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Unfavorable Land Endowment, Cooperation, and Reversal of Fortune

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

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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 natural land productivity 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 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) reversal of fortunes in the process of development can be traced to variation in natural 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) lower level of land productivity in the past is associated with higher levels of contemporary social capital; (iii) cooperation, as reflected by agricultural infrastructure, emerged primarily in places were land was not highly productive and collective action could have diminished the adverse effects of the environment and enhance agricultural output.

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

JEL Classification Numbers: O11, O13, O14, O31, O33, O41, O50

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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 persistent effects of cultural, institutional, and human capital characteristics, in the vast inequality across the globe.

This research advances the hypothesis that a reversal of fortune in the process of economic development can be traced to the effect of natural land productivity 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 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 essential for the development of agricultural infrastructure per se. Importantly, 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 productivity had a reduced incentive to cooperate in the development of agricultural infrastructure. While their favorable land endowment permitted their domination 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 natural land productivity. Nevertheless, despite the enhancement in their agricultural productivity, they lagged behind during the agricultural stage of development due to unfavorable land endowment. The intense cooperation though, generated a 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 consisting of five intermediate elements 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.

The first element suggests that less productive places had more incentives to develop agricultural infrastructure, that could mitigate the adverse effect of the natural environment. Resources allocated to the development of agricultural infrastructure enhanced productivity indirectly, but came on the account of direct agricultural production. Hence, the opportunity cost of the construction of agricultural infrastructure was higher in more productive places and therefore investment in infrastructure was more beneficial in places with unfavorable land endowment.

The second element of the mechanism establishes that the development of public agricultural infrastructure generated an incentive for cooperation. Since agricultural infrastructure is primarily a public good, collective action is essential for its optimal provision, in light of the incentive of individuals to minimize the allocation of their private resources to the production of public goods. Moreover, since collective action is conducive for cooperation, places with lower natural land productivity generated higher incentives for cooperation.

Traditional forms of agricultural infrastructure include, among others, irrigation systems, storage facilities and drainage systems. In Egypt, as early as 4000 years ago, surface irrigation was used, exploiting the annual flooding of the Nile (Adams, 1965; Butzer, 1976). Surface irrigation was also exploited in Mesopotamia and China, and canals were built to funnel larger volumes of water to more distant fields. Finally in Western Europe, the first large-scale irrigation was developed by the Romans, who built aqueducts to channel water from the mountains exploiting gravity as well as reservoirs to store the channelled water.

Other forms of agricultural infrastructure to enhance land productivity, included drainage and storage technologies. Ancient civilizations like the Egyptians, the Greeks, and the Chinese developed drainage systems, technologies that were further advanced by the Romans. In England, land drainage was initiated in the tenth century, in an attempt to re-claim areas adjoining the North Sea. By the late eighteenth and nineteenth centuries, the vast majority of available land had already been reclaimed by surface draining of lakes, marshes and fens. In addition, draining and diking was inaugurated by the Dutch in the 16th century to increase the fraction of arable land. Similarly, drainage in the United States took place primarily within two developmental periods, during 1870-1920 and 1945-1960, in an attempt to enlarge the fraction of land capable of agricultural production.[1]

Storage technologies were also widespread. Prior to industrialization in England, the cost of storage was overwhelming from the viewpoint of individual farmers (McCloskey and Nash, 1984). To mitigate the risk associated with agricultural production, collective action, either in the form of risk sharing or by developing communal facilities, was often adopted (Stead, 2004). Similarly, storage facilities were developed at the community level in Sweden in an attempt to cope with adverse climatic conditions, and had a significant effect on grain banks (magasins) during 18th and 19th century (Berg, 2007).

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[1] Overall, an estimated region of 110 million acres of agricultural land in the United States, is claimed to have benefited from artificial drainage as of 1985. At least 70 percent of this drained land is allocated to crops, 12 percent to pasture, 16 percent to woodland, and 2 percent in miscellaneous uses.

Importantly, all major forms of agricultural infrastructure were associated with 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.[2]

The third element of the mechanism advances the hypothesis that the emergence of social capital can be traced to the level of cooperation in the agricultural sector, in the creation of infrastructure that could mitigate the adverse effect of the natural environment. Indeed, according to the *Social Structural Approach*, differences in the manifestation of social capital are driven by the social interactions in which individuals are involved (Bowles and Gintis, 2002). Similarly, the emergence and prevalence of norms that facilitate fruitful interaction (such as norms of mutual trust) can be traced to the need for large-scale cooperation (Henrich et al., 2001).[3] Relatedly, Putnam (2000) suggests that social capital is primarily embedded in networks of reciprocal social relations.[4]

The fourth element of the mechanism suggests that social capital has persisted over time via different transmission mechanisms. Evolutionary theories, advance the "social learning" hypothesis, according to which norms and cultural traits that survive and are transmitted across generations are the ones that contribute to individual and group survival (Boyd and Richerson, 1985, 1995; Cavalli-Sforza and Feldman, 1981). The cultural transmission hypothesis suggests that preferences, beliefs and norms are intergenerationally transmitted via socialization processes, such as social imitation and learning (Bisin and Verdier, 2001).[5] Finally, political institutions are argued to have a crucial role in the transmission of social capital across generations (Tabellini, 2008; Guiso et al., 2008).[6]

The fifth element of the mechanism suggests that social capital is more complementary to the industrial sector.[7] It is designed to capture the importance of social capital in promoting

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[2] Natural experiments that took place in recent years in developing countries, 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 (Bardhan (2000) for communities in rural India, Uphoff and Wijayaratna (2000) for Sri-Lanka, and Ostrom (2000) for Nepal). In all cases, large scale cooperation at the community level was developed, thereby strengthening the communal ties.

[3] 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.

[4] Putnam et al. (1993) in their influential study about social capital, studied the cases of Northern and Southern Italy. They argue that in Northern Italy, where the structure of the society was more civic, a higher level of social capital was obtained, ultimately leading 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.

[5] There are different mechanisms through which social capital can be intergenerationally transmitted, such as imitation or deliberate inculcation by parents. The empirical literature documents a strong correlation in the propensity to trust between parents and children (Katz and Rotter, 1969; Dohmen et al., 2011). The persistence of trust between second-generation immigrants and current inhabitants of the country of origin, has also been explored in the literature (Borjas, 1992; Uslaner, 2002; Guiso et al., 2006; Algan and Cahuc, 2010).

[6] Tabellini (2008) advances the hypothesis that regions that had developed better institution and imposed more checks and balances on the executive experience higher levels of trust in contemporary societies. Guiso et al. (2008) attribute current differences in social capital between the Northern and the Southern regions of Italy to the fact that the Northern regions developed free city-states in the Middle Ages, as opposed to the hierarchical structures that were developed in the South. Thus they 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) trace the origins of mistrust in contemporary Africa to the impact of the transatlantic slave trade.

[7] This supposition can be confirmed empirically by regressing, in a cross section of countries, current economic outcomes, captured by per capita GDP in the year 2000, on trust, the share of employment in agriculture and their interactive term. The outcome of this regression shows that trust is positively affecting economic outcomes, the size

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.[8]

The proposed mechanism is aimed to identify the intermediate elements 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 fortune 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 the transition to industrialization.

At early stages of development, the economy is in a Malthusian regime where output is generated entirely by an agricultural sector that is subject to decreasing returns to labor. Aggregate productivity in the agricultural sector, is partly determined by the natural land productivity, and can be further enhanced by agricultural infrastructure. A fraction of the labor employed in the agricultural sector is allocated to the production of the private good, whereas the remaining fraction is allocated to the production of agricultural infrastructure. Technological progress in the agricultural sector is a gradual process fuelled by knowledge creation, which is positively affected by the size of the workforce in the agricultural sector. Resources generated by technological progress are channeled primarily towards an increase in population size, and the economy evolves towards a Malthusian equilibrium where income per capita remains stagnant along a dynamic path characterized by growing population and total factor productivity.

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. Once the industrial technology is adopted, the economy emerges into a Post-Malthusian regime of development, where the economy operates in both the agricultural and the industrial sector. The endogenous growth of total factor productivity in the industrial sector, along with intersectoral labor mobility, generates a dynamic path characterized by endogenously growing population and income per capita.

