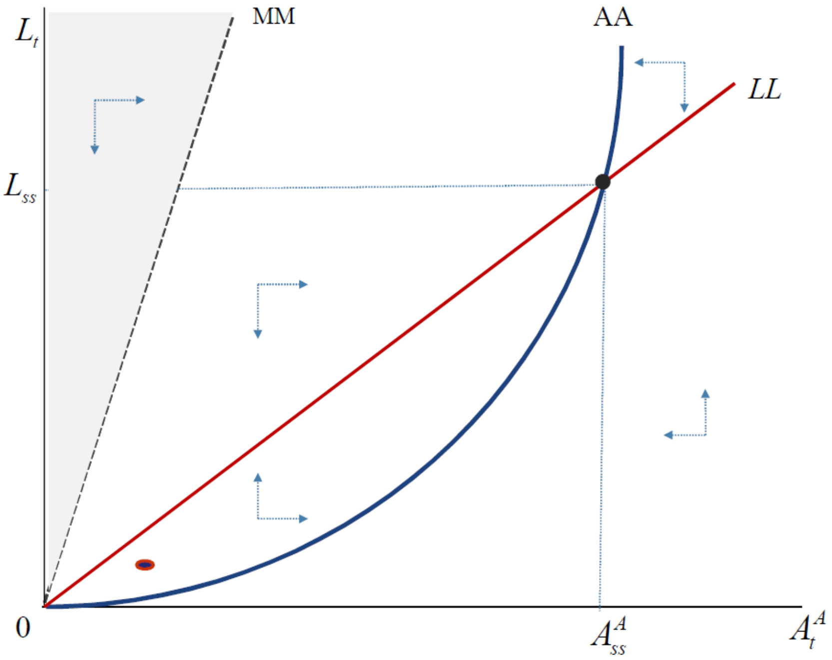
Proof. Part (1) follows immediately from Lemmas 3 and 6, and Corollary 3. Part (2) follows from the same results while observing that, above the Conditional Malthusian Frontier, $L_{t+1} - L_t > 0$ if $A_t^I > \tau/(1-\gamma)$, and if L_t is below the LL locus. ☐

5.1.4 The Phase Diagrams

Figures 2-3, depict the steady state in agricultural stage of development, and the transition from agriculture to industrialization. Figure 2 depicts the agricultural stage of development, in which the economy is in a steady state and is characterized by Malthusian dynamics, Figure 3 depicts the endogenous take-off to industrialization, where the economy enters a regime of sustained growth in per worker output and population.

The Agricultural Stage of Development Figure 2 depicts the economy while being in the agricultural stage of development, i.e. when productivity in the (latent) industrial sector, A_t^I, is below the critical level $\tau/(1-\gamma)$.

Figure 2: The Agricultural Stage of Development



This implies that the $MM_{|A^I_t}$ frontier in this stage resides above the LL locus, thereby implying that the economy is in a Malthusian regime and is characterized by a globally stable steady state equilibrium, (A^A_{ss}, L_{ss}), as defined by the point of intersection of the AA and LL loci. Using the functional forms of $L^{AA}\left(A^A_t;\xi\right)$ and $L^{LL}\left(A^A_t\right)$, specified in Lemmas 4 and 5 respectively, the Malthusian steady-state values of productivity in the agricultural sector, A^A_{ss}, and the size of the adult population, L_{ss}, are given by

$$A^A_{ss} = \left[\frac{(1-\gamma)\,a^a(1-a)^a\xi}{[\tau-[(1-\gamma)a^a(1-a)^{1-a}]]\,(1-\beta)^{1/\lambda}}\right]^{\frac{1-b-\lambda}{\lambda}} \equiv A^A_{ss}\left(\xi\right); \qquad (23)$$

$$L_{ss} = (1-\beta)^{1/\lambda}\left[\frac{(1-\gamma)\,a^a(1-a)^a\xi}{[\tau-[(1-\gamma)a^a(1-a)^{1-a}]]\,(1-\beta)^{1/\lambda}}\right]^{\frac{(1-b-\lambda)(1-b)}{\lambda^2}} \equiv L_{ss}\left(\xi\right). \qquad (24)$$

The system is characterized by a globally stable steady-state equilibrium.[30] At initial stages of development, productivity in the latent industrial sector is quite low and therefore the economy operates exclusively in the agricultural sector. Therefore the $MM_{|A^I_t}$ locus is located above the LL locus. In addition, in the region above the $MM_{|A^I_t}$ locus, as follows from Lemma 3, the size of the workforce diminishes over time, which eventually drops the economy below the Conditional Malthusian Frontier. Since the industrial sector is not yet sustainable in this stage of development, the economy converges to an agricultural regime characterized by a Malthusian equilibrium. In the region below the $MM_{|A^I_t}$ locus and above the LL locus, there is rather high workforce that implies wages rate so small as to place fertility below replacement rates and therefore the workforce diminishes over time. Conversely, below the LL locus, the size of the workforce is sufficiently small to

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[30] The unstable trivial steady state located at the origin of $\left(A^A_t, L_t\right)$ space is eliminated given $A^A_0 > 0$ and $L_0 > 0$.

allow for high wage rates and therefore for fertility above replacement, thereby implying an increasing population size.

Since the analysis takes place in the context of a discrete dynamical system, additional conditions are necessary to ensure that convergence to the steady state takes place monotonically over time and not in an oscillatory way.[31] Figure 2 is depicting the trajectories under the assumption that the parametric conditions described in Lemma 8 that ensure that the conditional dynamical system is locally nonoscillatory in the vicinity of the conditional Malthusian steady state.

The following Lemma imposes conditions on the eigenvalues of the Jacobian matrix of the conditional dynamical system evaluated at the steady-state equilibrium.

Lemma 8 *(The Local Stability Properties of the Conditional Malthusian Steady State) If* $A_t^I < \tau/\left(1-\gamma\right)$*, then the conditional steady-state equilibrium,* $\left(A_{ss}^A, L_{ss}\right)$*, of the dynamical system in (19) is:*

1. *characterized by the local monotonic evolution of both state variables,* A_t^R *and* L_t*, if and only if the Jacobian matrix,*

$$J\left(A_{ss}^R, L_{ss}\right) = \begin{bmatrix} \partial A^A\left(A_{ss}^A, L_{ss}; \omega\right)/\partial A_t^A & \partial A^A\left(A_{ss}^A, L_{ss}; \omega\right)/\partial L_t \\ \\ \partial L\left(A_{ss}^A, L_{ss}\right)/\partial A_t^R & \partial L\left(A_{ss}^R, L_{ss}\right)/\partial L_t \end{bmatrix},$$

has eigenvalues that are real and positive, i.e., if the following sufficient condition holds

$$\xi > \frac{\lambda[\tau-(1-\gamma)a^a(1-a)^{1-a}]}{(1-\gamma)a^a(1-a)^{1-a}}.$$

and;

2. *is locally asymptotically stable.*

Proof. See Appendix A. □

The Industrial Stage of Development Figure 3 depicts the dynamical system in the industrial stage of development, i.e. when industrial productivity, A_t^I, exceeds the critical level, $\tau/\left(1-\gamma\right)$.

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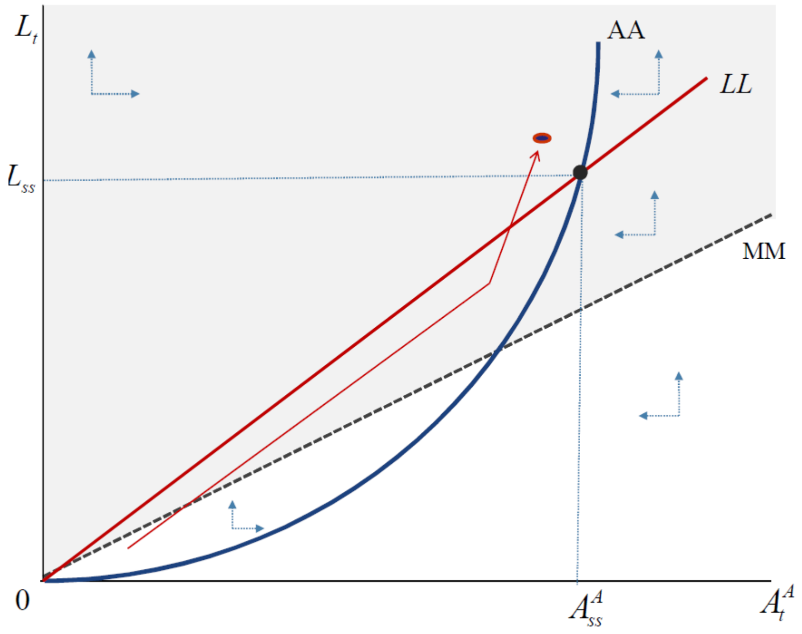
[31] The analysis would not be qualitatively different even in the case where the evolution towards the steady state took place in an oscillatory manner, since this is a feature that appears to be present during the Malthusian epoch. See, for example, Lagerlöf (2006) and Galor (2011).

Figure 3: Industrialization and the Take-off



At this stage of development, the $MM_{|A_t^I}$ frontier resides below the LL locus, as established in Lemma 7, and the economy enters a stage of sustained growth. Above the $MM_{|A_t^I}$ frontier, the wage rate increases over time, thereby allowing an increase in the size of the workforce as well as a sustained increase in productivity and output per worker.

The Transition from Agriculture to Industry The growth in productivity of the latent industrial sector in the process of development, from its initial level below the critical threshold, $\tau/(1-\gamma)$, to a level beyond this threshold is driving the transition from agriculture to industry.

Consistent with historical evidence, the transition from agriculture to industry, requires the emergence of the agricultural sector prior to the emergence of the industrial sector, i.e. the initial level of industrial productivity must satisfy the following condition.

$$A_0^I < \tau/(1-\gamma)\,. \tag{A3}$$

To assure the transition to the industrialization era, it is sufficient to assume that (latent) industrial productivity grows monotonically and eventually exceeds the critical magnitude, $\tau/(1-\gamma)$.

Let g_{t+1} denote the rate of productivity growth in the industrial sector between periods t and $t+1$. It follows directly from (16) that

$$g_{t+1} \equiv \frac{A_{t+1}^I - A_t^I}{A_t^I} = \frac{1}{1+\frac{1}{L_t + a\theta_t L_t - (1-a)\xi A_t^A}} \equiv g\left(L_t, A_t^A, \xi\right). \tag{25}$$

thereby implying that productivity in the industrial sector is growing over time, which ensures the transition from the agricultural stage of development to industrialization.

5.2 The Evolution of the Economy

The evolution of the economy is initially characterized by a Malthusian steady-state, along which the economy operates exclusively in the agricultural sector, which is followed by an endogenous industrialization and a subsequent take-off to a state of sustained economic growth.

5.2.1 The Agricultural Economy

In early stages of development, the economy operates exclusively in the agricultural sector due to the fact that the productivity in the (latent) industrial sector, A_t^I, is too low to allow the industrial sector to become operative (satisfying assumptions (A1) and (A3)). In this stage, the economy is in a Malthusian regime and the dynamical system, depicted in Figure 2, has a globally stable steady-state equilibrium, (A_{ss}^I, L_{ss}), towards which it gravitates (monotonically or in Malthusian oscillations).

Since at this stage of development only the agricultural sector is operative, the whole adult population is employed in this sector, and therefore from (2) it follows that the steady-state level of income per worker is

$$y_{ss} = \frac{a^a(1-a)^{(1-a)}\left(\xi A_{ss}^A(\xi) + L_{ss}(\xi)\right)}{L_{ss}(\xi)} \tag{26}$$

Using (23) and (24), the steady-state level of income per worker reflects the property of the Malthusian steady-state, implying that the long-run level of income is constant and independent of the level of technology. Therefore a higher productivity per worker is counterbalanced by a larger size of the working population. However, it is crucial to note that income per capita in the model is also affected by the level of natural land endowment, which gives rise to different levels of cooperation thereby implying different long-run levels of income per capital across countries with variations in land endowment.

5.2.2 From Agriculture to Industry

The driving force behind the transition from agriculture to industry, is the growth of productivity in the (latent) industrial sector. In the process of development, increases in the industrial productivity, rotate the Conditional Malthusian Frontier, $MM_{|A_t^I}$ clockwise in the $\left(A_t^A, L_t\right)$ space of Figure 2. Eventually, productivity of the industrial sector surpasses the critical threshold level $a^a(1-a)^{(1-a)}\left(\xi A_t^A + L_t\right)/L_t$, which renders the industrial sector operative and drops the Conditional Malthusian Frontier below the LL locus as depicted in Figure 3.

As the economy enters the era of industrialization, there no longer exists a globally stable Malthusian steady state in the $\left(A_t^A, L_t\right)$ space. Upon entering into the industrialization regime, the economy enters into an era of sustained endogenous growth, where income per worker is growing over time driven by the growth of industrial productivity.

5.3 Natural Land Endowment and Comparative Development

The effect of natural land endowment on comparative development, through the emergence of cooperation and social capital, can be examined based on the effect of the land endowment on

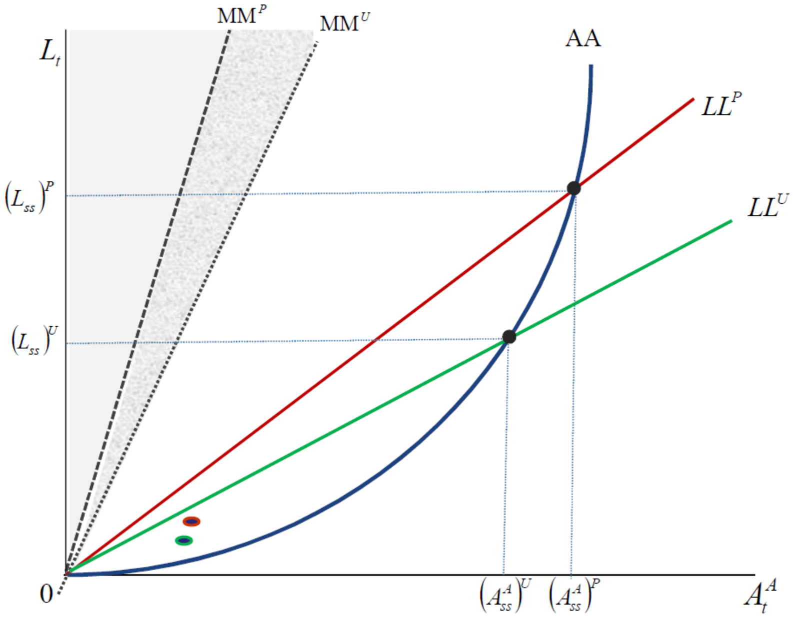
Malthusian equilibrium outcomes in the agricultural stage of development, and on the timing of industrialization and the take-off to a state of sustained economic growth.