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of the agricultural sector is negatively associated with current economic outcomes, and importantly the interactive term has a negative coefficient. Hence, reassuringly, as implied by the negative coefficient of the interactive term, the positive effect of trust on current economic outcomes is diminishing with the size of the agricultural sector, thereby implying that trust is more complementary in enhancing economic activity in more industrialized societies.

[8] 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.

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 endowment 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, has also 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 in 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 suitability for agriculture across countries, the research further explores the testable predictions of the theory: (i) a reversal of fortune in the process of development can be traced to variation in land suitability 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) lower level of land suitability in the past is associated with higher levels of contemporary social capital, and (iii) 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.

Consistent with the predictions of the theory, the empirical analysis first 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. The examination of comparative development at the agricultural stage of development employs a Malthusian perspective, thereby assuming that technologically advanced economies had a larger rather than richer population (Ashraf and Galor, 2011). 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 suitability on population densities in the years 1, 1000 and

1500. Land suitability is proxied by 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.[9]

The historical analysis reveals a negative relationship between log land suitability and 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, namely the timing of the Neolithic revolution, distance from technological frontier in the year 1500, as well as geographical characteristics, the estimated linear coefficient associated with log land suitability implies that a 1% increase in land suitability would increase population density by 0.43%.

To establish a "reversal of fortune" with respect to natural land endowments, the analysis employs cross country variation in land suitability, to explain the cross-country variation in log income per capita in the year 2000. A number of potentially confounding factors and alternative hypothesis suggested by the related literature on comparative development are accounted for. The geography channel is controlled through a number of geographical controls that may affect economic outcomes today. The institutional hypothesis that suggests that a "reversal of fortune" can be traced to the impact of European colonization on comparative development, is accounted for through a number of controls including European colonies dummies, legal origins dummies and institutional quality controls. Furthermore, controls for the disease environment, ethnic fractionalization and religion shares are employed.

Importantly, as suggested by the theory, it is not the direct effect of land suitability that drives the reversal of fortune but instead the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation. In the absence of migration, the country's level of social capital is captured by its natural land endowment. However, in the post-colonial era, where mass migration has taken place, the level of social capital in each country reflects the weighted average of land suitability among its ancestral population. Hence, in order to capture this distinction, two alternative empirical strategies are adopted. First, the sample is restricted to countries with a large percentage of native population, thereby implying that the social capital that has been accumulated in the past, is still a prevalent norm among the native population. Second, the measure of land suitability is adjusted to capture the portable component of natural land endowment, namely social capital, using the weighted average of the land suitability of the ancestral population of each country today.

The results from the contemporary analysis reveal a positive relationship between log adjusted land suitability and log income per capita in the year 2000. Once geographical, institutional and cultural factors are accounted for, it is shown that a 1% increase in adjusted land suitability can account for a 0.26% decrease in income per capita. Reassuringly, the highly significant and negative effect of land suitability on income per capita, persists when the analysis is conducted using the original measure of land suitability while restricting the sample for countries with native population higher than 75%. In the restricted sample it is shown that a 1% increase in land suitability can account for a 0.21% decrease in income per capita.

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[9] 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.

Second, reassuringly, the empirical analysis establishes that the reversal of fortune captures the adverse effect of natural land productivity on social capital as reflected by the contemporary level of generalized trust. Importantly, since the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation, affects the current level of trust, the measure of land suitability is adjusted to capture the portable component of natural land endowment, namely social capital, using the weighted average of the land suitability of the ancestral population of each country today. In particular, adjusted land suitability has a highly significant positive effect on the current level of trust, controlling for geographical and institutional factors, ethnic fractionalization, disease environment and dummies for continents, colonial and legal origins and major religion shares. Reassuringly, similar results are obtained if an alternative measure of social capital is employed, namely the extent of participation in civic activities (La Porta et al., 1997). Furthermore, the qualitative results remain intact if as an additional robustness check, the unadjusted measure of land suitability is employed and the sample of countries is restricted to those with native population larger than 75%.

Third, the empirical analysis establishes that higher suitability of land for agriculture is associated with a lower level of cooperation in the agricultural sector, as reflected by the fraction of irrigated land. In the absence of extensive cross-country data on irrigation prior to industrialization, the analysis is based on the fraction of irrigated land for a sample of non-industrial countries in the year 1900. Consistently with the predictions of the theory, the empirical analysis reveals a statistically significant and robust negative effect of the log land suitability on the fraction of irrigated land in the year 1900. In particular a 1% increase in land suitability is associated with a 0.48% decrease in the fraction of irrigated land.

The adverse effect of natural land productivity on cooperation in earlier periods is examined based on several proxies of cooperation: a) communication in the year 1 CE, b) transportation in the year 1 CE, and c) medium of exchange in the year 1 CE.[10] According to the theory, sophisticated means of communication, transportation and medium of exchange have been catalysts in the advancement of large-scale cooperation, and thus, under-development of these technologies reflects the adverse effect of land suitability on the extent of cooperation. Nevertheless, it could be plausibly argued that the advancement of these technologies captures the degree of trade, associated with higher land suitability, as opposed to the emergence of cooperation in an environment characterized by lower land suitability. Reassuringly however, a more suitable land for agriculture in these societies had an adverse effect on the technological levels of these three sectors, suggesting that the dominating effect was indeed that of reduced cooperation. Moreover, the adverse effect of land suitability on the development of these technologies remains significant if the degree of inequality in the suitability of land for agriculture – a more direct proxy for the trade channel in early stages of development

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[10] The development of each of each these three sectors is measured 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, the index is assigned a value of 0 under the absence of domestically used articles and currency, a value of 1 under the presence of only domestically used articles and the value of 2 under the presence of both.

– is accounted for. As expected, the evidence suggests that indeed societies characterized by a higher degree of inequality in the suitability of land for agriculture, and therefore societies that had an increased incentive to trade, developed more advanced communication and transportation technologies as well as more sophisticated mediums of exchange. Nevertheless, low land suitability has still a significant positive effect on cooperation, as reflected by the development of these technologies.

The remainder of the paper is organized as follows: Section 2 reviews the related literature. Section 3 develops a formal theoretical model that generates the main hypotheses. Section 4 presents empirical findings consistent with the proposed hypotheses. Finally, section 5 concludes.

2 Advances with Respect to the Related Literature

This research contributes to the literature that explore of the origins of comparative development, reversal of fortune, and social capital.

First, the research sheds new light on the origins of the contemporary differences in income per capita across the globe. Various theories of comparative development have been advanced in the literature. The role of geography, institutions, colonialism, culture, human capital, ethnolinguistic fractionalization and genetic diversity has been at the center of research attempting to account for differential development patterns across the globe.

The geographical hypothesis suggests that environmental conditions affected economic performance directly, through their effect on health, work effort, and agricultural productivity (Huntington, 1915; Myrdal, 1968; Jones, 1981; Landes, 1998; Sachs and Malaney, 2002). Moreover, the indirect effect of geography, has been underlined by Diamond (1997) who has established the geographical determinants of the timing of the Neolithic revolution and their persistent effect on comparative development.[11]

The role of institutions in fostering economic growth have been advanced by North and Thomas (1973), Mokyr (1990), and Greif (1993), and has been empirically established by Hall and Jones (1999), La Porta et al. (1999), Rodrik et al. (2004), and Acemoglu et al. (2005). In addition, initial geographical conditions and their association with inequality gave rise to persistent differences in institutional quality across regions (Engerman and Sokoloff, 2000; Acemoglu et al., 2005; Galor et al., 2009).

The cultural hypothesis, as advanced by Weber (1905, 1922) and Landes (1998, 2006) proposes, that norms and ethics that enhanced entrepreneurial spirit and thus innovation brought about a rapid transition at industrial stages of development. The adverse effect of ethnolinguistic fractionalization on economic development has been examined by Easterly and Levine (1997) and Alesina et al. (2003), and the hump-shaped effect of genetic diversity on economic outcomes, reflecting the trade-off between the beneficial and the detrimental effects of diversity on productivity, is explored in Ashraf and Galor (2011b).

Finally, 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

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[11] This channel is examined empirically by Olsson and Hibbs (2005) and (Ashraf and Galor, 2011a).

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).

This research, in contrast, identifies a novel mechanism through geographical characteristics affect contemporary economic outcomes, underlining the role of unfavorable land endowment in the emergence of cooperation, and thus social capital, and its persistent effect on comparative economic development.

Second, the research provides an alternative theory for the reversal of fortune in the performance of economies in the process of development. Existing theories propose three alternative hypotheses for the reversal of fortune. According to the "temperate drift hypothesis", while geographical conditions favored the tropics in early stags of development, agricultural technologies had higher complementarity with geographical conditions in temperate areas, generating a reversal in economic outcomes in the long-run (Bloch, 1966; Mokyr, 1990). Attentively, Acemoglu et al. (2005) have argued that the imposition of extractive institutions by European colonizers in relatively affluent regions during the pre-industrial era brought about the reversal in the relative performance in the long-run. Finally, Ashraf and Galor (2011c), establish that societies that were geographically isolated, and thus culturally homogeneous, operated more efficiently in the agricultural stage of development, but their lack of cultural diversity reduced their adaptability and thus delayed their industrialization.

The proposed theory, in contrast, suggests that a reversal of fortune can be traced to the beneficial effect of natural land productivity on economic outcomes in the agricultural stage of development, and its detrimental effect on the level of cooperation and social capital and therefore on the pace of industrialization in the long-run.[12]

Third, the research contributes to the understanding of the emergence of social capital in the process of development. Existing studies suggest that cooperation and sociopolitical networks gave rise to social capital (Bowles and Gintis, 2002; Henrich et al., 2001). This research extends the argument and suggests that indeed the origins of social capital can be traced to large-scale cooperation, which however emerged as early as thousands of year ago, coinciding with the emergence of agriculture and the need of the community to cooperate for the development of agricultural infrastructure that could mitigate the adverse effect of the natural environment.[13]

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[12] Interestingly, this result is applicable to a broad set of countries, thereby capturing reversals within the European continent or the overtaking of Asia by Europe in the transition to industrialization (Landes, 1998), as opposed to the institutional hypothesis that is relevant for colonized counties.

[13] The geographic origins of trust have been explored earlier by Durante (2010). Unlike the proposed mechanism that focuses on the effect of unfavorable natural land productivity on cooperation in the construction of physical agricultural infrastructure, Durante explores the role of climatic variability and thus the insurance motive in the emergence of trust. Moreover, in contrast to Durante who establishes empirically the reduced form relationship between climatic variability in the past and contemporary level of trust, the current paper establishes empirically the channel through which unfavorable land productivity affected the contemporary level of trust, establishing its intermediate effect on cooperation in the agricultural stage of development. Furthermore, unlike the focus of Durante on the origins of trust, the current research main focus is on comparative development and reversal of fortune, where the geographical origins of trust is only an intermediary mechanism for the hypothesis as a whole.

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. 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, $\xi \in (0,1)$, 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

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

where the supply of land is constant over time and is normalized such that $X = 1$.[14]

Hence, natural land productivity, ξ, is complemented by acquired productivity, A_t^A, and is substituted by public infrastructure, G_t. Moreover, while agricultural infrastructure is beneficial regardless of the level of natural productivity, its marginal benefit is higher in less productive places.

The labor force in the agricultural sector is allocated between the production of public infrastructure and the direct production of final output. A fraction z_t of the labor force employed in the agricultural sector is devoted to the production of G_t, whereas the remaining fraction $(1 - z_t)$, is employed in the production of the final output.

Hence the production of agricultural output is

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

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, $\left[\xi A_t^A + \frac{1}{\xi} G_t\right]$, captures the trade-off between allocating labor in the production of the final good and the production of the public good.

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

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 to further enhance land productivity.[15]

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 output is produced exclusively in the agricultural sector. 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 increases land productivity, but it reduces the labor employed 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 to the production of the public good, so as to maximize agricultural output, i.e.,

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

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

Hence, noting (1),

$$z_t = a - \frac{(1-a)\xi^2 A_t^A}{\theta_t L_t}. \tag{6}$$

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.

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 wage rate of agricultural labor in time t, w_t^A, is

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

where $v \equiv a^a(1-a)^{(1-a)} \in (0,1)$.

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

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

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

From (7) and (8) it is evident that as employment in the agricultural sector decreases, the demand for labor increases without bound, while productivity in the industrial sector remains finite. Hence, 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, if 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) The industrial sector is economically viable in period t if and only if*

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

Proof. Follows from (7)-(8) and the perfect mobility of labor between sectors. □

The threshold level of productivity, $\hat{A}_t^I$, reflects the fact 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, w_t^A, as long as the entire labor force, L_t, is employed in the agricultural sector (i.e. $\theta_t = 1$).

Corollary 1 *(The Population Threshold for the Economic Viability of the Industrial Sector) The industrial sector is economically viable in period t if and only if*

$$L_t \geq \frac{v\xi^{2-a}A_t^A}{A_t^I - v\xi^{-a}} = \hat{L}\left(A_t^A, A_t^I\right) \equiv \hat{L}_t.$$

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

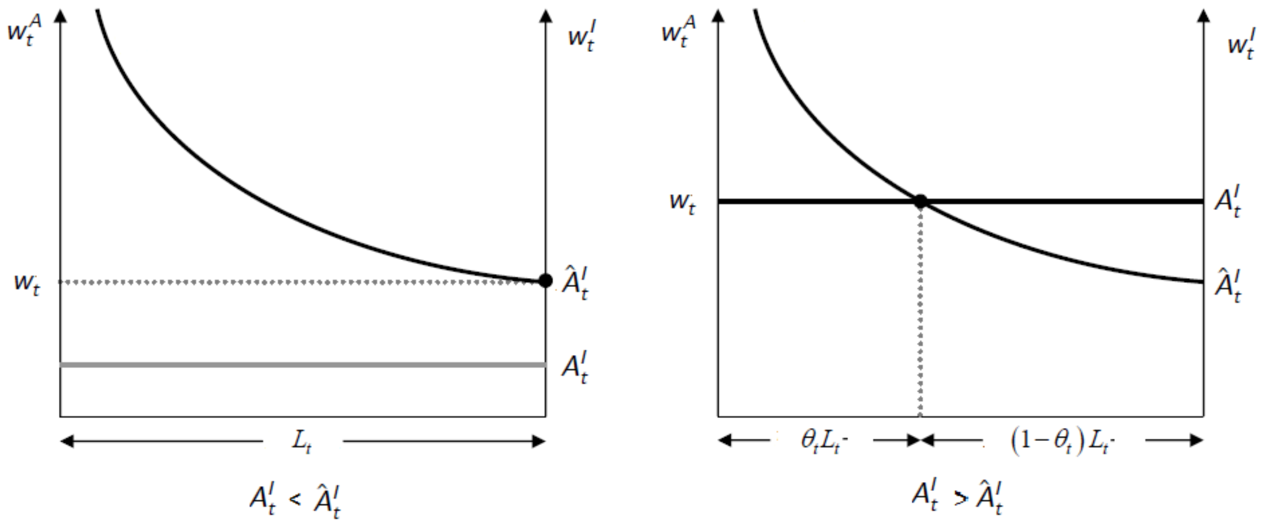
Let $\theta_t \in (0,1]$ denotes the fraction of the economy's labor force employed in the agricultural sector in period t, i.e., $\theta_t \equiv L_t^A/L_t$. As follows from Lemma 1 and depicted in Figure 1, if $A_t^I < \hat{A}_t^I$, then only the agricultural sector is active and therefore the entire labor force will be employed in this sector. Therefore the wage rate in the economy, w_t, will be the associated wage rate in the agricultural sector, w_t^I. However, if $A_t^I \geq \hat{A}_t^I$, then the industrial sector will become operative, and 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

$$\theta_t \equiv L_t^A/L_t = \begin{cases} 1 & \text{if} \quad A_t^I < \hat{A}_t^I \\ \\ \frac{v\xi^{2-a}A_t^A}{A_t^I - v\xi^{-a}}\frac{1}{L_t} & \text{if} \quad A^I \geq \hat{A}_t^I, \end{cases} \tag{9}$$

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

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

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. Hence,using the restrictions imposed by Lemma 1

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

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.[16] 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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[16] 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 therefore

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

which, following (10), yields

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

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.[17]

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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[17] 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.[18] In the long run, the cooperation in the production of agricultural infrastructure, contributes to societal social capital that ultimately benefits the process of industrialization.[19]

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.[20]

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

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

where the initial level of industrial productivity, $A^I_0 > v\xi^{-a}$, is given.