Proposition 1 *(The Effect of Natural Land Endowment on the Equilibrium in the Agricultural Stage of Development) Under assumption (A2), as long as the economy remains exclusively agricultural, an increase in the quality of natural land endowment has a beneficial effect on the steady-state levels of productivity in the agricultural sector and the size of the adult population, and an ambivalent effect on the steady-state level of income per capita, i.e., for all* $\xi \in (0,1)$*,*

$$\begin{array}{ccc} dA^A_{ss}/d\xi > 0; & & dL_{ss}/d\xi > 0; \\ dy_{ss}/d\xi \gtreqless 0 & \text{if and only if} & 2\lambda + b \gtreqless 1 \end{array}$$

Proof. Follows immediately from differentiating (23), (24), and (26) with respect to ξ while noting assumption (A2). $\square$

Figure 4: The Effect of an Increase in Natural Land Endowment on the Malthusian Equilibrium



Geometrically, as depicted in Figure 4, a higher value of ξ, while it leaves the AA locus unaffected, it causes the LL locus to reside closer to the L_t-axis in $\left(A^A_t, L_t\right)$ space, thereby yielding higher steady-state levels of adult population size and agricultural productivity.

Therefore, an economy that is characterized by more favorable natural land endowment, is also associated with a relatively superior conditional Malthusian steady state in terms of the economy's level of agricultural productivity per worker and the size of its working population.

The long-run level of income per capita is not unaffected by variations in land productivity, however this effect is ambivalent. The effect of natural land endowment on the long-run steady state value of income per capita, operates exclusively through affecting the steady state level of population, since variations in the population affect the steady state level of agricultural productivity. Whenever the "fishing out" effect is not very strong and/or the decreasing returns to knowledge creation are not very high, i.e. whenever $2\lambda + b > 1$, then increases in population due to an increase in ξ, can speed up increases in the agricultural productivity, A_t^A, thereby implying that the dissipating effect of an increasing population is being counterbalanced by an increasing agricultural productivity and therefore an improvement in natural land endowment is associated with a higher steady state income per capita.

Conversely, whenever the "fishing out" effect is quite strong and/or the decreasing returns to knowledge creation are very high, i.e. whenever $2\lambda + b < 1$, then an increase in population due to an increase in ξ, is still increasing the agricultural productivity, A_t^A, through knowledge creation, however this increase is not sufficiently high to counterbalance the effect of an increasing population on long-run income per capita, thereby implying that an improvement in natural land endowment is associated with a lower steady state income per capita.

The effect of a variation in natural land endowment is cancelled out whenever $2\lambda + b = 1$, a feature consistent with the Malthusian equilibrium, implying that in this particular case, variations in land endowment and the emerging level of cooperation, do not differentially affect income per capital across countries. In this particular case, the increase of population due to an increase in the natural land endowment, is exactly counterbalanced by the increase in agricultural productivity and therefore the long-run level of income per capital remains unchanged.

This analysis implies that the characteristic of the Malthusian equilibrium, i.e. the fact that adjustments in population and productivity were such that equalized long-run income per capita across countries, is valid only when adjustment take place via these two variables. In the case where additional variables are part of the adjustment process, namely the level of cooperation as suggested by this research, and adjustment in the Malthusian equilibrium operates through a number of different channels, then differences in income per capita across countries may emerge even in the context of a Malthusian world.

The inferiority of the conditional Malthusian steady state, in a society with more favorable natural land endowment, stems from the fact that agricultural production in these places is higher, and they can therefore sustain a larger population. The assumption that agricultural infrastructure fully depreciates in every time period[32], implies that the more favorably endowed place will always produce more than the less favorably endowed place since it can always choose to invest as much in agricultural infrastructure.

Variations in natural land endowment, however, have an effect on the level of cooperation in the production of agricultural infrastructure and on the timing of industrialization (through the creation and transmission of social capital) and thus, on the take-off to a state of sustained economic growth. This effect is summarized in the following proposition.

Proposition 2 *(The Effect of Natural Land Endowment on the Timing of Industrialization and the Take-off from Malthusian Stagnation) Consider an economy in a conditional Malthusian steady-state equilibrium. Under assumptions (A2) and (A4), an increase in land productivity, has a detrimental*

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[32] This assumption is equivalent, with respect to qualitative predictions of the model, to the one that the community in the agricultural sector fully internalizes the externalities emerging from agricultural infrastructure.

effect on the timing of the adoption of industry and, thus, on the timing of the take-off from Malthusian stagnation, i.e.,

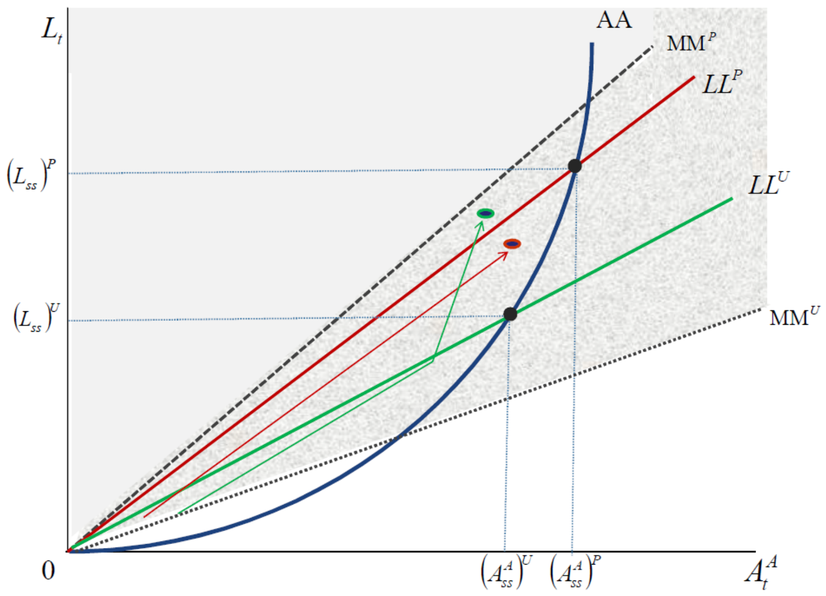
$$dg_{ss}/d\xi < 0.$$

Proof. Follows immediately from differentiating (25) in the steady state with respect to ξ . □

Hence, productivity growth in the (latent) industrial sector at the conditional Malthusian steady-state equilibrium is monotonically decreasing in the level of natural land productivity, ξ.

The earlier take-off from the conditional Malthusian steady state by a society with less favorable natural land endowment, stems from the fact that the cooperation in the agricultural sector to develop infrastructure that could mitigate the adverse effect of land, generates higher social capital, a crucial element for the development of the industrial sector. Therefore productivity growth in the (latent) industrial sector is higher for less productive countries in the process of development.

Figure 5: Overtaking of the Low Land Productivity Economy in the Industrialization Era



Geometrically, as depicted in Figure 4, a higher value of ξ causes the $MM_{|A_t^I}$ frontier to reside closer to the L_t-axis in $\left(A_t^A, L_t\right)$ space. This, combined with the fact that industrial productivity in the more productive place take place at a lower pace, implies that favorably endowed places may industrialize later, as depicted in Figure 5.

Following Propositions 1 and 2, variation in natural land endowment across societies is associated with the phenomenon of overtaking. Specifically, less favorable natural land endowment generates an inferior economic outcome in the agricultural stage of development, but it ultimately stimulates an earlier industrialization and, thus, an earlier take-off to a state of sustained economic growth. As such, natural land productivity of societies can have a profound effect on their historical experience with regard to the process of development.

Corollary 4 *(Natural Land Endowment and Overtaking) Consider two societies indexed by* $i \in \{U, P\}$*. Suppose that society* U *is characterized by a lower natural land endowment and that* $\xi^U < \xi^P$*, where* ξ^i *is the natural land endowment of society* i*. Society* U *will then be characterized by an inferior productivity in the Malthusian regime, but it will overtake society* P *via an earlier take-off into the industrial regime.*

6 Cross-Country Evidence

This section empirically examines the hypotheses that (i) a reversal of fortunes in the process of development can be traced to variation in land productivity across countries. Economies characterized by favorable land endowment dominated the world economy in the agricultural stage of development but were overtaken in the process of industrialization; (ii) cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could diminish the adverse effects of the environment and enhance agricultural output; (iii) lower level of land productivity in the past is associated with higher levels of contemporary social capital.

6.1 Empirical Strategy and Data

6.1.1 Empirical Strategy

To empirically examine the hypothesis that unfavorable natural land endowment has had a persistent positive impact on current economic outcomes through the emergence of cooperation and social capital, the analysis exploits cross-country variations in land productivity for agriculture to explain cross-country comparative development in years 1500 and 2000 respectively. The examination of comparative development at agricultural stages of development employs a Malthusian perspective, thereby assuming that temporary gains in income per capita were reflected to a larger but not richer population. Hence, as a proxy for prosperity in the agricultural stage of development, the research employs historical data on population density. To establish a "reversal of fortune" with respect to natural land endowments, the analysis employs cross country variations in land productivity, to explain the cross-country variation in log income per capita in 2000.

As suggested by the research, the effect of land productivity endowment on comparative development operates via the emergence of cooperation in the development of agricultural infrastructure and social capital. To address the issue of cooperation, the study employs data related to major forms of agricultural infrastructure that have been commonly used in pre-industrial era, as a proxy for the level of cooperation in agricultural societies, namely the extent of irrigation in the year 1900. To overcome data limitations, additional measures are used as proxies for cooperation, namely a) Communication in the year 1 b) Transportation in the year 1 c) Medium of Exchange in the year 1. The underlying assumption justifying the use of these measures, is that they can be viewed as by-products of cooperation in the development of agricultural infrastructure. The emergence of social capital is empirically addressed by employing an index of trust, constructed using the WVS (World Values Surveys) database.

In examining the impact of land endowment in economic outcomes in agricultural societies, the analysis controls for a number of channels. These channels include the timing of the Neolithic Revolution, due to its impact on the diffusion of agricultural technologies, as well as geographical factors, such as absolute latitude, access to waterways, average ruggedness, average elevation as well as dummies for landlocked countries and islands, all of which may have had a persistent effect on agricultural output and economic outcomes. As already stressed, the examination of comparative development in societies that are in the agricultural stage of development, requires a Malthusian interpretation of development outcomes, namely gains in income per capital at the time were only temporary since they implied a larger, but not richer, population (Ashraf and Galor, 2011a). Therefore to test the hypothesis that favorable land endowment had a positive impact on economic development during the agricultural stage, the analysis exploits cross-country variation in land endowment to explain the cross-country variations in log population density in the years 1, 1000, and 1500.

To establish a "reversal of fortune" with respect to natural land endowments, the analysis employs cross country variations in land productivity to explain the cross-country variation in log income per capita in 2000. A number of potentially confounding factors and alternative hypothesis suggested by the related literature with respect to comparative development are accounted for. The geography channel is controlled through a number of geographical controls that may affect economic outcomes today. The institutions hypothesis, that implies a "reversal of fortune" arising from the impact of European colonization, is accounted for though a number of controls including legal origins dummies, European colony dummies, institutional quality controls as well as population density in the year 1500, therefore controlling for the channel suggested by Acemoglu et al. (2001). Further controls about disease environment, ethnic fractionalization and religion shares are employed.

Crucially, as this research argues, it is not land productivity per se that drives the reversal of fortunes but instead, what is important is the portable component associated with land productivity, namely the level of cooperation developed and the social capital that emerged as the outcome of cooperation. Therefore two alternative strategies are adopted. Either the land productivity measure is adjusted to capture the portable component of natural land endowment, namely social capital, or the sample is restricted to countries with a percentage of native population above 75%. The adjustment of the land productivity index is based on the use of the migration matrix constructed by Putterman and Weil (2010), which provides estimates of the proportion of the ancestors in 1500 of one country's population today that were living within what are now the borders of that and each of the other countries. Therefore a measure of adjusted land productivity is constructed, that is the weighted average of the land productivity of the ancestral population of each country today. The second approach is less sophisticated, limiting the sample to countries that have a percentage of native population above 75%, thereby implying that the social capital that has been accumulated in the past, is still a prevalent norm among the native population.

The main hypothesis, namely the "reversal of fortunes", relies empirically on two intermediate building blocks. The first building block suggests that variations in land productivity led to variations in the level of cooperation developed in the agricultural sector, in an effort to mitigate the adverse effect of the natural environment. To capture the extent of cooperation in the agricultural sector, data on agricultural infrastructure data are used as a proxy. To address this issue, the study employs data related to major forms of agricultural infrastructure, that have been commonly used in pre-industrial era, as a proxy for the level of cooperation in agricultural societies, namely the extent of irrigation in the year 1900. This is the earliest date for which data on agricultural intervention are available.

The fact that data on irrigation come from year 1900 raises two potential issues. The first issue is that in the year 1900, a number of countries in the sample had already industrialized. Therefore upon industrialization and the acceleration of industrial technical progress, it is likely that agricultural infrastructure, such as irrigation, was affected as well and it would be plausible to assume that the early industrialized countries further expanded their irrigation infrastructure. In this case what would be reflected in this empirical relationship is the effect of the stage of economic development on the expansion of irrigation. Therefore, to ensure that irrigation in the year 1900 does not reflect the stage of economic development, the sample excludes countries that were members of the OECD in 1985. A measure of industrialization would potentially be more appropriate to limit the sample size and exclude the early industrialized countries, however the deficiency of this approach would be that the threshold level should be exogenously chosen. The choice of countries that were a member of the OECD in the year 1985, despite the fact that it refers to a later date than the one under examination, i.e. irrigation in the year 1900, it captures though the countries that experienced an early transition, and additionally, it is a more natural way to split the sample.

The second limitation stems from the fact that since the irrigation data are dated from the year 1900, where migration had already taken place in a number of countries, it could be argued that it is not the land productivity per se that affects the emergence of irrigation but also some portable component associated with land productivity. If migrants carry with them the specific human and social capital associated with the development of an irrigation system, this could imply that a higher fraction of irrigated land would emerge in countries with migrants possessing this specific human capital. This argument could be countered by arguing that, what this regression is aiming to capture is the trade-off in the allocation of resources between the production of the final and the public good. Even if a group of migrants have the necessary human and social capital for the development of agricultural infrastructure, they would still have a reduced incentive to invest in infrastructure as opposed to countries with more favorable natural land endowment. Nevertheless, this particular channel is controlled in the analysis, by restricting the sample of countries to the ones with a percentage of native population higher than 75%, following the same rational with the effect of land productivity on economic outcomes in the year 2000.

In an attempt to overcome data limitations and establish the robustness of the effect of natural land endowment on cooperation, additional measures are used as proxies for cooperation, namely: a) Communication in the year, 1 b) Transportation in the year, 1 c) Medium of Exchange in the year 1. The underlying assumption justifying the use of these measures is that they can be viewed as by-products of cooperation in the development of agricultural infrastructure. Agricultural societies that invested time and labor force to intervene in the intensive margin of agriculture, as a means to enhance land productivity, are the most likely candidates to have developed sophisticated means of communication and move gradually to non-mnemonic records and ultimately to written records, as the outcome of large-scale cooperation. The indirect effects of cooperation can be even more clearly indicated in the context of transportation, whereby a transition from human transportation to draft or pack animals and ultimately to vehicles could significantly facilitate the development of agricultural infrastructure. Given the resources needed to undertake an investment of this magnitude, it would be plausible to assume that more sophisticated mediums of exchange, namely domestically used articles and currency, would emerge in places that had an increase incentive to develop agricultural infrastructure.

The second building block pertains to the persistence of social capital across time. It is hypothesized that countries with unfavorable land endowment manifest higher levels of social capital and trust today. Data on social capital rely on an index of trust constructed by the World Values Survey database. A number of channels must be accounted for, namely geographical factor, institutions, ethnic fractionalization, disease environment and dummies on legal origins, European colony and major religion shares. As was the case with the regressions on per capital income in 2000, it is the portable component of land productivity that matters, therefore the study employs a measure of adjusted land productivity and also restricts the sample of countries to those with native population higher than 75%, to demonstrate the robustness of the results. As a robustness analysis, a different proxy of social capital has also been employed, namely the extent of participation in civic activities, as defined by La Porta et al. (1997).

6.1.2 The Data

Data on population density (in persons per square km) are derived by McEvedy and Jones (1978). Despite the inherent measurement problems associated with historical data, they are widely regarded as a standard source for population and income per capita data in the long-run growth literature.[33]

Land productivity measure is an index of the average suitability of land for cultivation, based on geospatial data on various ecological factors, related to climatic factors and soil quality. These factors include (i) growing degree days, (ii) the ratio of potential to actual evapotranspiration, (iii) soil carbon density, and (iv) soil pH. The index is reported at a half-degree resolution by Ramankutty et al. (2002). The average of land quality is thus the average value of the index across the grid cells within a country. This measure is obtained from the data set of Michalopoulos (2011).

One potential source of concern with respect to the measure of land productivity is about whether current data on the suitability of land for cultivation reflect land suitability in the past. What is crucial for the hypothesis advanced in this research, namely that reversal of fortunes in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector, is the ranking of countries with respect to their land productivity. It is assumed that land productivity as measured today, reflects the ranking of land productivity in the past. Intense cultivation and human intervention can affect the quality of land for cultivation over time, however it would be plausible to argue that the effect of human intervention on land quality affected all countries proportionally and therefore may have introduced a non-systematic error, in which case it would have harder to detect a relationship between variability in land quality and measures of economic outcomes and cooperation in the past. Therefore, so long as the ranking

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[33] For a more extensive discussion on the data see (Ashraf and Galor, 2011a).

in land productivity among countries in maintained, the relevant argument is unaffected by potential measurement errors.

The assumption that ranking has not been affected, is further enhanced by evidence related to the construction of the index, as documented by Ramankutty et al. (2002) and addressed by Michalopoulos (2011) and Nunn and Qian (2011), on a similar index constructed by the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) 2002 database. The first argument pertains to the fact, that one of the two components of the index is based upon climatic conditions, which have not significantly changed during the period of examination. Therefore, even if soil quality properties have significantly changed over time, this would still have a partial effect on the total index of land productivity. A second feature of the index, is that biophysical factors, such as topography and irrigation, and socioeconomic factors such as market price or incentive structure, which are important for determining whether land will be cultivated, are not part of the index, and the argument for adopting such an approach is based upon the observation that at the global scale, Ramankutty et al. (2002) find that climate and soil factors form the major constraints on cultivation, and adequately describe the major patterns of agricultural land. Finally, it can be argued that, since the measure employed denotes the average level of land quality within a given country, and given variations within countries, it would be implausible to anticipate that deteriorations in land quality in particular segments of the country, could affect the average land quality of a country, to the extent that it would change its overall ranking.

The adjustment of the land productivity index is based on the use of the migration matrix constructed by Putterman and Weil (2010) which provides estimates of the proportion of the ancestors in 1500 of one country's population today that were living within what are now the borders of that and each of the other countries. Therefore a measure of adjusted land productivity is constructed, that is the weighted average of the land productivity of the ancestral population of each country today. The variable of the percentage of native population is constructed by (Ashraf and Galor, 2011a), based on the migration matrix of Putterman and Weil (2010).

Data on irrigation are reported by Freydank and Siebert (2008), who have constructed a set of annual values of area equipped for irrigation for all 236 countries during the time period 1900 - 2003.[34] The *Irrigation in 1900* variable is using the data for the year 1900 and is expressed as a ratio of irrigated land over arable land. The limitation of the data lies in the fact that a number of countries had already industrialized in the year 1900. However evidence on the study suggests that major contributing countries have changed little with respect to the land equipped for irrigation during the 20th century, thereby implying that major expansions in their irrigation systems are likely to have taken place prior to industrialization. In addition, prior data for these countries that were used as a basis for interpolation to construct the database indicate that a significant part of the irrigation infrastructure had been constructed in years prior 1900 (Framji et al., 1981). Nevertheless to ensure that the extent of irrigation does not reflect the stage of economic development, the sample is limited to the subset of countries that were not member of the OECD in 1985.

Data on a) Communication in the year 1 b) Transportation in the year 1 c) Medium of Exchange in the year 1 are constructed from Peregrine's (2003) *Atlas of Cultural Evolution*, and

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[34] The values are provided in 1000 ha units

aggregated at the country level by Ashraf and Galor (2011a). Each of these three sectors is reported on a 3-point scale, as evaluated by various anthropological and historical sources. The level of technology in each sector is indexed as follows. In the communications sector, the index is assigned a value of 0 under the absence of both true writing and mnemonic or non-written records, a value of 1 under the presence of only mnemonic or non-written records, and a value of 2 under the presence of both. In the transportation sector, the index is assigned a value of 0 under the absence of both vehicles and pack or draft animals, a value of 1 under the presence of only pack or draft animals, and a value of 2 under the presence of both. In the Medium of Exchange sector, the index is assigned a value of 0 under the absence of domestically used articles and currency, a value of one under the presence of only domestically used articles and the value of 2 under the presence of both. In all cases, the sector-specific indices are normalized to assume values in the [0; 1]-interval. Given that the cross-sectional unit of observation in Peregrine's dataset is an archaeological tradition or culture, specific to a given region on the global map, and since spatial delineations in Peregrine's dataset do not necessarily correspond to contemporary international borders, the culture-specific technology index in a given year is aggregated to the country level by averaging across those cultures from Peregrine's map that appear within the modern borders of a given country.

Data on trust come for the *World Values Survey.* They are built upon the fraction of total respondents within a given country, from five different waves (1981-2008) based on their answers on the question "Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people".

6.2 Empirical Findings

6.2.1 The Impact of Land Productivity on Development in the Agricultural Stage

Table 1 establishes, in line with the theory, that favorable land endowment had a beneficial impact on economic development in the agricultural stage. Specifically, accounting for a variety of potentially confounding factors, the table demonstrates a positive effect of the log land productivity on log population density in the year 1500[35].

Employing a 148 cross-country sample, Column (1) reveals that log land productivity possesses a statistically significant positive relationship with population density in 1500 , conditional on continental fixed effects. The estimated linear coefficient associated with log land productivity implies that a 1 percentage point increase in land productivity would increase population density by 0.57% in 1500.

Column (2) augments the analysis of Column (1) with a number of exogenous geographical controls, all of which are important determinants of population density in the Malthusian epoch, as established in the empirical analysis of Ashraf and Galor (2011a). In particular it employs controls on absolute latitude, access to waterways, average ruggedness, average elevation as well as dummies for landlocked countries and islands, all of which may have had a persistent effect on agricultural output and economic outcomes. While these other factors do indeed confer statistically significant

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[35] Similar results are establishes for the effect of log land on log population density in the years 1CE and 1000 CE. and can be found in the Appendix.

Table 1: Land Productivity and Comparative Development in the Agricultural Stage

	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in 1500			
Log Land Productivity	0.572***	0.428***	0.442***	0.431***
	(0.0753)	(0.0644)	(0.0578)	(0.0531)
Log Average Ruggedness		0.180	0.247*	0.254**
		(0.134)	(0.125)	(0.114)
Log Average Elevation		-0.00712	-0.126	-0.158
		(0.124)	(0.124)	(0.103)
Log Absolute Latitude		-0.422***	-0.303**	-0.373***
		(0.161)	(0.144)	(0.142)
Mean Distance to Nearest Coast or River		-0.415**	-0.376**	-0.370**
		(0.196)	(0.172)	(0.165)
% of Land within 100 km of Coast or River		0.930**	0.841**	0.745**
		(0.366)	(0.350)	(0.330)
Log Years Since Neolithic			1.108***	0.873***
			(0.213)	(0.218)
Distance to Frontier in 1500				–0.201***
				(0.0383)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	148	148	148	148
R-squared	0.553	0.671	0.724	0.754

Summary This table establishes the significant positive effect of land productivity on population density in the year 1500, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier and fixed effects for landlocked country, island, and unobserved continental fixed effects.

Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

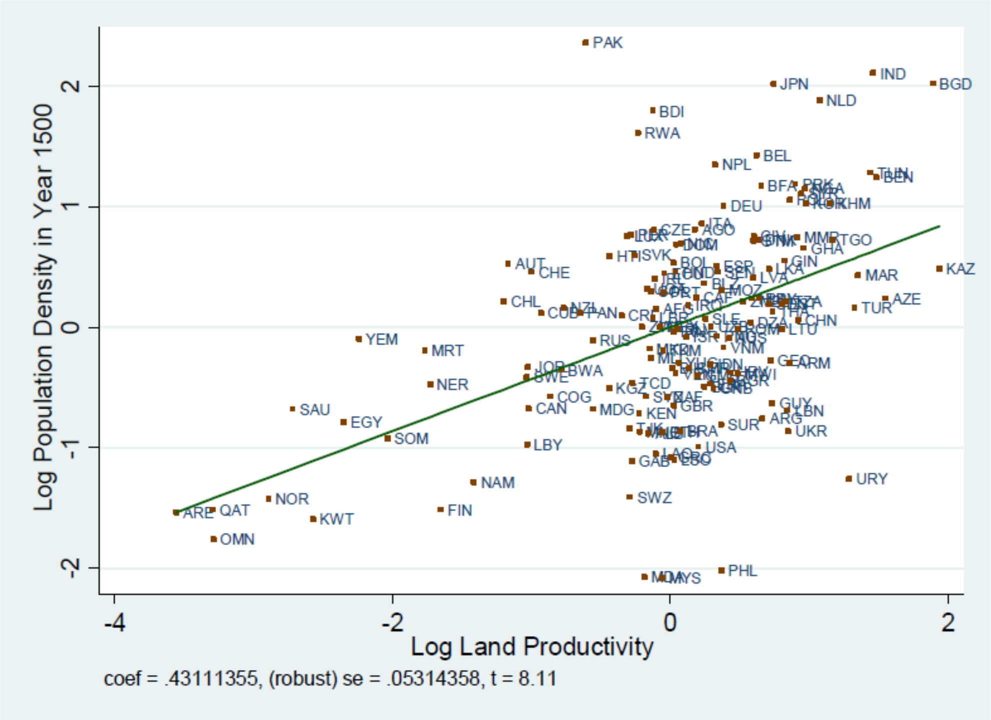
effects on population density in 1500, log land productivity continues to have a statistically significant beneficial impact on economic development in this period, with the point estimate of the relevant coefficient remaining largely unchanged in comparison to its estimate in Column (1).

The regression presented in Column (3) further augments the analysis with additional controls on the timing of the Neolithic Revolution which has been argued to have a beneficial effect on economic outcomes in the year 1500. Nevertheless and despite the statistical significance of this channel, the point estimate and statistical significance of the coefficient associated with log land productivity remains largely intact.

Column (4) introduces into the analysis distance from the closest technological frontier as derived by Ashraf and Galor (2011a). As predicted in their research, distance from the closest technological frontier has a significant negative impact on economic development. Reassuringly however, and despite the significance of this channel, the point estimate and statistical significance of the coefficient associated with log land productivity remains remarkably stable. According to the regression, a one percentage point increase in land productivity is associated with a 0.43% increase in population density in 1500.

The evidence presented in Table 1 therefore establishes, in accordance with the theory, that indeed favorable land endowment had a beneficial impact on economic development during the agricultural stage of development. The positive effect of land productivity on economic outcomes in the year 1500 is depicted on the scatter plot in Figure 6.