In particular, A^I_t reflects the inertia of past productivity in the industrial sector, $\omega L_t A^I_t$, captures the advancement in productivity due to the application of new knowledge to the existing level of productivity; $\omega \in (0,1)$.[21]

The beneficial effect of cooperation for the creation of agricultural infrastructure, on the industrial productivity, is captured by $z_t\theta_t L_t A^I_t$, where $z_t\theta_t$ is the fraction of the population employed in the production of agricultural infrastructure.[22]

The beneficial effect of past 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 captured by the level of past productivity, A^I_t. Cooperation at time t is captured implicitly as social capital in period $t+1$.

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

[19] 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.

[20] 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)

[21] $\omega \in (0,1)$ captures the fact that only a fraction of the population contributes to the creation of new knowledge in the industrial sector. While it can be argued that people employed in the industrial sector can contribute to the creation of new knowledge in the industrial sector, indirectly, it would be less plausible to argue that all people employed in the agricultural sector can positively influence knowledge creation in the industrial sector. It is therefore assumed that a constant fraction of the total workforce is positively affecting knowledge creation in industry.

[22] One can assume that once the industrial sector is active each extended household allocates labor to both the industrial and the agricultural sector. Hence, the entire society is exposed to the externalities of contemporary cooperation in the agricultural sector.

4.1.2 Agricultural Productivity

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

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

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

βA^A_t captures the inertia from past productivity of the agricultural sector in period t, where $\beta \in (0,1)$ captures the erosion in agricultural productivity due to imperfect transmission from one generation to the other.[23] The term $(L_t)^\lambda (A^A_t)^b$ captures a "learning by doing effect". In particular the formulation implies both diminishing returns to population driven knowledge creation, and a "fishing out" effect (i.e. $\lambda \in (0,1)$), namely the negative effect of past discoveries on current discoveries. In addition, it is assumed that there is a lower degree of complementarity between the advancement of the knowledge frontier and the existing stock of sector-specific productivity in the agricultural, namely $b < 1$. Furthermore $\lambda + b < 1$.

It should be noted that agricultural infrastructure is assumed to be fully depreciated within one period, and the productivity in the agricultural sector is not affected by the level of agricultural infrastructure.[24]

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

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

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 affects population dynamics when the economy operates exclusively in the agricultural sector, whereas after industrialization it affects population dynamics only indirectly, through its effect on industrial productivity.

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[23] 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 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 assure smaller depreciation in the industrial sector.

[24] 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.

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 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 productivity, ξ, is fully determined by a sequence $\left\{A_t^A, A_t^I, L_t; \xi\right\}_{t=0}^{\infty}$ that reflects 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

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

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 captures 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 cooperation in the development of infrastructure in agricultural sector, in determining the characteristics of the Malthusian equilibrium and the timing of the take-off to the industrial era.[25]

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

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[25] 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 fortune" 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 new insights.

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 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 the region 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,*

$$L_t = \frac{v\xi^{2-a} A_t^A}{A_t^I - v\xi^{-a}} \equiv \hat{L}\left(A_t^A, A_t^I\right),$$

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 the $\left(A_t^A, L_t\right)$ 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* $L_t \geq \hat{L}\left(A_t^A, A_t^I\right)$,

$$L_{t+1} - L_t \gtreqqless 0 \quad \Leftrightarrow \quad A_t^I \gtreqqless \tfrac{\tau}{1-\gamma}$$

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 the $\left(A_t^A, L_t\right)$ 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,*

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

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

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* $A_t^A > 0$*,*

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

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, agricultural 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,*

$$L_t = \frac{(1-\gamma)v\xi^{2-a}A_t^A}{\tau-(1-\gamma)v\xi^{-a}} \equiv L^{LL}\left(A_t^A\right),$$

where $\tau > (1-\gamma)v\xi^{-a}$, $dL_t^{LL}/dA_t^A > 0$*, 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. □

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

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

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 its steady state level, 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* $\left(A_t^A, L^{LL}\left(A_t^A\right)\right) \in LL$,

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

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. □

Thus, for $A_t^I < \tau/(1-\gamma)$, 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 $A_t^I = \tau/(1-\gamma)$. After this point, for $A_t^I > \tau/(1-\gamma)$ 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* $A_t^I < \frac{\tau}{(1-\gamma)}$*, 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

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

2. If $A_t^I > \frac{\tau}{(1-\gamma)}$, 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,

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

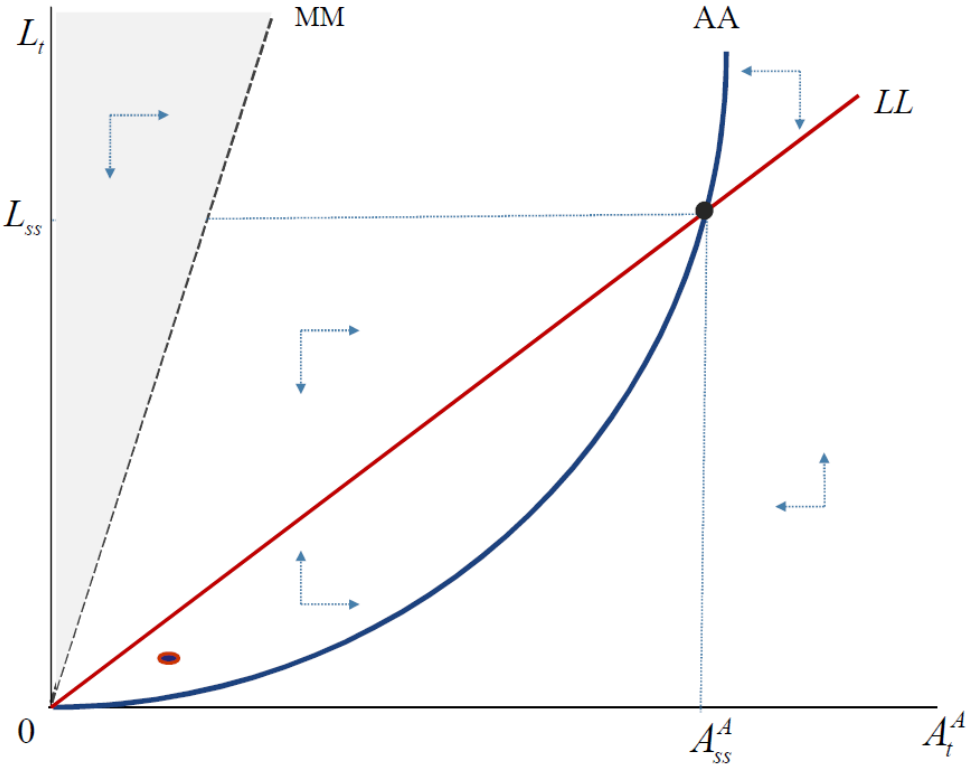
Proof. Part (1) follows immediately from Lemmas 3 and 6, and Corollary 3. Part (2) follows from the same Lemmas while observing that, above the Conditional Malthusian Frontier, $L_{t+1} - L_t > 0$ if $A_t^I > \tau/(1-\gamma)$, and if L_t is below the LL locus. □

5.1.4 The Phase Diagrams

Figures 2-3, illustrated the steady state in agricultural stage of development, and the transition from agriculture to industry. Figure 2 illustrates the agricultural stage of development, in which the economy is in a steady state and is characterized by Malthusian dynamics, Figure 3 illustrates 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 illustrates the economy when operating 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 $L^{LL}\left(A^A_t;\xi\right)$, 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

$$A^A_{ss} = \frac{1}{(1-\beta)^{\frac{1}{1-b}}}\left[\frac{\tau-(1-\gamma)\,v\xi^{-a}(1-\beta)^{\frac{1}{1-b}}}{(1-\gamma)v\xi^{2-a}}\right]^{\frac{\lambda}{-1+b+\lambda}} \equiv A^A_{ss}(\xi)\,; \tag{23}$$