Figure 6: Land Productivity and Population Density in the Year 1500



coef = .43111355, (robust) se = .05314358, t = 8.11

Exploiting variations across a sample of 107 countries for which data on the full set of variables used by the analysis are available, Column (1) reveals that, conditional on continental fixed effects, land productivity possesses a statistically significant negative relationship with income per capita

Table 2: Land Productivity and Comparative Development in the Industrial Era

	(1)	(2)	(3)	(4)	(5)	(6)
	Dep. Var.: Log Per Capita Income in 2000					
Log Land Productivity	-0.201***	-0.247***	-0.252***	-0.271***	-0.197**	-0.218***
	(0.0621)	(0.0585)	(0.0690)	(0.0690)	(0.0878)	(0.0809)
Log Average Ruggedness		-0.0899	-0.0215	0.0611	0.0652	0.118
		(0.147)	(0.104)	(0.111)	(0.109)	(0.114)
Log Average Elevation		0.215	-0.00637	-0.204	-0.221*	-0.257*
		(0.168)	(0.117)	(0.130)	(0.132)	(0.142)
Log Absolute Latitude		0.163	-0.119	0.0112	0.0111	0.0202
		(0.125)	(0.116)	(0.155)	(0.143)	(0.227)
Distance to Near Coast/River		-0.367*	-0.310*	-0.179	-0.222	-0.293**
		(0.196)	(0.184)	(0.174)	(0.172)	(0.141)
% Land within 100km of Water		0.582	0.0220	-0.184	-0.160	-0.340
		(0.395)	(0.323)	(0.353)	(0.356)	(0.338)
Log Adj. Years Since Neolithic		-0.279	-0.0306	0.000315	0.231	0.106
		(0.260)	(0.197)	(0.293)	(0.331)	(0.330)
Ethnolinguistic Fractionalization			-0.799**	-0.416	-0.507	-0.305
			(0.351)	(0.362)	(0.346)	(0.365)
Polity IV			0.104***	0.0651**	0.0693**	0.0687**
			(0.0234)	(0.0268)	(0.0266)	(0.0307)
% of Pop at Risk of Malaria			-1.103***	-1.240***	-1.037**	-1.163***
			(0.290)	(0.409)	(0.398)	(0.427)
Population Density in 1500					-0.141	
					(0.0968)	
Continental Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes	Yes
Legal Origin Dummies	No	No	No	Yes	Yes	Yes
European Colony Dummy	No	No	No	Yes	Yes	Yes
Major Religion Shares	No	No	No	Yes	Yes	Yes
Native Population >0.75	No	No	No	No	No	Yes
Observations	107	107	107	107	107	83
R-squared	0.601	0.687	0.803	0.853	0.858	0.911

Summary: This table establishes the significant negative effect of land productivity on per capita income in the year 2000 CE, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, adjusted years since the Neolithic transition, ethnolinguistic fractionalization, quality of institutions, disease environment, and fixed effects for landlocked country, island, legal origin, European colony, and unobserved continental fixed effects. Column (5) establishes that the effect of land productivity on per capita income in the year 2000 does not operate through population density in the year 1500. Column (6) restricts the sample to countries with a fraction of native population higher than 75 percent, implying that it is the portable component of land productivity, namely social capital, that is affecting current economic outcomes.
Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, Australia, Europe, North America, South America and Oceania; (iii)the set of legal origins dummies in columns (4)-(6) includes a fixed effect for British legal origin, French origin, German origin, Scandinavian origin and Socialist origin; (iv) the set of major religion shares dummies in columns (4)-(6) includes a fixed effect for Catholic share, Muslim share, Protestant share, and other religious shares; (v)the set of European colony dummies in columns (4)-(6) include a fixed effect for British colony, French colony, Portuguese colony, Spanish colony and other European colony; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

in 2000. Specifically, the regression coefficient implies that a one percentage point increase in land productivity is associated with a 0.20% decrease in income per capita in 2000.

Column (2) augments the current analysis with a number of geographical controls and for the timing of the Neolithic Revolution. As is evident from the results, while some of these other factors do possess statistically significant correlations with income per capita in 2000, the persistent adverse effect of land productivity on development in the industrial stage remains qualitatively robust, maintaining statistical significance and increasing somewhat in magnitude under these additional controls.

Column (3) reveals that, introducing into the analysis additional controls for ethnolinguistic fractionalization, institutional controls and disease environment, further augments the point estimate and statistical significance associated with the coefficient on land productivity, despite the significance of these controls in income per capita in 2000.

To ensure that the observed reversal in the impact of land productivity on economic outcomes is not being driven by the institutional channels associated with European colonialism (Acemoglu et al., 2005), the regression in Column (4) introduces controls for legal origins and colonial dummies. Additionally it introduces controls for major religion shares. Reassuringly, the regression coefficient associated with the land productivity remains largely robust.[36]

The analysis in Column (5) assures that the observed adverse effect of land productivity on development in the industrial stage is not simply reflecting a "reversal of fortune" that is associated with the level of economic development in 1500, as captured by log population density in this time period. The results reassuringly indicate that (i) there is no statistically significant negative correlation between development outcomes in the industrial vs. agricultural stages of development, and, more importantly, (ii) the magnitude of the persistent detrimental effect of land productivity on per-capita income in 2000 is largely unaffected under this explicit control for unobserved historical persistence, diminishing only moderately in magnitude and in statistical significance.

Crucially, in the context of the proposed theory what is important with respect to the effect of land productivity on current economic outcomes, is not land productivity per se but instead the portable component associated with land productivity, namely the social capital that emerged as the outcome of cooperation in the agricultural sector for the development of agricultural infrastructure. Column (6) addresses this issue by restricting the sample to 83 countries that have native population over 55% of the total population retaining all the controls introduced in Column (5). Remarkably the results strongly support the hypothesis, with the coefficient of land productivity increasing both in magnitude (doubling) and statistical significance. Clearly, when the sample is restricted to the native population it is indeed the portable component of land

productivity, namely the level of social capital that is causing the reversal of fortune as opposed to the land productivity per se.[37]

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[36] Additional robustness analysis has been conducted by introducing a dummy for OPEC countries that have high levels of income due to abundant natural resources. Nevertheless the results remain largely intact.

[37] The threshold level of the native population is chosen in a way that minimizes the trade-off between the reduced observations and the fraction of the native people. This trade-off becomes even more critical in following regression on the level of trust for which the sample size is rather limited from the outset. Choosing a higher threshold would significantly reduce the size without qualitatively altering the results.

In the regression on economic outcomes in the year 2000, it is crucial to highlight that employing the adjusted measure of land productivity, using the migration matrix constructed by Putterman and Weil (2010), is not the optimal strategy because one should employ both measures of land productivity, namely the adjusted and the unadjusted, since both factors can have an impact on current economic outcomes. Since though the two measures are highly correlated, reliable results could not be obtained.

The evidence presented in Table 2 therefore demonstrates, consistently with the theory, that land productivity has had a persistent detrimental impact on economic development in the course of industrialization, due to the reduced incentive it generated for cooperation in the agricultural sector and ultimately the lower level of social capital that emerged as the outcome of the reduced cooperation. The negative effect of land productivity on economic outcomes in the year 2000 is depicted on the scatter plot in Figure (7). Figure (8) indicates the same effect for the restricted sample of countries with a fraction of the native population higher than 75%.

Figure 7: Land Productivity and Economic Outcomes in the Year 2000

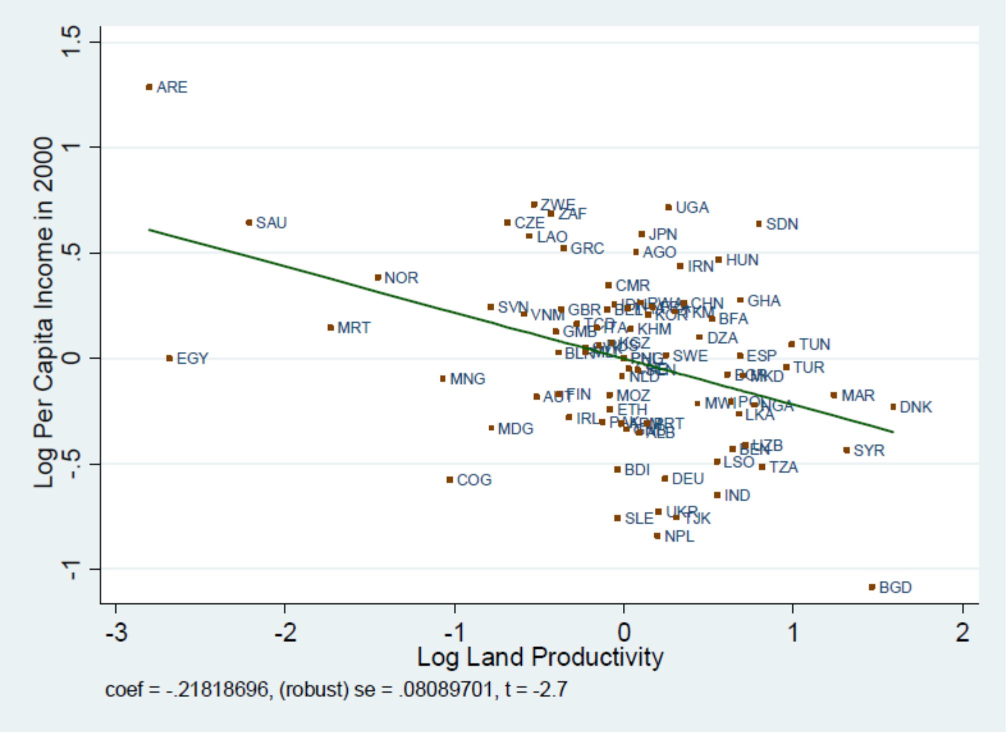
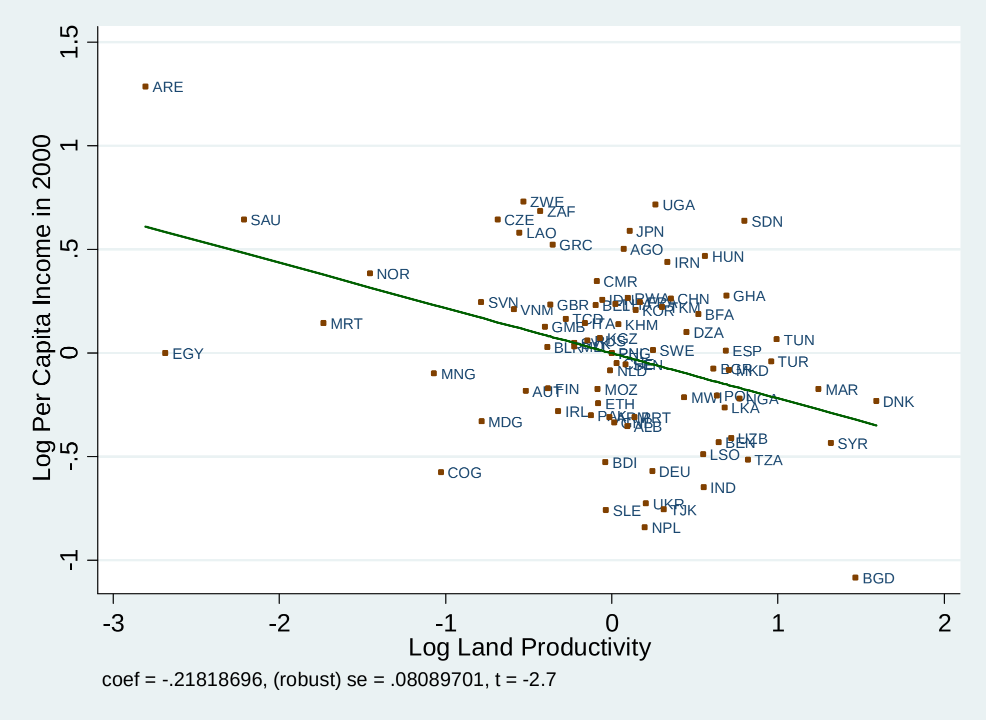


Figure 8: Land Productivity and Economic Outcomes in the Year 2000-Restricted Sample



6.2.2 The Impact of Land Productivity on Cooperation in the Agricultural Stage

The evidence presented so far establishes a reversal of fortune in the process of economic development with respect to natural land endowment. Tables 3, 4, 5 and 6 establish that this reversal operates through the cooperation developed in the agricultural sector in an effort to mitigate the adverse effect of land. Cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could diminish the adverse effects of the environment and enhance agricultural output. The primary measure that is used for cooperation in the agricultural sector is the fraction of irrigated land over the fraction of arable land in the year 1900. A has already been mentioned, the limitation of the data lies in the fact that a number of countries had already industrialized in the year 1900. Therefore to ensure that the extent of irrigation does not reflect the stage of economic development, the whole analysis will be conducted with the sample limited to the subset of countries that were not members of the OECD in 1985.

Consistently with the predictions of the theory, Table 3 establishes that countries with unfavorable land endowment had an increased incentive to invest in agricultural infrastructure as a means to mitigate the adverse effect of land. In particular, the analysis reveals a statistically significant and robust negative effect of the log land productivity on the fraction of irrigated land in 1900.

Exploiting variations across a sample of 72 countries for which data on the full set of variables used by the analysis are available, Column (1) in Table 3 reports a statistically significant effect, at the 5%, of land productivity on the fraction of irrigated land, while controlling only for continental fixed effects.

Table 3: Cooperation in the Agricultural Stage-Irrigation

	(1)	(2)	(3)	(4)	(5)
			Dep. Var.: Irrigation in 1900		
Log Land Productivity	-0.283**	-0.448***	-0.430***	-0.439***	-0.483***
	(0.141)	(0.123)	(0.112)	(0.109)	(0.151)
Log Average Ruggedness		0.329	0.472	0.494	0.226
		(0.317)	(0.337)	(0.331)	(0.402)
Log Average Elevation		0.574*	0.517	0.429	0.862**
		(0.308)	(0.326)	(0.324)	(0.401)
Log Absolute Latitude		0.216	0.200	0.142	0.456
		(0.189)	(0.198)	(0.202)	(0.499)
Mean Distance to Nearest Coast or River		-0.482	-0.260	-0.320	-0.0499
		(0.369)	(0.391)	(0.410)	(0.551)
% of Land within 100 km of Coast or River		2.615***	2.907***	2.746**	4.312***
		(0.969)	(1.034)	(1.056)	(1.464)
Log Years Since Neolithic			0.965	0.622	0.912
			(0.672)	(0.722)	(0.949)
Distance to Frontier in 1500				-0.154	-0.0533
				(0.0945)	(0.120)
Continental Dummies	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes
Native Population >0.75	No	No	No	No	Yes
Observations	72	72	72	72	44
R-squared	0.461	0.672	0.688	0.697	0.758

Summary This table establishes the significant adverse effect of land productivity on cooperation, as proxied by the fraction of irrigated land over arable lad in the year 1900, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1500, and fixed effects for landlocked country, island, and unobserved continental fixed effects. The statistical significance of the coefficient in Column (5), which restricts the sample to a subset of countries with a fraction of native population higher than 75%, ensures that it is the adverse effect of land that is positively affecting cooperation in the year 1900 and not the specific human capital of the migrant population. Notes: (i) The dataset excludes countries that were not a member of the OECD in 1985, in an attempt to exclude the countries that had already industrialized in 1900; (ii) Data on irrigation are reported by Freydank and Siebert (2008), who have constructed a set of annual values of area equipped for irrigation for all 236 countries during the time period 1900 - 2003. The irrigation variable is using the data for the year 1900 CE and is expressed as a ratio of irrigated land over arable land; (iii) log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (iv) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia, Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (v) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (vi) robust standard error estimates are reported in parentheses; (vii) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

Column (2) enriches the analysis with a number of exogenous geographical controls, namely absolute latitude, access to waterways, average ruggedness, average elevation as well as dummies for landlocked countries and islands, all of which are crucial factors for the development of irrigation systems. Despite the statistical significance of the geographical controls, and particularly of controls that are associated with access to waterways, the analysis establishes a statistically significant negative effect of land productivity on the development of irrigation in the year 1900.

Column (3) controls for the timing of the Neolithic Revolution that could have positively affected the emergence of more extensive irrigation infrastructure. Nevertheless the coefficient remains largely intact and statistically significant.

Column (4) is controlling for the distance from the nearest technological frontier in the year 1500, which is a crucial channel since it would imply that more sophisticated irrigation methods could be developed. Nevertheless the coefficient of land productivity remains highly significant and intact.

Since the irrigation data are dated from the year 1900, where migration had already taken place in a number of countries, it could be argued that it is not the land productivity per se that affects the emergence of irrigation but also some portable component associated with land productivity. If migrants carry with them the specific human and social capital associated with the development of an irrigation system, this could imply that a higher fraction of irrigated land would emerge in countries with migrants possessing this specific human capital. This argument could be countered by arguing that what this regression is aiming to capture is the trade-off in the allocation of resources between the production of the final and the public good. Even if a group of migrants have the necessary human and social capital for the development of agricultural infrastructure, they would still have a reduced incentive to invest in infrastructure as opposed to countries with more favorable land endowment. Nevertheless, this particular channel is controlled in the analysis by restricting the sample of countries to the ones with a percentage of native population higher than 75%, following the same rational with the effect of land productivity on economic outcomes in the year 2000. Column (5) which is controlling for this potential channel establishes the adverse effect of land productivity on the development of irrigation in the year 1900, with the coefficient increasing in magnitude implying that a 1% increase in land productivity would be associated with a 0.483 decrease in the fraction of irrigated land.

The evidence presented in table 3, is thereby establishing the adverse effect of land productivity on the emergence of irrigation. The negative effect of land productivity on the fraction of irrigated land in the year 1900 is depicted on the scatter plot in Figure (9). Figure (10) indicates the same effect for the restricted sample of countries with a fraction of the native population higher than 75%.

Figure 9: Land Productivity and Irrigation in the Year 1900

coef = -.43871109, (robust) se = .10859322, t = -4.04

Figure 10: Land Productivity and Irrigation in the Year 1900-Restricted Sample

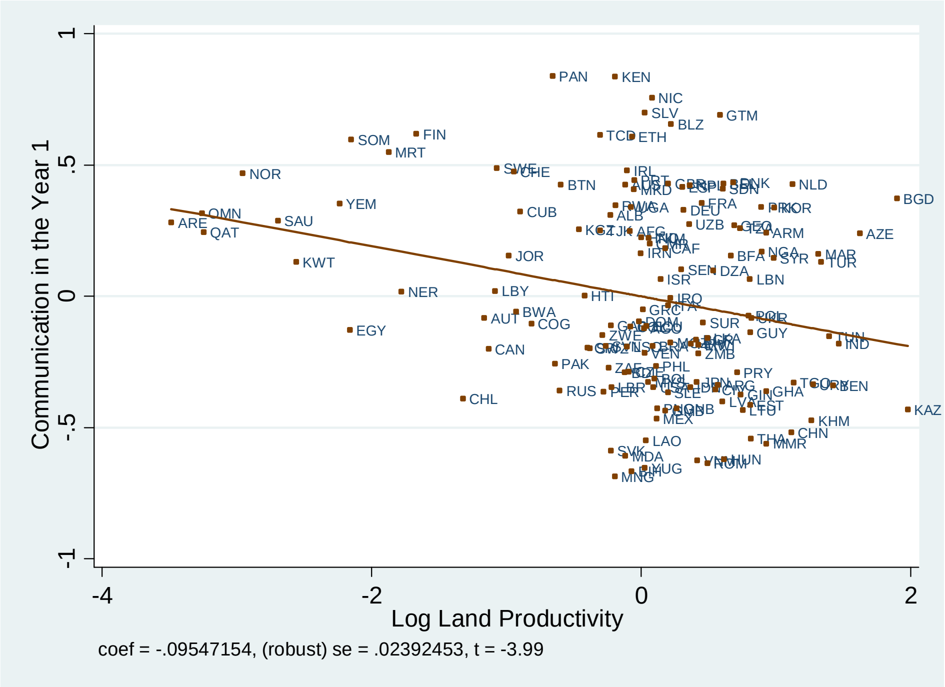
coef = -.48305914, (robust) se = .15075863, t = -3.2

In the absence of more extended agricultural infrastructure historical data, three alternative measures are used as proxies for cooperation, namely a) Communication in the year 1, b) Transportation in the year 1, and c) Medium of Exchange in the year 1. The rational in employing these particular data is that societies that had an increased incentive to cooperate in the agricultural sector for the development of infrastructure that would mitigate the adverse effect of land, are rather likely to have developed more sophisticated means of communication, transportation and medium of exchange, so as to facilitate cooperation.

Exploiting variations across a sample of 143 countries for which data on the full set of variables used by the analysis are available, Column (1) in Table 4 establishes, conditional on continental fixed effects, a statistically significant negative effect of land productivity on the development of sophisticated means of communication in the year 1. Column (2) enriches the analysis with geographical controls. Whereas the controlled factors do possess statistically significant correlations with the development of means of communication in the year 1, the persistent effect of land productivity in the development of means of communication remains statistically significant. Column (3) controls for the timing of the Neolithic Revolution that is attested to have affected the emergence of more developed communication means. Nevertheless the coefficient remains largely intact and statistically significant. Column (4) controls for the distance from the nearest technological frontier, however the coefficient remains remarkably stable.

The evidence presented in Table 4, is thereby establishing the detrimental effect of land productivity on the emergence of more sophisticated means of communication during the agricultural stage of development. The positive effect of land productivity on communication in the year 1 is depicted on the scatter plot in Figure (11).

Figure 11: Land Productivity and Communication in the Year 1



coef = -.09547154, (robust) se = .02392453, t = -3.99

Employing a 143 cross country sample, Column (1) in table 5 establishes, conditional on continental fixed effects, a statistically significant negative effect of land productivity on the development of sophisticated means of transportation in the year 1. Column (2) further augments the analysis with additional geographical controls. Despite the statistical significance of the additional controls,

Table 4: Cooperation in the Agricultural Stage-Communication

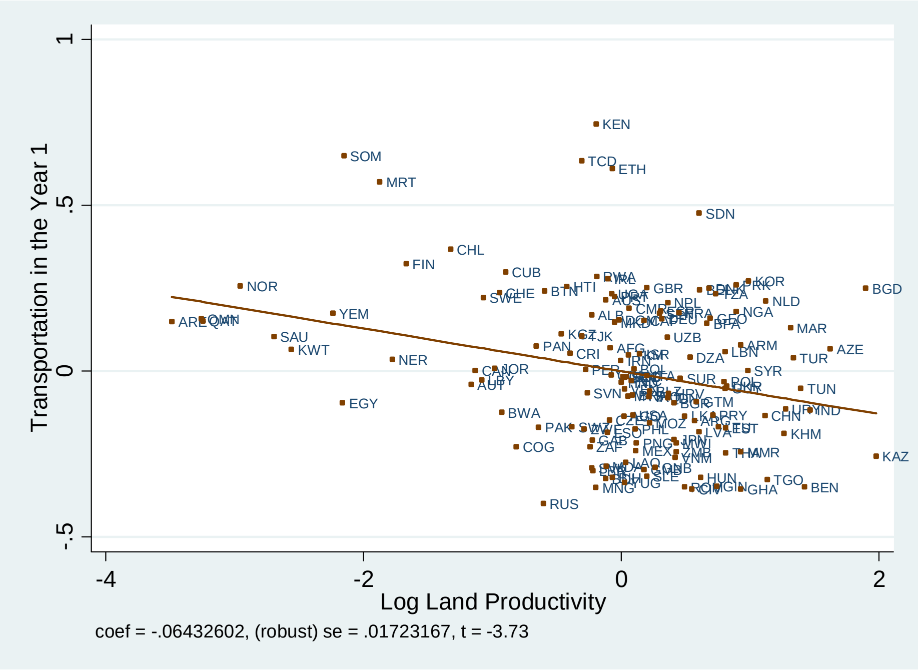
	(1)	(2)	(3)	(4)
	Dep. Var.: Communication in the Year 1			
Log Land Productivity	-0.0892***	-0.101***	-0.0958***	-0.0955***
	(0.0219)	(0.0234)	(0.0236)	(0.0239)
Log Average Ruggedness		0.0485	0.0711	0.0626
		(0.0540)	(0.0537)	(0.0524)
Log Average Elevation		0.0224	-0.0143	-0.0153
		(0.0538)	(0.0535)	(0.0498)
Log Absolute Latitude		0.0629	0.0961*	0.0836*
		(0.0549)	(0.0500)	(0.0495)
Mean Distance to Nearest Coast or River		0.0408	0.0528	0.0601
		(0.111)	(0.103)	(0.102)
% of Land within 100 km of Coast or River		0.203	0.169	0.158
		(0.183)	(0.177)	(0.174)
Log Years Since Neolithic			0.325***	0.258***
			(0.0934)	(0.0983)
Distance to Frontier in the Year 1				-0.0521***
				(0.0188)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	143	143	143	143
R-squared	0.274	0.328	0.376	0.388

Summary: This table establishes the significant adverse effect of land productivity on cooperation, as proxied by the means of communication in the year 1, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1, and fixed effects for landlocked country, island, and unobserved continental fixed effects. Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) data on communication in the year 1 are constructed from Peregrine's (2003) Atlas of Cultural Evolution, and aggregated at the country level by Ashraf and Galor (2011a). The measure is reported on a 3-point scale, as evaluated by various anthropological and historical sources; (iii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

the persistent effect of land productivity in the development of means of communication remains statistically significant and largely unaffected. Column (3) enriches the analysis by controlling for the timing of the Neolithic Revolution however the coefficient remains intact. Column (4) establishes similar results even after controlling for the distance from the nearest technological frontier.

The evidence presented in table 5, is thereby establishing the detrimental effect of land productivity on the emergence of more sophisticated means of transportation during the agricultural stage of development. The positive effect of land productivity on transportation in the year 1 is depicted on the scatter plot in Figure (12).

Figure 12: Land Productivity and Transportation in the Year 1



Employing a 143 cross country sample, Column (1) in Table 6 establishes, conditional on continental fixed effects, a statistically significant negative effect of land productivity on the development of sophisticated mediums of exchange in the year 1. Column (2) further augments the analysis with additional geographical controls, reassuringly though the coefficient of land productivity remains intact. Column (3) controls for the timing of the Neolithic Revolution, whereas Column (4) controls for the distance from the nearest technological frontier. In both cases and whereas the controlled factors do possess statistically significant correlations with the development of medium of exchange in the year 1, the persistent effect of land productivity in the development of medium of exchange remains statistically significant.

The evidence presented in Table 6, is thereby establishing the detrimental effect of land productivity on the emergence of more sophisticated medium of exchange during the agricultural stage of development. The positive effect of land productivity on the medium of exchange in the year 1 is depicted on the scatter plot in Figure (13).

Table 5: Cooperation in the Agricultural Stage-Transportation

	(1)	(2)	(3)	(4)
	Dep. Var.: Transportation in the Year 1			
Log Land Productivity	-0.0661***	-0.0687***	-0.0645***	-0.0643***
	(0.0162)	(0.0176)	(0.0170)	(0.0172)
Log Average Ruggedness		0.0111	0.0291	0.0249
		(0.0366)	(0.0358)	(0.0349)
Log Average Elevation		0.0265	-0.00274	-0.00325
		(0.0384)	(0.0378)	(0.0358)
Log Absolute Latitude		0.0217	0.0481	0.0419
		(0.0419)	(0.0381)	(0.0384)
Mean Distance to Nearest Coast or River		0.0140	0.0235	0.0271
		(0.0828)	(0.0764)	(0.0754)
% of Land within 100 km of Coast or River		0.0379	0.0113	0.00585
		(0.0985)	(0.0944)	(0.0931)
Log Years Since Neolithic			0.259***	0.226***
			(0.0630)	(0.0674)
Distance to Frontier in the Year 1				-0.0257**
				(0.0109)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	143	143	143	143
R-squared	0.673	0.685	0.721	0.725

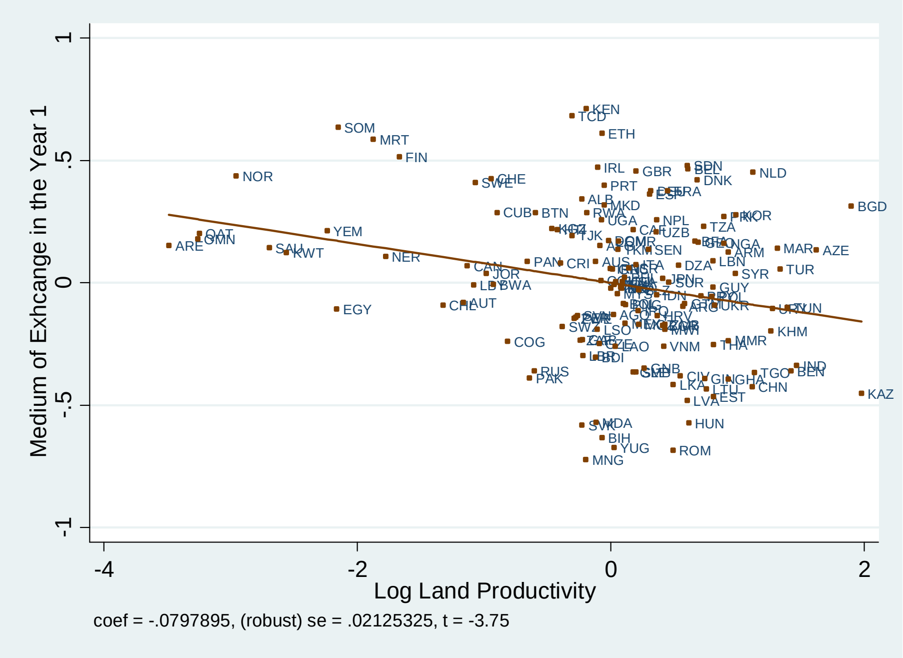
Summary: This table establishes the significant adverse effect of land productivity on cooperation, as proxied by the means of transportation in the year 1, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1, and fixed effects for landlocked country, island, and unobserved continental fixed effects. Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) data on transportation in the year 1 are constructed from Peregrine's (2003) Atlas of Cultural Evolution, and aggregated at the country level by Ashraf and Galor (2011a). The measure is reported on a 3-point scale, as evaluated by various anthropological and historical sources; (iii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data ; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