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

The system is characterized by a globally stable steady-state equilibrium.[26] At early 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 places 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

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[26] 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 $L_0 > 0$.

the region below the $MM_{|A_t^I}$ locus and above the LL locus, there is rather high workforce that implies wage rates 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 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.[27] 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* $A_t^I < \tau / (1-\gamma)$*, 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

$$\xi < \left[\frac{(1-\gamma)\, v}{\tau} \frac{\left[\beta(1-\beta)^{\frac{b}{1-b}} + b(1-\beta)^{\frac{1}{1-b}} + \lambda(1-\beta)^{\frac{1}{(1-b)}}\right]}{\lambda} \right]^{1/a}.$$

2. *is locally asymptotically stable.*

Proof. See Appendix A. □

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

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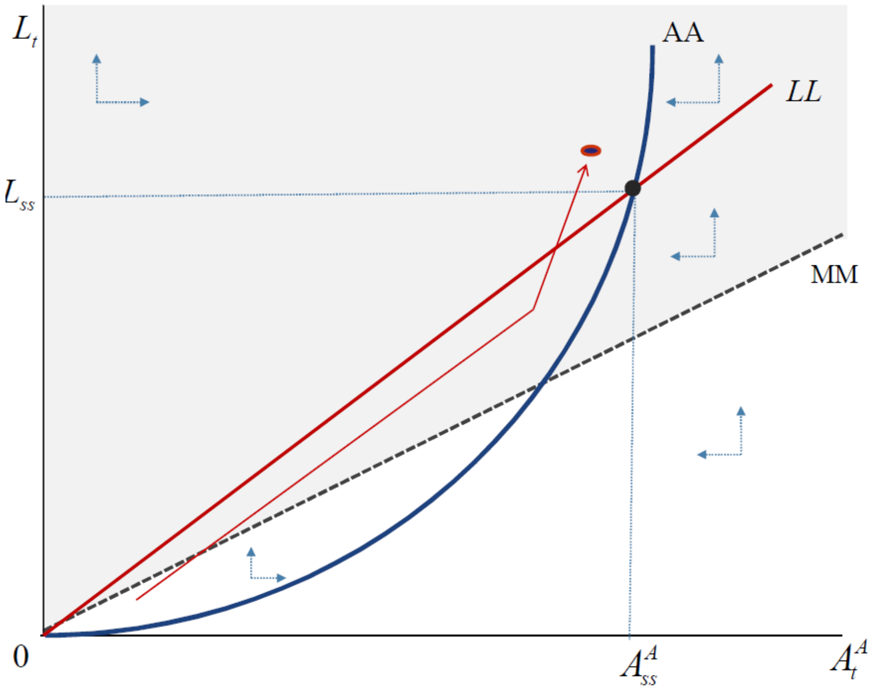
[27] The analysis would not be qualitatively different even in the case where the evolution towards the steady state took place in an oscillatory manner, since this is a feature that appears to be present during the Malthusian epoch. See, for example, Lagerlöf (2006) and Galor (2011).

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

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

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

5.2 The Evolution of the Economy

The evolution of the economy is initially characterized by a Malthusian steady-state. The economy initially operates exclusively in the agricultural sector but ultimately it experiences 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 of development, the economy is in a Malthusian regime and the dynamical system, illustrated in Figure 2, has a globally stable steady-state equilibrium, $(A_{ss}^I,\ L_{ss})$, towards which it gravitates monotonically.

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

$$y_{ss} = \frac{\tau}{1-\gamma} \tag{26}$$

Using (23) and (24), the steady-state level of income per worker captures the property of the Malthusian steady-state, 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.

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 $\frac{1-\gamma}{\tau} v \xi^{1-a}\left[\frac{\xi A_t^A}{L_t}+\frac{1}{\xi}\right]$, 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 no effect on steady state income per capita, i.e.*

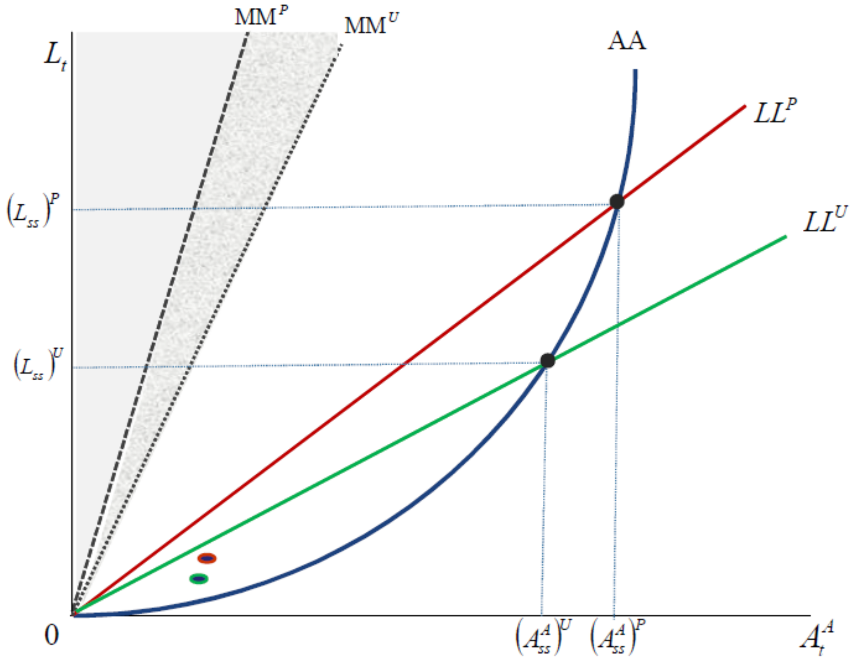
$$dy_{ss}/d\xi = 0$$

and for $\xi > \frac{(1-\gamma)v2(1-\beta)^{\frac{1}{1-b}}}{(2-a)\tau}$

$$dA^A_{ss}/d\xi > 0 \quad \textit{and} \quad dL_{ss}/d\xi > 0$$

Proof. Follows immediately from differentiating (23), (24), and (26) with respect to ξ while noting assumption (A2).[28] $\square$

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.

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[28] Note that if $\xi < \frac{(1-\gamma)v2(1-\beta)^{\frac{1}{1-b}}}{(2-a)\tau}$, the this would imply that $dA^A_{ss}/d\xi < 0$ and $dL_{ss}/d\xi < 0$, i.e. that for sufficiently low levels of land productivity, an increase in land productivity may adversely affect steady state values of population and agricultural productivity. However, this result captures the effect of land productivity through the incentives for investment in infrastructure. Had this channel been shut off, i.e., investment in infrastructure is not feasible, then $dA^A_{ss}/d\xi > 0$ and $dL_{ss}/d\xi > 0 \ \forall \ \xi$. Therefore to be consistent with historical evidence that suggests that more fertile places were sustaining larger populations, the analysis is limited to the range of productivities where $\xi > \frac{(1-\gamma)v2(1-\beta)^{\frac{1}{1-b}}}{(2-a)\tau}$.

In accordance with the predictions of the Malthusian theory (Ashraf and Galor, 2011a), the long-run level of income per capita is not affected by variations in natural land productivity, thereby implying that adjustments in population and productivity were such that equalized long-run income per capita across countries.

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.

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 natural land productivity, can have a detrimental effect on the timing of the adoption of industry and, thus, on the timing of the take-off from Malthusian stagnation, i.e.,*[29]

$$dg^I_{ss}/d\xi > 0 \quad \textit{if} \quad \xi > \left[\tfrac{(1-\gamma)v}{\tau}(1-a)(\omega+a)+(1-\beta)^{\frac{1}{1-b}}\right]^{1/a}$$

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

Hence, if natural land productivity is sufficiently high, then it can have an adverse effect on productivity growth in the (latent) industrial sector at the conditional Malthusian steady-state equilibrium. 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.