TABLE 6: Cooperation in the Agricultural Stage-Medium of Exchange

	(1)	(2)	(3)	(4)
	Dep. Var.: Medium of Exchange in the Year 1			
Log Land Productivity	-0.0756***	-0.0845***	-0.0801***	-0.0798***
	(0.0183)	(0.0208)	(0.0210)	(0.0213)
Log Average Ruggedness		0.0608	0.0799*	0.0733
		(0.0471)	(0.0466)	(0.0456)
Log Average Elevation		-0.0156	-0.0466	-0.0474
		(0.0427)	(0.0423)	(0.0398)
Log Absolute Latitude		0.0126	0.0406	0.0310
		(0.0425)	(0.0386)	(0.0388)
Mean Distance to Nearest Coast or River		-0.0199	-0.00983	-0.00422
		(0.0979)	(0.0916)	(0.0908)
% of Land within 100 km of Coast or River		-0.0246	-0.0528	-0.0613
		(0.133)	(0.130)	(0.128)
Log Years Since Neolithic			0.275***	0.223***
			(0.0725)	(0.0777)
Distance to Frontier in the Year 1				-0.0401***
				(0.0144)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	143	143	143	143
R-squared	0.495	0.520	0.557	0.565

Summary: This table establishes the significant adverse effect of land productivity on cooperation, as proxied by the medium of exchange in the year 1, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1, and fixed effects for landlocked country, island, and unobserved continental fixed effects. Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) data on medium of exchange in year 1000 are constructed from Peregrine's (2003) Atlas of Cultural Evolution, and aggregated at the country level by Ashraf and Galor (2011a). The measure is reported on a 3-point scale, as evaluated by various anthropological and historical sources; (iii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

Figure 13: Land Productivity and Medium of Exchange in the Year 1



coef = -.0797895, (robust) se = .02125325, t = -3.75

Reassuringly, as is evident from Tables 3, 4, 5 and 6, there is a statistically significant adverse effect of land productivity on a number of proxies for cooperation during the agricultural stage of development, namely a) Fraction of irrigated land in the year 1900, b) Communication in the year 1, c) transportation in the year 1, d) Medium of exchange in the year 1. The measure for irrigation is a direct measure of cooperation in the agricultural stage of development, whereas the alternative measures can be viewed as by-products of cooperation in the development of agricultural infrastructure.

6.2.3 The Impact of Land Productivity on Trust in the Industrial Stage

Consistently with the predictions of the theory, Table 7 establishes that countries with unfavorable land endowment manifest higher levels of social capital and trust today. In particular, the analysis reveals a statistically significant and robust negative effect of the log adjusted land productivity on the index of trust. Crucially, in the regression of trust, a measure of the adjusted land productivity is appropriate, since it lays emphasis on the portable component of land productivity. As opposed to the regression on per capita income in the year 2000, the measure of land productivity does not have to be employed in the analysis, since there is no effect of land productivity on trust and therefore the measure of adjusted land productivity can be easily employing without any collinearity issues arising.

Exploiting variations across a sample of 72 countries for which data on the full set of variables used by the analysis are available, Column (1) reveals that, conditional on continental fixed effects, adjusted land productivity possesses a statistically significant negative relationship with trust.

Column (2) augments the current analysis with a number of exogenous geographical controls as well as with a control for the timing of the Neolithic Revolution. As is evident from the results, the persistent adverse effect of land productivity on trust in the industrial stage remains

Table 7: Adjusted Land Productivity and Trust

	(1)	(2)	(3)	(4)	(5)
			Dep. Var.: Trust		
Log Adjusted Land Productivity	-0.0909***	-0.100***	-0.0966***	-0.0656**	
	(0.0173)	(0.0200)	(0.0220)	(0.0242)	
Log Land Productivity					-0.0540***
					(0.0165)
Log Average Ruggedness		0.00677	0.00649	-0.0313	-0.0312
		(0.0427)	(0.0422)	(0.0356)	(0.0403)
Log Average Elevation		-0.0132	-0.0130	-0.000261	-0.0137
		(0.0716)	(0.0697)	(0.0472)	(0.0488)
Log Absolute Latitude		-0.00193	-0.0345	0.109**	0.0838
		(0.0283)	(0.0442)	(0.0404)	(0.0558)
Distance to Near Coast/River		-0.0895**	-0.0848**	-0.0220	-0.0290
		(0.0345)	(0.0334)	(0.0407)	(0.0487)
% Land within 100km of Water		-0.0120	-0.0324	0.0111	0.00714
		(0.108)	(0.108)	(0.0878)	(0.109)
Log Adj. Years Since Neolithic		-0.0506	-0.0585	0.232**	0.209*
		(0.0745)	(0.0781)	(0.101)	(0.121)
Ethnolinguistic Fractionalization			-0.101	0.0850	0.217
			(0.104)	(0.110)	(0.139)
Polity IV			0.00267	-0.0154*	-0.0138*
			(0.00520)	(0.00754)	(0.00792)
% of Pop at Risk of Malaria			-0.0658	0.172	0.0706
			(0.114)	(0.120)	(0.122)
Continental Dummies	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes
Legal Origin Dummies	No	No	No	Yes	Yes
European Colony Dummy	No	No	No	Yes	Yes
Major Religion Shares	No	No	No	Yes	Yes
Native Population >0.75	No	No	No	No	Yes
Observations	57	57	57	57	49
R-squared	0.415	0.514	0.537	0.788	0.818

Summary: This table establishes the significant adverse effect of adjusted land productivity on per the current level of generalized trust, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, adjusted years since the Neolithic transition, ethnolinguistic fractionalization, quality of institutions, disease environment, and fixed effects for landlocked country, island, legal origin, European colony, and unobserved continental fixed effects. Column (5) restricts the sample to countries with a fraction of native population higher than 75 percent and is employing a measure of land productivity as opposed to adjusted land productivity, as an additional robustness check to the results that it is the portable component of land productivity, namely cooperation developed in the agricultural sector, that is affecting current economic outcomes. Notes: (i) Data on trust come from five different waves of the World Values Survey (1981-2008) and they are built upon the fraction of total respondents within a given country, based on their answers on the question "Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people"; (ii) log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (iii) The measure for adjusted land productivity is adjusting the land productivity index, based on the use of the migration matrix constructed by Putterman and Weil (2010) which provides estimates of the proportion of the ancestors in 1500 of one country's population today that were living within what are now the borders of that and each of the other countries. (iv) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, Australia, Europe, North America, South America and Oceania; (v) the set of legal origins dummies in columns (4)-(6) includes a fixed effect for British legal origin, French origin, German origin, Scandinavian origin and Socialist origin; (vi) the set of major religion shares dummies in columns (4)-(6) includes a fixed effect for Catholic share, Muslim share, Protestant share, and other religious shares; (vii) the set of European colony dummies in columns (4)-(6) include a fixed effect for British colony, French colony, Portuguese colony, Spanish colony and other European colony; (viii) robust standard error estimates are reported in parentheses; (ix) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

qualitatively robust, maintaining statistical significance and increasing somewhat in magnitude under these additional controls.

Column (3) further arguments the analysis by introducing additional controls for ethnolinguistic fractionalization, institutional controls and disease environment. A greater degree of fractionalization could be detrimental for trust whereas better institutions have historically been associated with less trust (Putnam, 2007), whereas better institutions may be associated with higher levels of trust. Nevertheless, even after controlling for these additional channels the coefficient remains largely intact.

To ensure that the observed impact of land productivity on trust is not being driven by the institutional channels associated with European colonialism, and keeping in line with the structure of the table on the effect of adjusted land productivity on current economic outcomes, the regression in Column (4) introduces controls for legal origins, colonial dummies as well as dummies on major religion shares. Even after controlling for all this additional channels, the regression coefficient associated with the land productivity remains largely robust.

Whereas adjusted land productivity is the appropriate measure, Column (5) conducts a robustness check by using the measure of log land productivity and restricting the sample to the countries that have a percentage of native population higher than 75%. Reassuringly, while the coefficient drops slightly in magnitude, its statistical significance remains unaffected.

The evidence presented in Table 7 therefore demonstrates, consistently with the theory, that indeed the land productivity has had a persistent detrimental impact on current levels of trust, due to the reduced incentive it generated for cooperation in the agricultural sector and ultimately the lower level of social capital that emerged and persisted as the outcome of the reduced cooperation.[38] The negative effect of land productivity on the generalized level of trust is depicted on the scatter plot in Figure (14). Figure (15) indicates the same effect for the restricted sample of countries with a fraction of the native population higher than 75%.

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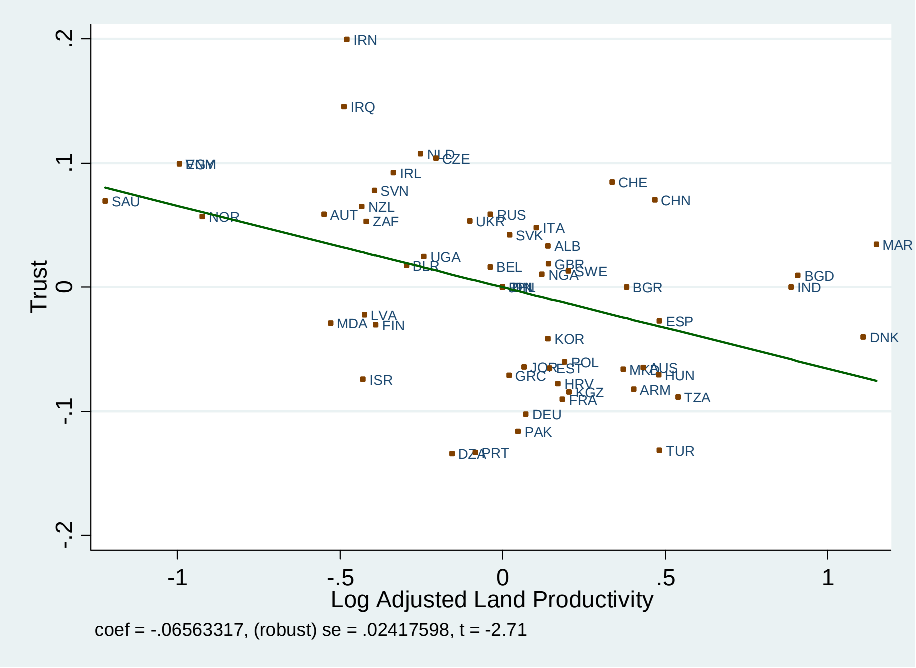
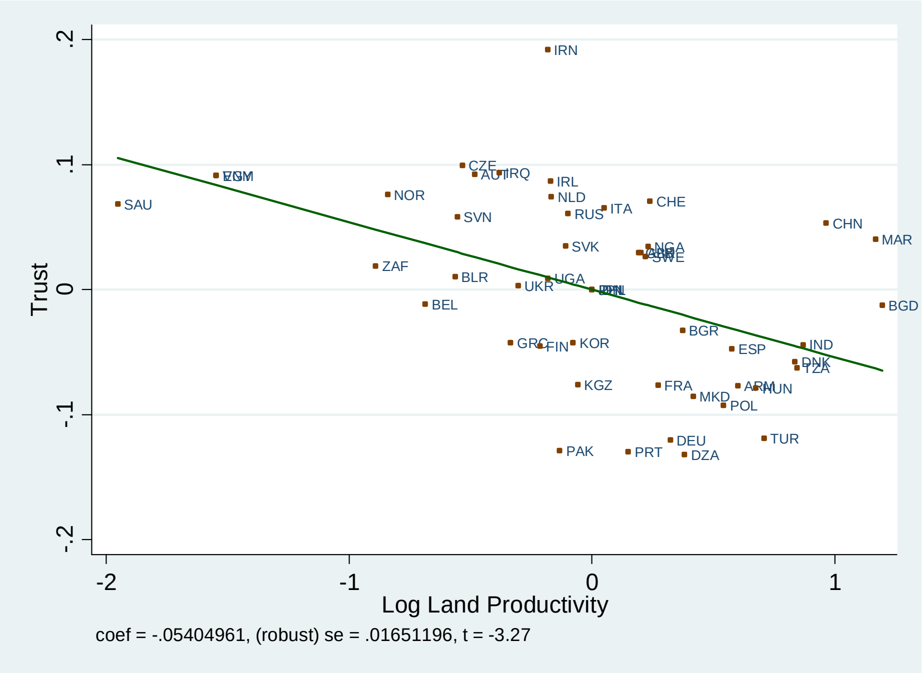
[38] Reassuringly, similar results, that establish a negative and statistically significant effect of land productivity on current levels of social capital are obtained, when employing an alternative proxy of social capital, namely the extend of participation in civic activities, as defined by La Porta et al. (1997), despite the fact that the sample is rather limited (24 countries).

Figure 14: Land Productivity and Trust



coef = -.06563317, (robust) se = .02417598, t = -2.71

Figure 15: Land Productivity and Trust-Restricted Sample



coef = -.05404961, (robust) se = .01651196, t = -3.27

7 Concluding Remarks

This research argues that reversal of fortunes in the process of economic development can be traced to the effect of land endowment on the desirable level of cooperation in the agricultural sector. In early stages of development, unfavorable land endowment enhanced the economic incentive for cooperation in the creation of agricultural infrastructure that could mitigate the adverse effect of the natural environment. Nevertheless, despite the beneficial effects of cooperation on the intensive margin of agriculture, low land productivity countries lagged behind during the agricultural stage of development. However, as cooperation, and its persistent effect on social capital, have become increasingly important in the process of urbanization and industrialization, the transition from agriculture to industry among unfavorable land endowment economies was expedited, permitting those economies that lagged behind in the agricultural stage of development, to overtake the high land productivity economies in the industrial stage of development.

The fundamental hypothesis of this research originates from the realization that the evolution of the wealth of nations has been driven in part by the trade-off between land productivity and the level of cooperation and social capital, in different stages of development. Social capital emerged initially as the outcome of cooperation in the agricultural sector, in an effort to further enhance land productivity. While cooperation in the agricultural sector had direct beneficial effect on agricultural productivity, via the development of agricultural infrastructure, its indirect effect on the emergence of social capital accelerated the transition to the industrial stage of development.