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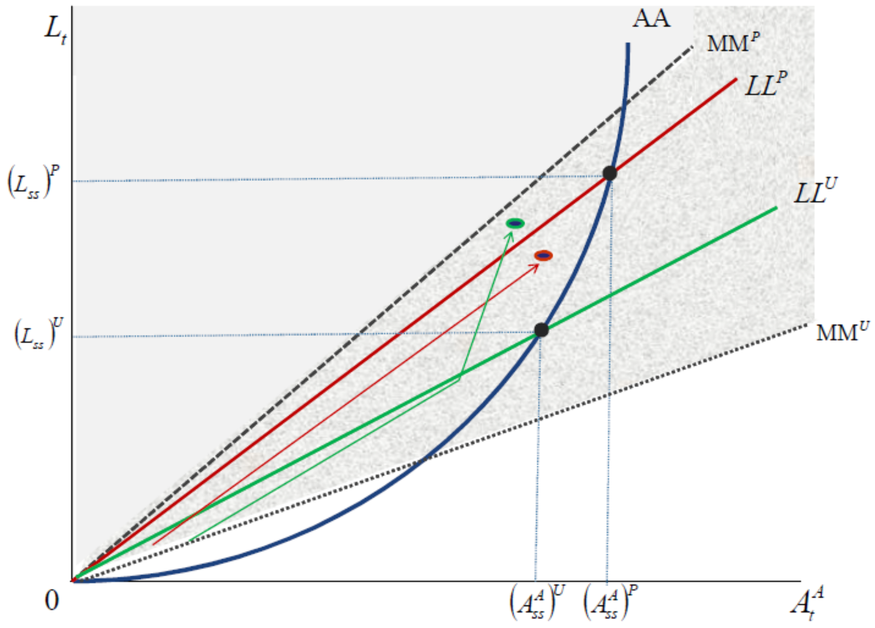
[29] It should be noted that the restrictions on ξ in Propositions 1 and 2 and Lemma 8, are mutually consistent for a range of parameter values.

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



Geometrically, as depicted in Figure 4, for sufficiently high ξ, a higher value of ξ causes the $MM_{|A^I_t}$ frontier to reside closer to the L_t-axis in $\left(A^A_t, L_t\right)$ space. This, combined with the fact that industrial productivity in the more productive place takes 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.

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 can 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 fortune in the process of development can be traced to variation in land suitability 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) lower level of land suitability in the past is associated with higher levels of contemporary social capital, and (iii) 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.

6.1 Empirical Strategy and Data

6.1.1 Empirical Strategy

Consistent with the predictions of the theory, the empirical analysis will first establish 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. The examination of comparative development at the agricultural stage of development employs a Malthusian perspective, thereby assuming that technologically advanced economies had a larger rather than richer population (Ashraf and Galor, 2011). 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 suitability on population densities in the years 1, 1000 and 1500. In examining the impact of land suitability in economic outcomes in agricultural societies, the analysis controls for a number of alternative channels. These channels include the timing of the Neolithic Revolution, due to its impact on the advancement and 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, islands and continental fixed effects, all of which may have had a persistent effect on agricultural output and economic outcomes.

To establish a “reversal of fortune” with respect to natural land endowment, the analysis employs cross country variation in land suitability, to explain the cross-country variation in log income per capita in the year 2000. A number of potentially confounding factors and alternative hypothesis suggested by the related literature on comparative development are accounted for. The geography channel is controlled through a number of geographical controls that may affect economic outcomes today. The institutional hypothesis, that suggests that a "reversal of fortune" can be traced to the impact of European colonization on comparative development, is accounted for through a number of controls including European colonies dummies, legal origins dummies and institutional quality controls. Furthermore, controls for the disease environment, ethnic fractionalization and religion shares are employed.

Importantly, as suggested by the theory, it is not the direct effect of land suitability that drives the reversal of fortune but instead the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation. In the absence of migration, the country’s level of social capital is captured by its natural land endowment. However, in the post-colonial era, where mass migration has taken place, the level of social capital in each country reflects the weighted average of land suitability among its ancestral population. Hence, in order to capture this distinction, two alternative empirical strategies are adopted. First, the sample is restricted to countries with a large percentage of native population, thereby implying that the social capital that has been accumulated in the past, is still a prevalent norm among the native population. Second, the measure of land suitability is adjusted to capture the portable component of natural land endowment. Therefore a measure of adjusted land suitability is constructed using the weighted average of the land suitability of the ancestral population of each country today. The adjustment of the land suitability index is based on the migration matrix constructed by Putterman and Weil (2010), which provides estimates of the proportion of the ancestors in the year 1500 of one country’s population today that were living within what are now the borders of that and each of the other countries.

Second, the empirical analysis establishes that the reversal of fortune captures the adverse effect of natural land productivity on social capital as reflected by the contemporary level of generalized trust. Importantly, since the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation, affects the current level of trust, the measure of land suitability is adjusted to capture the portable component of natural land endowment, namely social capital, using the weighted average of the land suitability of the ancestral population of each country today. A number of alternative channels are accounted for, namely geographical and institutional factors, ethnic fractionalization, disease environment and dummies for continents, legal origins, European colonies and major religion shares. In addition, an alternative measure of trust is employed, namely the extent of participation in civic activities (La Porta et al., 1997). Furthermore, as an additional robustness check, the unadjusted measure of land suitability is employed and the sample of countries is restricted to those with native population larger than 75%, as an additional robustness control.

Third, the empirical analysis establishes that higher suitability of land for agriculture is associated with a lower level of cooperation in the agricultural sector, as reflected by the fraction of irrigated land. In the absence of extensive cross-country data on irrigation prior to industrialization, the analysis is based on the fraction of irrigated land for a sample of non-industrial countries in the year 1900. The exclusion of industrialized countries is based upon membership in the OECD in the year 1985, under the assumption that membership was restricted to advanced, and thus early industrialized countries. In the light of the fact that industrialized countries are more advanced technologically, the restriction of the sample is aimed to eliminate the possibility that the extent of irrigation is capturing the stage of development as opposed to the trade-offs associated with the development of infrastructure.

Given that in the year 1900 mass migration has already taken place in a number of countries, a potential concern would be that irrigation is affected by some sort of specific human capital carried by the migrants, which could reduce the opportunity cost associated with the development of irrigation. Hence in order to capture this aspect the sample is restricted to countries with a large percentage of native population.[30]

In the absence of more extensive data on agricultural infrastructure in antiquity, the adverse effect of natural land productivity on cooperation in earlier periods is examined based on several proxies of cooperation: a) communication in the year 1 CE, b) transportation in the year 1 CE, and c) medium of exchange in the year 1 CE. According to the theory, sophisticated means of communication, transportation and medium of exchange have been catalysts in the advancement of large-scale cooperation, and thus, under-development of these technologies reflects the adverse effect of land suitability on the extent of cooperation. Nevertheless, it could be plausibly argued that the advancement of these technologies captures the degree of trade, associated with higher land suitability, as opposed to the emergence of cooperation in an environment characterized by lower

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[30] It could be plausibly argued though that since early industrialized countries are excluded from the sample, migration is unlikely to be a major factor in the analysis.

land suitability. Reassuringly however, a more suitable land for agriculture in these societies had an adverse effect on the technological levels of these three sectors, suggesting that the dominating effect was indeed that of reduced cooperation. Moreover, the adverse effect of land suitability on the development of these technologies remains significant if the degree of inequality in the suitability of land for agriculture – a more direct proxy for the trade channel in early stages of development – is accounted for. The analysis further controls for a number of channels, that may have had a persistent effect on cooperation, including the timing of the Neolithic Revolution, geographical factors, such as absolute latitude, access to waterways, average ruggedness, average elevation as well as dummies for landlocked countries, islands and continents.

6.1.2 The Data

Data on historical 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.[31]

Land suitability 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. Therefore 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.[32] 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 Michalopoulos (2011).

One potential source of concern with respect to the measure of land suitability is whether current data on the suitability of land for cultivation reflect land suitability in the past. Importantly, the critical aspect of the data for the tested hypothesis is the ranking of countries with respect to their land suitability as opposed to the actual measure of land suitability. Hence the identifying assumption is that the ranking of land suitability as measured today, reflects the ranking of land suitability in the past.