Variations in natural land productivity and their effect on the emergence of agricultural infrastructure and cooperation had therefore a profound effect on the differential pattern of development across the globe. Interestingly, investment in infrastructure that has been widely advocated as a growth boosting strategy for developing countries spontaneously emerged centuries earlier in an effort to mitigate the adverse effect of natural environment. Unfortunately, however, the beneficial externalities that were associated with these activities in the past are no longer present.

In accordance with the predictions of the theory, empirical evidence suggests that, accounting for a wide variety of potentially confounding factors, (i) a reversal of fortunes in the process of development can be traced to variation in land productivity across countries. Economies characterized by favorable land endowment dominated the world economy in the agricultural stage of development but were overtaken in the process of industrialization; (ii) cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could diminish the adverse effects of the environment and enhance agricultural output; (iii) lower level of land productivity in the past is associated with higher levels of contemporary social capital.

The proposed mechanism could capture the emergence of risk mitigating social networks in remote and harsh climatic environments and the fundamental forces behind the emergence of the welfare state. The advent of the welfare state in the region of Scandinavia, for instance, can be traced to the long lasting effects of this form of cooperation.

Appendices

A Proofs

Proof of Lemma 8. Under $A_t^I < \tau/(1-\gamma)$, the Jacobian matrix of the conditional dynamical system, comprised of (17) and (18), is given by

$$\begin{aligned} J\left(A_t^A, L_t\right) &= \begin{bmatrix} \partial A_{t+1}^A/\partial A_t^A & \partial A_{t+1}^A/\partial L_t \\ \\ \partial L_{t+1}/\partial A_t^A & \partial L_{t+1}/\partial L_t \end{bmatrix} \\ &= \begin{bmatrix} \beta + b(L_t)^{\lambda}(A_t^A)^{b-1} & \lambda(L_t)^{\lambda-1}(A_t^A)^{b} \\ \\ \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)}\xi & \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)} \end{bmatrix}, \qquad \text{(A.1)} \end{aligned}$$

which, when evaluated at the conditional steady state given by (23) and (24), yields

$$J\left(A_{ss}^A, L_{ss}\right) = \begin{bmatrix} \beta + b(1-\beta) & \lambda(1-\beta)^{\lambda-1}\left[\frac{(1-\gamma)a^a(1-a)^{1-a}\xi}{[\tau-[(1-\gamma)a^a(1-a)^{1-a}]](1-\beta)^{1/\lambda}}\right]^{\frac{-(1-b-\lambda)^2}{\lambda^2}} \\ \\ \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)}\xi & \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)} \end{bmatrix} \equiv J_{ss}. \qquad \text{(A.2)}$$

To ensure that the system has two positive eigenvalues, it must be established that:

$$\begin{aligned} Det\left(J_{ss}\right) &> 0, \text{and} \\ Tr\left(J_{ss}\right) &> 0, \forall \xi \in (0,1)\,. \end{aligned}$$

From (A.2) it follows that for $Det\left(J_{ss}\right) > 0$, $\xi > \lambda[\tau-(1-\gamma)a^a(1-a)^{1-a}]/(1-\gamma)a^a(1-a)^{1-a}$ is a sufficient condition. In addition it is clear from (A.2), that $Tr\left(J_{ss}\right) > 0, \forall \xi \in (0,1)\,.$

Given so far that the discrete dynamical system has two positive eigenvalues, it is clear from the phase diagram in Figure 2, that $\left(A_{ss}^A, L_{ss}\right)$ is a locally asymptotically stable node of the conditional dynamical system for any ξ, and convergence takes places monotonically $\square$

B Variable Definitions and Sources

Outcome Variables

Population Density in the Year 1, 1000, and 1500. Population density (in persons per square km) for given year is calculated as population in that year, as reported by McEvedy and Jones (1978), divided by total land area as reported by the World Bank's *World Development Indicators*. The cross-sectional unit of observation in McEvedy and Jones' (1978) data set 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.

Income Per Capita in 2000. Real GDP per capita, in constant 2000 international dollars, as reported by the World Bank's *World Development Indicators*.

Irrigation in 1900. Data on irrigation are reported by Freydank and Siebert (2008). They have constructed a set of annual values of area equipped for irrigation for all 236 countries during the time period 1900 - 2003. The values are provided in 1000 ha units. The *Irrigation in 1900* variable is using the data for the year 1900 and is expressed as the ln of the ratio of irrigated land over arable land.

Communication in Year 1, Transportation in Year 1, Medium of Exchange in Year 1. Data on a) Communication in the year 1 b) Transportation in the year 1 c) Medium of Exchange in the year ,1 are constructed from Peregrine's (2003) Atlas of Cultural Evolution, and aggregated at the country level by Ashraf and Galor (2011a). Each of these three sectors is reported on a 3-point scale, as evaluated by various anthropological and historical sources. The level of technology in each sector is indexed as follows. In the communications sector, the index is assigned a value of 0 under the absence of both true writing and mnemonic or non-written records, a value of 1 under the presence of only mnemonic or non-written records, and a value of 2 under the presence of both. In the transportation sector, the index is assigned a value of 0 under the absence of both vehicles and pack or draft animals, a value of 1 under the presence of only pack or draft animals, and a value of 2 under the presence of both. In the Medium of Exchange sector, the index is assigned a value of 0 under the absence of domestically used articles and currency, a value of one under the presence of only domestically used articles and the value of 2 under the presence of both. In all cases, the sector-specific indices are normalized to assume values in the [0; 1]-interval. Given that the cross-sectional unit of observation in Peregrine's dataset is an archaeological tradition or culture, specific to a given region on the global map, and since spatial delineations in Peregrine's dataset do not necessarily correspond to contemporary international borders, the culture-specific technology index in a given year is aggregated to the country level by averaging across those cultures from Peregrine's map that appear within the modern borders of a given country.

Mean Generalized Trust. The fraction of World Values Survey (WVS) respondents that agreed with the statement "most people can be trusted."

Geographical Variables

Land Productivity. Land quality is an index of the average suitability of land for cultivation, based on geospatial data on various ecological factors including (i) growing degree days, (ii) the ratio of potential to actual evapotranspiration, (iii) soil carbon density, and (iv) soil pH. The index is reported at a half-degree resolution by Ramankutty et al. (2002). The average of land quality is thus the average value of the index across the grid cells within a country. The average of land quality is thus the average value of the index across the grid cells within a country. This measure is obtained from the data set of Michalopoulos (2011).

Land Productivity (Adjusted). The cross-country weighted average of the Land Productivity measure. The weight associated with a given country in the calculation represents the fraction of the year 2000 population (of the country for which the measure is being computed) that can trace its ancestral origins to the given country in the year 1500 . The ancestry weights are obtained from the World Migration Matrix (1500–2000) of Putterman and Weil (2010).

Percentage of Arable Land. The percentage of a country's total land area that is arable as reported by the World Bank's World Development Indicators.

Total Land Area. The total land area of a country in millions of square km as reported by the World Bank's *World Development Indicators.*

Absolute Latitude. The absolute value of the latitude of a country's approximate geodesic centroid as reported by the CIA's *World Factbook.*

Percentage of Land within 100 km of Waterway. The percentage of a country's total land area that is located within 100 km of an ice-free coastline or sea-navigable river. This variable was originally constructed by Gallup et al. (1999) and is part of Harvard University's CID Research Datasets on *General Measures of Geography* available online.

Average Elevation. The average elevation of a country in thousands of km above sea level, calculated using geospatial elevation data reported by the G-ECON project (Nordhaus, 2006) at a 1-degree resolution. The measure is thus the average elevation across the grid cells within a country.

Average Ruggedness. The measure is the average degree of ruggedness across the grid cells within a country, calculated using geospatial elevation data reported by the G-ECON project (Nordhaus, 2006) at a 1-degree resolution. This variable is obtained from the data set of Michalopoulos (2011).

Small Island and Landlocked Dummy. 0/1-indicators for whether or not a country is a small island nation, and whether or not it possesses a coastline. These variables are constructed by Ashraf and Galor (2011a) based on information reported by the CIA in The World Factbook online resource.

Percentage of Population at Risk of Malaria. A geographically-based index gauging the extent of malaria endemicity as reported by Kiszewski et al. (2004).

Distance Variables

Distance to Frontier in the Year 1, 1000 and 1500.: The distance, in thousands of kilometers, from a country's modern capital city to the closest regional technological frontier in the year 1500, as reported by Ashraf and Galor (2011a). Specifically, the authors employ historical urbanization estimates from Tertius Chandler (1987) and George Modelski (2003) to identify frontiers based on the size of urban populations, selecting the two largest cities from each continent that belong to different sociopolitical entities.

Years since Neolithic Revolution. The number of thousand years elapsed, until the year 2000, since the majority of the population residing within a country's modern national borders began practicing sedentary agriculture as the primary mode of subsistence. This measure, reported by Putterman (2008), is compiled using a wide variety of both regional and country-specific archaeological studies as well as more general encyclopedic works on the transition from hunting and gathering to agriculture during the Neolithic.

Years since Neolithic Revolution (Adjusted). The cross-country weighted average of the timing of the Neolithic Revolution. The weight associated with a given country in the calculation represents the fraction of the year 2000 population (of the country for which the measure is being computed) that can trace its ancestral origins to the given country in the year 1500 . The ancestry weights are obtained from the World Migration Matrix, 1500–2000, of Putterman and Weil (2010).

Institutional Variables

Ethnic Fractionalization. A fractionalization index, constructed by Alesina et al. (2003), that captures the probability that two individuals, selected at random from a country's population, will belong to different ethnic groups.

Polity IV. The 1960–2000 mean of an index that quantifies the extent of institutionalized democracy, as reported in the Polity IV data set. The Polity IV democracy index for a given year is an 11-point categorical variable (from 0 to 10) that is additively derived from Polity IV codings on the (i) competitiveness of political participation, (ii) openness of executive recruitment, (iii) competitiveness of executive recruitment, and (iv) constraints on the chief executive.

Legal Origins. A set of dummy variables, reported by La Porta et al. (1999), that identifies the legal origin of the Company Law or Commercial Code of a country. The five legal origin possibilities are: (i) English Common Law, (ii) French Commercial Code, (iii) German Commercial Code, (iv) Scandinavian Commercial Code, and (v) Socialist or Communist Laws.

European Colony. An indicator for whether or not a country was colonized by a European nation as coded by Acemoglu et al. (2005). The variable equals 1 for colonized countries.

Major Religion Shares. A set of variables, from La Porta et al. (1999), that identifies the percentage of a country's population belonging to the three most widely spread religions of the world. The religions identified are: (i) Roman Catholic, (ii) Protestant, (iii) Muslim, and iv) Other.

Percentage of Native Population. The variable of the percentage of native population is constructed by (Ashraf and Galor, 2011a), based on the migration matrix of Putterman and Weil (2010).

C Descriptive Statistics and Additional Empirical Results

Table C.1: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Population Density in the Year 1500

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Log Population Density in 1500	0.923	1.516	-3.816	3.842	1.000								
(2)	Log Land Productivity	-1.355	1.265	-5.809	-0.049	0.374	1.000							
(3)	Log Average Ruggedness	4.346	1.042	1.282	6.370	0.249	0.323	1.000						
(4)	Log Average Elevation	5.935	1.101	-0.650	7.950	-0.060	-0.026	0.540	1.000					
(5)	Log Absolute Latitude	3.020	0.922	0.000	4.158	0.123	-0.036	0.176	-0.094	1.000				
(6)	Distance to Nearest Coast or River	0.343	0.453	0.014	2.385	-0.315	-0.231	-0.078	0.352	-0.025	1.000			
(7)	% of Land within 100 km of Coast or River	0.443	0.367	0.000	1.000	0.400	0.298	0.094	-0.565	0.256	-0.667	1.000		
(8)	Log Years Since Neolithic	8.352	0.592	5.991	9.259	0.515	-0.134	0.218	0.126	0.330	-0.025	0.120	1.000	
(9)	Distance to Frontier in the Year 1500	7.291	1.577	0.000	9.287	-0.366	-0.015	-0.129	0.004	-0.323	0.161	-0.220	-0.399	1.000

Note: Number of observations = 148.

Table C.2: Descriptive Statistics for the Analysis of the Impact of Land Productivity in Per Capita GDP in 2000

		Summary Statistics				Pairwise Correlations										
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	Log Per Capita Income in 2000	8.335	1.240	6.144	10.440	1.000										
(2)	Log Land Productivity	-1.413	1.250	-5.686	-0.177	-0.075	1.000									
(3)	Log Average Ruggedness	4.259	1.078	1.282	6.370	0.134	0.270	1.000								
(4)	Log Average Elevation	0.171	0.145	0.001	0.621	-0.269	-0.019	0.621	1.000							
(5)	Log Absolute Latitude	3.057	0.965	0.000	4.158	0.572	-0.029	0.192	-0.135	1.000						
(6)	Distance to Near Coast/River	0.390	0.497	0.022	2.385	-0.405	-0.217	-0.058	0.392	-0.090	1.000					
(7)	% of Land within 100 km of Coast or River	0.418	0.376	0.000	1.000	0.557	0.308	0.063	-0.607	0.334	-0.666	1.000				
(8)	Log Adjusted Years Since Neolithic	8.452	0.495	7.213	9.249	0.475	-0.076	0.325	-0.060	0.450	-0.120	0.356	1.000			
(9)	Ethnolinguistic Fractionalization	0.454	0.267	0.001	0.930	-0.637	-0.106	-0.299	0.099	-0.569	0.253	-0.444	-0.412	1.000		
(10)	Polity IV	3.764	3.739	0.000	10.000	0.693	0.262	0.143	-0.230	0.447	-0.360	0.527	0.240	-0.479	1.000	
(11)	% of Pop at Risk of Malaria	0.371	0.444	0.000	1.000	-0.723	0.013	-0.337	0.023	-0.749	0.142	-0.406	-0.620	0.667	-0.498	1.000

Note: Number of observations = 107.

Table C.3: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Irrigation in the Year 1900

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Irrigation in 1900	-39.268	2.095	-43.687	-34.730	1.000								
(2)	Log Land Productivity	-1.536	1.381	-5.686	-0.0739	-0.277	1.000							
(3)	Log Average Ruggedness	4.324	0.899	2.252	6.305	0.373	0.297	1.000						
(4)	Log Average Elevation	5.995	0.875	3.068	7.911	0.127	-0.118	0.471	1.000					
(5)	Log Absolute Latitude	2.752	0.778	0.000	4.094	0.117	-0.215	0.184	0.126	1.000				
(6)	Distance to Nearest Coast or River	0.329	0.403	0.020	2.385	-0.336	-0.263	-0.232	0.296	0.228	1.000			
(7)	% of Land within 100 km of Coast or River	0.396	0.342	0.000	1.000	0.233	0.373	0.274	-0.580	-0.034	-0.627	1.000		
(8)	Log Years Since Neolithic	8.341	0.516	6.907	9.259	0.419	-0.317	0.120	0.180	0.358	0.054	-0.148	1.000	
(9)	Distance to Frontier in 1500	7.319	1.668	0.000	8.794	-0.262	0.127	-0.156	-0.217	-0.304	-0.045	0.049	-0.343	1.000

Note: Number of observations = 72.

Table C.4: Descriptive Statistics for the Analysis of the Impact of Land Prod. on Medium of Exchange in the Year 1

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Medium of Exchange in the Year 1	0.483	0.443	0.000	1.000	1.000								
(2)	Log Land Productivity	-1.348	1.274	-5.809	-0.049	-0.373	1.000							
(3)	Log Average Ruggedness	4.378	1.052	1.282	6.616	0.128	0.317	1.000						
(4)	Log Average Elevation	5.947	1.124	-0.650	7.950	0.119	-0.017	0.557	1.000					
(5)	Log Absolute Latitude	3.005	0.930	0.000	4.158	0.327	-0.044	0.185	-0.085	1.000				
(6)	Distance to Nearest Coast or River	0.345	0.455	0.014	2.385	0.058	-0.224	-0.067	0.348	-0.011	1.000			
(7)	% of Land within 100 km of Coast or River	0.436	0.364	0.000	1.000	-0.015	0.285	0.072	-0.574	0.236	-0.658	1.000		
(8)	Log Years Since Neolithic	8.379	0.572	5.991	9.259	0.590	-0.165	0.247	0.157	0.364	-0.038	0.139	1.000	
(9)	Distance to Frontier in the Year 1	7.344	1.299	0.000	9.066	-0.349	0.016	-0.236	-0.040	-0.359	0.183	-0.239	-0.501	1.000

Note: Number of observations = 143

Table C.5: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Communication in the Year 1

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Communication in the Year 1	0.484	0.461	0.000	1.000	1.000								
(2)	Log Land Productivity	-1.348	1.274	-5.809	-0.049	-0.327	1.000							
(3)	Log Average Ruggedness	4.378	1.052	1.282	6.616	0.122	0.317	1.000						
(4)	Log Average Elevation	5.947	1.124	-0.650	7.950	0.101	-0.017	0.557	1.000					
(5)	Log Absolute Latitude	3.005	0.930	0.000	4.158	0.321	-0.044	0.185	-0.085	1.000				
(6)	Distance to Nearest Coast or River	0.345	0.455	0.014	2.385	0.036	-0.224	-0.067	0.348	-0.011	1.000			
(7)	% of Land within 100 km of Coast or River	0.436	0.364	0.000	1.000	0.041	0.285	0.072	-0.574	0.236	-0.658	1.000		
(8)	Log Years Since Neolithic	8.379	0.572	5.991	9.259	0.495	-0.165	0.247	0.157	0.364	-0.038	0.139	1.000	
(9)	Distance to Frontier in the Year 1	7.344	1.299	0.000	9.066	-0.377	0.016	-0.236	-0.040	-0.359	0.183	-0.239	-0.501	1.000

Note: Number of observations = 143.

Table C.6: Descriptive Statistics for the Analysis of the Impact of Land Prod. on Transportation in the Year 1

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Transportation in the Year 1	0.545	0.422	.000	1.000	1.000								
(2)	Log Land Productivity	-1.348	1.274	-5.809	-0.049	-0.339	1.000							
(3)	Log Average Ruggedness	4.378	1.052	1.282	6.616	0.143	0.317	1.000						
(4)	Log Average Elevation	5.947	1.124	-0.650	7.950	0.104	-0.017	0.557	1.000					
(5)	Log Absolute Latitude	3.005	0.930	0.000	4.158	0.466	-0.044	0.185	-0.085	1.000				
(6)	Distance to Nearest Coast or River	0.345	0.455	0.014	2.385	0.062	-0.224	-0.067	0.348	-0.011	1.000			
(7)	% of Land within 100 km of Coast or River	0.436	0.364	0.000	1.000	0.052	0.285	0.072	-0.574	0.236	-0.658	1.000		
(8)	Log Years Since Neolithic	8.379	0.572	5.991	9.259	0.7045	-0.165	0.247	0.157	0.364	-0.038	0.139	1.000	
(9)	Distance to Frontier in the Year 1	7.344	1.299	0.000	9.066	-0.405	0.016	-0.236	-0.040	-0.359	0.183	-0.239	-0.501	1.000

Note: Number of observations = 143.

Table C.7: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Trust

		Summary Statistics				Pairwise Correlations										
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	Trust	0.315	0.148	.070	0.653	1.000										
(2)	Log Land Productivity	-1.123	0 .935	-4.117	-0.201	-0.408	1.000									
(3)	Log Average Ruggedness	4.516	1.059	1.282	6.217	-0.140	0.146	1.000								
(4)	Log Average Elevation	5.888	0.992	3.050	7.907	-0.188	-0.129	0.744	1.000							
(5)	Log Absolute Latitude	3.524	0.705	0.000	4.158	0.252	-0.037	-0.008	-0.289	1.000						
(6)	Distance to Near Coast/River	0.259	0.423	0.022	2.385	-0.105	-0.379	0.100	0.398	-0.179	1.000					
(7)	% of Land within 100 km of Coast or River	0.563	0.363	0.000	1.000	0.007	0.532	-0.088	-0.615	0.322	-0.647	1.000				
(8)	Log Adjusted Years Since Neolithic	8.693	0.331	7.824	9.249	0.135	0.069	0.334	0.195	0.352	-0.085	0.059	1.000			
(9)	Ethnolinguistic Fractionalization	0.328	0.238	0.001	0.930	-0.317	-0.037	0.017	0.324	0.352	0.281	-0.438	-0.276	1.000		
(10)	Polity IV	5.548	3.884	0.000	10.000	0.191	0.223	-0.035	-0.339	0.468	-0.315	0.417	-0.005	-0.350	1.000	
(11)	% of Pop at Risk of Malaria	0.108	0.267	0.000	1.000	-0.244	0.064	-0.021	0.173	-0.845	0.155	-0.259	-0.418	0.499	-0.368	1.000

Note: Number of observations = 57.

Table C.8: Impact of Land Productivity on Population Density in the Year 1000

	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in the Year 1000			
Log Land Productivity	0.479***	0.369***	0.403***	0.414***
	(0.0825)	(0.0683)	(0.0586)	(0.0574)
Log Average Ruggedness		0.221	0.298**	0.277**
		(0.138)	(0.127)	(0.122)
Log Average Elevation		-0.113	-0.263**	-0.233**
		(0.127)	(0.125)	(0.116)
Log Absolute Latitude		-0.432**	-0.277*	-0.326**
		(0.188)	(0.156)	(0.157)
Mean Distance to Nearest Coast or River		-0.529**	-0.471**	-0.395**
		(0.234)	(0.194)	(0.196)
% of Land within 100 km of Coast or River		0.432	0.341	0.467
		(0.409)	(0.383)	(0.393)
Log Years Since Neolithic			1.424***	1.166***
			(0.234)	(0.257)
Distance to Frontier in the Year 1000				-0.200***
				(0.0730)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	143	143	143	143
R-squared	0.439	0.579	0.675	0.688

Summary: This table establishes the significant positive effect of land productivity on population density in the year 1000, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1000,, and fixed effects for landlocked country, island, and unobserved continental fixed effects. Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

Figure C.1: Impact of Land Productivity on Population Density in the Year 1000

Table C.9: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Population Density in the Year 1000

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Log Population Density in 1000	.499	1.452	-4.510	2.989	1.000								
(2)	Log Land Productivity	-1.355	1.270	-5.809	-0.049	0.310	1.000							
(3)	Log Average Ruggedness	4.346	1.046	1.282	6.370	0.249	0.330	1.000						
(4)	Log Average Elevation	5.957	1.110	-0.650	7.950	-0.072	-0.024	0.535	1.000					
(5)	Log Absolute Latitude	3.025	0.913	0.000	4.158	0.111	-0.020	0.165	-0.098	1.000				
(6)	Distance to Nearest Coast or River	0.350	0.459	0.014	2.385	-0.341	-0.234	-0.083	0.348	-0.024	1.000			
(7)	% of Land within 100 km of Coast or River	0.443	0.370	0.000	1.000	0.376	0.301	0.077	-0.582	0.248	-0.673	1.000		
(8)	Log Years Since Neolithic	8.368	0.585	5.991	9.259	0.572	-0.137	0.240	0.127	0.362	-0.043	0.150	1.000	
(9)	Distance to Frontier in 1500	7.372	1.212	0.000	9.058	-0.328	0.187	-0.131	-0.008	-0.321	0.134	-0.099	-0.099	1.000

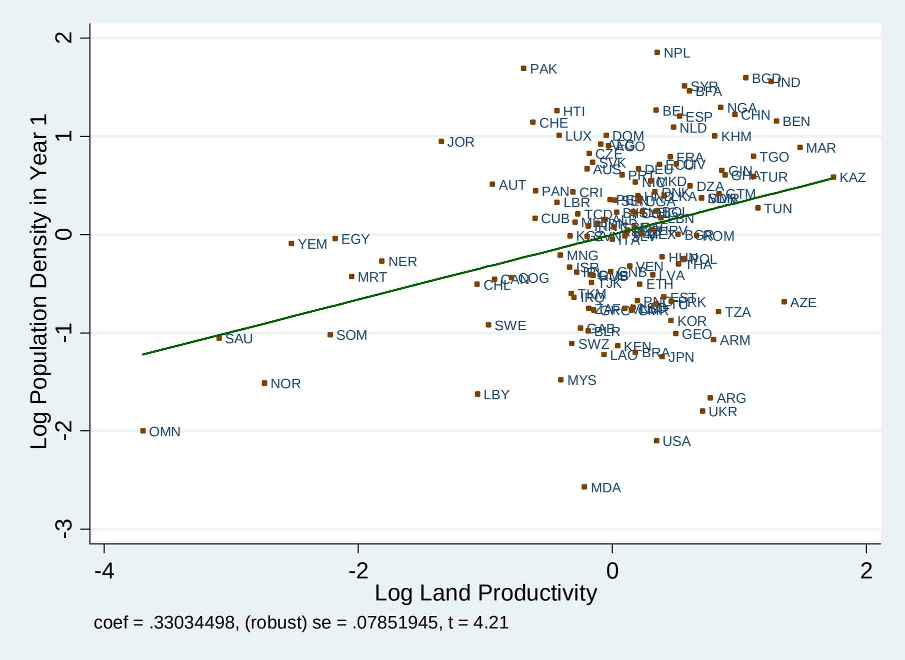
Note: Number of observations = 143.

Table C.10: Impact of Land Productivity on Population Density in the Year 1

	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in the Year 1			
Log Land Productivity	0.448***	0.281***	0.342***	0.330***
	(0.102)	(0.101)	(0.0797)	(0.0785)
Log Average Ruggedness		0.124	0.280**	0.238*
		(0.173)	(0.139)	(0.130)
Log Average Elevation		0.0286	-0.263*	-0.252**
		(0.153)	(0.135)	(0.120)
Log Absolute Latitude		-0.0952	0.0276	-0.0186
		(0.196)	(0.136)	(0.137)
Mean Distance to Nearest Coast or River		-0.760***	-0.635***	-0.603***
		(0.264)	(0.197)	(0.191)
% of Land within 100 km of Coast or River		0.519	0.322	0.343
		(0.486)	(0.404)	(0.399)
Log Years Since Neolithic			2.068***	1.767***
			(0.298)	(0.314)
Distance to Frontier in the Year 1				-0.203***
				(0.0607)
Continental Dummies	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes
Observations	129	129	129	129
R-squared	0.460	0.705	0.558	0.723

Summary: This table establishes the significant positive effect of land productivity on population density in the year 1, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, distance from the nearest technological frontier in the year 1, and fixed effects for landlocked country, island, and unobserved continental fixed effects. Notes: (i) Log land productivity is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate suitability for cultivation, such as growing degree days and the ratio of actual to potential evapotranspiration, as well as ecological indicators of soil suitability for cultivation, such as soil carbon density and soil pH; (ii) the set of continent dummies in Columns (1)-(4) include a fixed effect for Africa, the Americas, Australia and Europe. An Oceania dummy is not included due to a single observation for this continent in the corresponding regression samples, restricted by the availability of income per capita data; (iii) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (iv) robust standard error estimates are reported in parentheses; (v) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

Figure C.2: Impact of Land Productivity on Population Density in the Year 1



coef = .33034498, (robust) se = .07851945, t = 4.21

Table C.11: Descriptive Statistics for the Analysis of the Impact of Land Productivity on Population Density in the Year 1000

		Summary Statistics				Pairwise Correlations								
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Log Population Density in 1	-0.022	1.549	-4.510	3.169	1.000								
(2)	Log Land Productivity	-1.271	1.140	-5.477	0-.073	0.254	1.000							
(3)	Log Average Ruggedness	4.410	1.044	1.282	6.370	0.241	0.260	1.000						
(4)	Log Average Elevation	5.943	1.106	-0.650	7.950	-0.053	-0.152	0.550	1.000					
(5)	Log Absolute Latitude	3.060	0.922	0.000	4.127	0.302	0.024	0.220	-0.049	1.000				
(6)	Distance to Nearest Coast or River	0.343	0.467	0.020	2.385	-0.375	-0.339	-0.105	0.304	0.031	1.000			
(7)	% of Land within 100 km of Coast or River	0.454	0.367	0.000	1.000	0.407	0.454	0.096	-0.547	0.224	-0.659	1.000		
(8)	Log Years Since Neolithic	8.416	0 .548	5.991	9.259	0.647	-0.122	0.264	0.278	0.380	0.021	0.041	1.000	
(9)	Distance to Frontier in the Year 1	7.268	1.330	0.000	9.066	-0.504	-0.023	-0.256	-0.088	-0.351	0.167	-0.198	-0.468	1.000

Note: Number of observations = 129.

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