If intense cultivation and human intervention affected soil quality over time, this could have affected all countries proportionally and therefore it would introduce a non-systematic error. This would not only leave the ranking of countries with respect to land suitability for agriculture unaffected, but would also enhance the difficulty to detect a significant effect on land suitability. Importantly, even in the presence of a systematic error, it would be implausible to argue that the ranking of countries with respect to land suitability has been reversed, based on two observations, similar to the ones made by Michalopoulos (2011) and Nunn and Qian (2011). First, one of the two components of the index is based upon climatic conditions, which have not significantly changed

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[31] For a more extensive discussion on this data see Ashraf and Galor (2011a).

[32] The argument for adopting such an approach is based upon the observation that at the global scale, climate and soil factors form the major constraints on cultivation, and adequately describe the major patterns of agricultural land (Ramankutty et al., 2002),

during the period of examination.[33] Therefore, even if the characteristics of soil quality have significantly changed over time, this would still have a limited effect on the total index of land suitability. Second, given that the measure of land suitability captures the average level of land suitability within a given country, 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 suitability 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 the year 1500 of one country's population today that were living within what are now the borders of that and each of the other countries. The measure of adjusted land suitability is the weighted average of the land suitability of the ancestral population of each country today. The migration matrix of Putterman and Weil (2010) is also the basis of the measure of the percentage of native population, as constructed by (Ashraf and Galor, 2011a).

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* variable employs data for the year 1900 and is expressed as the fraction of irrigated land over arable land. Despite the fact that data is from the year 1900, evidence suggests that most 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 have primarily occurred prior to industrialization. In addition, data for the period prior 1900 were used as a basis for interpolation, again indicating that a significant part of the irrigation infrastructure had been constructed in the years prior industrialization (Framji et al., 1981).

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

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[33] Durante (2010) has examined at the relationship between climatic conditions for the years 1900-2000 and 1500-1900. In particular he looks at the relationship separately for average precipitation, average temperature, precipitation variability and temperature variability. His findings confirm that regions with more variable climate in the present years were also characterized by more variate climate in the past, thereby reassuringly implying that climatic conditions have not significantly changed over time.

[34] The values are provided in 1000 ha units

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 Suitability 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 the positive effect of the log land suitability 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 the year 1500, conditional on continental fixed effects. The estimated linear coefficient associated with log land suitability implies that a 1% increase in land suitability would increase population density by 0.57% in the year 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 effects on population density in the year 1500, log land suitability 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 had 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 suitability remains largely intact.

Column (4) introduces into the analysis distance from the nearest technological frontier as derived by Ashraf and Galor (2011a). As predicted in their research, distance from the nearest 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 suitability remains remarkably stable. According to the

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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 Suitability and Comparative Development in the Agricultural Stage

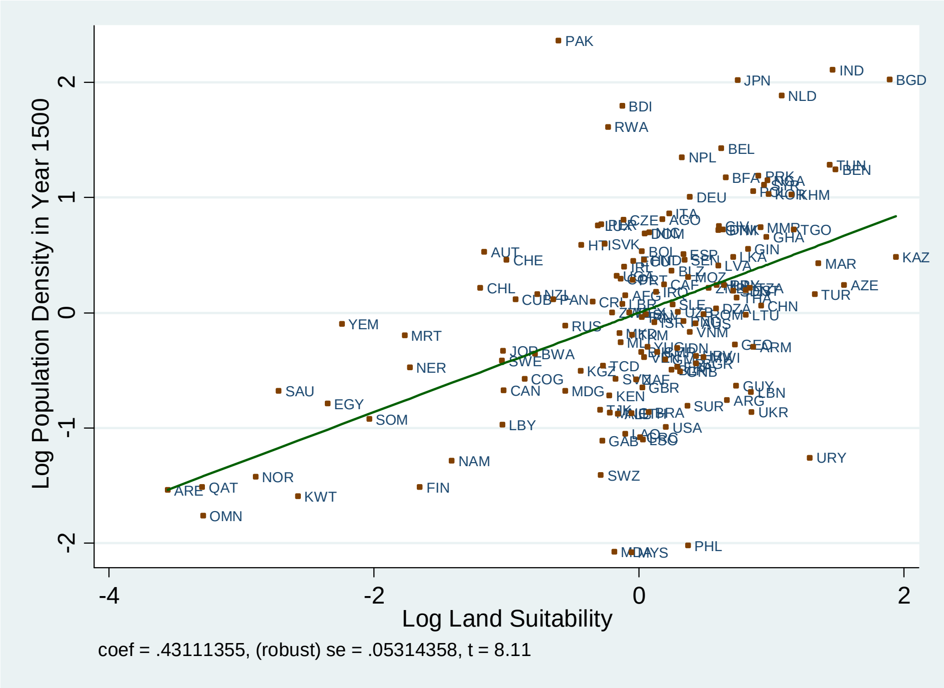
	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in 1500			
Log Land Suitability	0.572***	0.428***	0.442***	0.431***
	(0.0753)	(0.0644)	(0.0578)	(0.0531)
Log Average Ruggedness		0.180	0.247*	0.254**
		(0.134)	(0.125)	(0.114)
Log Average Elevation		-0.00712	-0.126	-0.158
		(0.124)	(0.124)	(0.103)
Log 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 suitability 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 suitability 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) includes 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 is 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.

regression, a 1% increase in land suitability is associated with a 0.43% increase in population density in the year 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 suitability on economic outcomes in the year 1500 is depicted on the scatter plot in Figure 6.

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



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

Table 2 establishes, in line with the theory, that favorable land endowment has an adverse effect on current economic outcomes, thereby establishing a reversal of fortune. Importantly, as suggested by the theory, it is not the direct effect of land suitability that drives the reversal of fortune but instead the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation. In the absence of migration, the country's level of social capital is captured by its natural land endowment. However, in the post-colonial era, where mass migration has taken place, the level of social capital in each country reflects the weighted average of land suitability among its ancestral population. Hence, in order to capture this distinction, two alternative empirical strategies are adopted. First, the measure of land suitability is adjusted to capture the portable component of natural land endowment. The adjustment of the land suitability 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 the year 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 suitability is constructed using the weighted average of the land suitability of the ancestral population of each country today. Second, the sample is restricted to countries with a large percentage of native population, thereby implying that the social capital that has been accumulated in the past, is still a prevalent norm among the native population.

Specifically, accounting for a variety of potentially confounding factors, the table demonstrates the negative effect of the log adjusted land suitability on the log of income per capita in the year 2000.

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, adjusted land suitability possesses a statistically significant negative relationship with income per capita in the year 2000. Specifically, the regression coefficient implies that a 1% point increase in adjusted land suitability is associated with a 0.18% decrease in income per capita in the year 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 factors do possess statistically significant correlations with income per capita in the year 2000, the persistent adverse effect of adjusted land suitability 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 adjusted land suitability, despite the significance of these controls in income per capita in the year 2000.

To ensure that the observed reversal in the impact of adjusted land suitability 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 adjusted land suitability remains largely robust, showing that a 1% point increase in adjusted land suitability is associated with a 0.26% decrease in income per capita in the year 2000.

Column (5) is employing a measure of unadjusted land suitability and is restricting the sample to 84 countries that have native population over 75% of the total population, while retaining all the controls introduced in Column (4). Remarkably the results strongly support the hypothesis.[36]

The evidence presented in Table 2 therefore demonstrates, consistently with the theory, that land suitability 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 adjusted land suitability on economic outcomes in the year 2000 is depicted on the scatter plot in Figure (7).[37] Figure (8) indicates the effect of land suitability

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[36] 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. Choosing a higher threshold would significantly reduce the size without qualitatively altering the results.

[37] One potential concern may be that the adverse effect of land productivity on current economic outcomes is reflecting the effect of the "natural resource curse". Reassuringly though, the negative correlation between the index of land productivity and income from natural resources as a fraction of GDP implies that the adverse effect of land productivity on contemporary economic outcomes does not capture the resource curse. Controlling though for OPEC countries, or alternatively for natural resources as a fraction of GDP as an additional robustness check, does not qualitatively affect the results.

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

	(1)	(2)	(3)	(4)	(5)
			Dep. Var.: Log Per Capita Income in 2000		
Log Adjusted Land Suitability	-0.189**	-0.263***	-0.272***	-0.261***	
	(0.079)	(0.078)	(0.084)	(0.098)	
Log Land Suitability					-0.211***
					(0.0765)
Log Average Ruggedness		-0.152	-0.0867	-0.0016	0.114
		(0.156)	(0.104)	(0.119)	(0.121)
Log Average Elevation		0.277	0.0616	-0.14	-0.194
		(0.181)	(0.121)	(0.139)	(0.150)
Log Absolute Latitude		0.182	-0.0973	0.0248	-0.106
		(−0.127)	(−0.12)	(−0.158)	(0.185)
Distance to Near Coast/River		-0.422**	-0.364*	-0.223	-0.320**
		(0.199)	(0.185)	(0.177)	(0.160)
% Land within 100km of Water		0.603	0.0509	-0.22	-0.348
		(0.414)	(0.345)	(0.373)	(0.414)
Log Adj. Years Since Neolithic		-0.221	0.0343	0.0304	-0.0635
		(0.269)	(0.201)	(0.307)	(0.271)
Ethnolinguistic Fractionalization			-0.846**	-0.521	-0.597*
			(0.360)	(0.388)	(0.322)
Polity IV			0.105***	0.0626**	0.0772**
			(0.025)	(0.029)	(0.0331)
% of Pop at Risk of Malaria			-1.065***	-1.137**	-1.180**
			(0.334)	(0.483)	(0.460)
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	107	107	107	107	84
R-squared	0.584	0.675	0.791	0.84	0.898

Summary: This table establishes the significant negative effect of adjusted land suitability 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) restricts the sample to countries with a fraction of native population higher than 75 percent and is employing a measure of land suitability as opposed to adjusted land suitability, as an alternative approach to capture the portable component of land suitability, namely the social capital being the outcome of cooperation in the agricultural sector. Notes: (i) Log land suitability 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 measure for adjusted land suitability is adjusting the land suitability 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. (iii) the set of continent dummies in Columns (1)-(4) includes a fixed effect for Africa, Australia, Europe, North America, South America and Oceania; (iv) 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; (v) 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; (vi) the set of European colony dummies in columns (4)-(6) includes a fixed effect for British colony, French colony, Portuguese colony, Spanish colony and other European colony; (vii) robust standard error estimates are reported in parentheses; (viii) *** 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.

on current economic outcomes for the restricted sample of countries, having a fraction of native population higher than 75%.

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

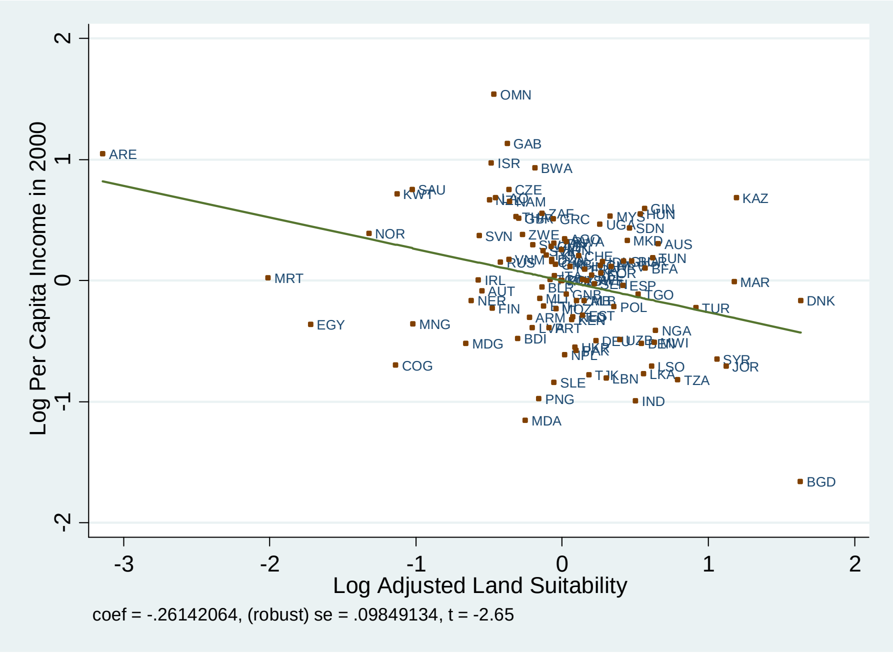
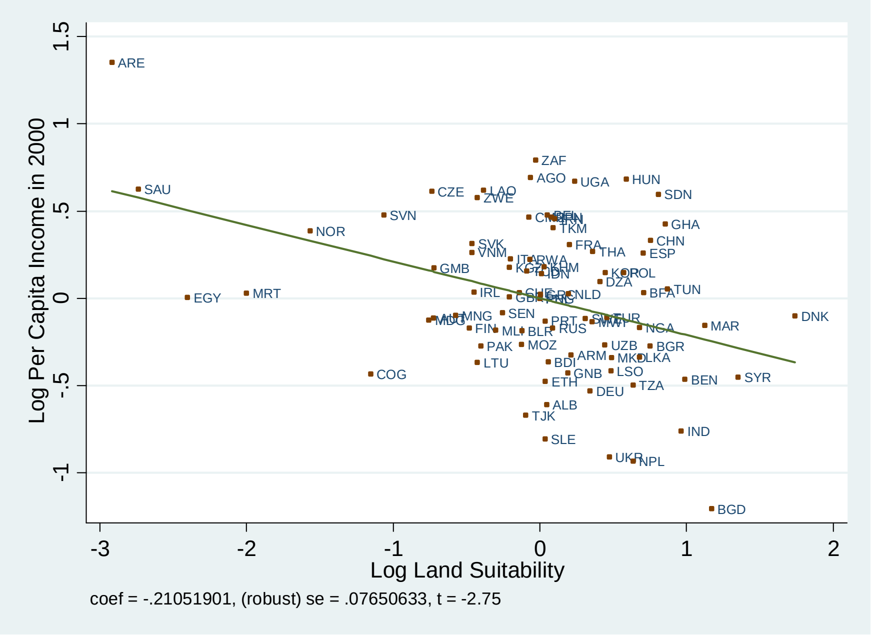


Figure 8: Land Suitability and Economic Outcomes in the Year 2000-Restricted Sample



6.2.2 The Impact of Land Suitability on Trust in the Industrial Stage

Consistently with the predictions of the theory, Table 3 establishes that countries with unfavorable land endowment manifest higher levels of social capital and trust today. Importantly, since the portable component associated with land suitability, namely the social capital that emerged as the outcome of cooperation, affects the current level of trust, the measure of land suitability is adjusted to capture the portable component of natural land endowment, namely social capital, using the weighted average of the land suitability of the ancestral population of each country today (Putterman and Weil, 2010). In particular, the analysis reveals a statistically significant and robust negative effect of the log adjusted land suitability on the index of trust.

Exploiting variations across a sample of 57 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 suitability 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 suitability on trust in the industrial stage remains 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 may be associated with more trust (Putnam, 2007). Nevertheless, even after controlling for these additional channels the coefficient remains largely intact.

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

Whereas adjusted land suitability is the appropriate measure, Column (5) conducts a robustness check by using the measure of log land suitability and restricting the sample to the countries that have a percentage of native population higher than 75%, thereby implying that the norms of social capital and trust are still prevalent among the native population. While the coefficient drops slightly in magnitude, its statistical significance remains unaffected.

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) and indicated in Column (6).

The evidence presented in Table 3 therefore demonstrates, consistently with the theory, that indeed the land suitability 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. The negative effect of adjusted land suitability on the generalized level of trust is depicted on the scatter plot in Figure (14). Figure (15) illustrates the adverse effect of land suitability on the current levels of trust, for the restricted sample of countries with a fraction of the native population higher than

Table 3: Adjusted Land Suitability and Trust

	(1)	(2)	(3)	(4)	(5)	(6)
	Dep. Var.: Trust					Dep. Var.: Civic Participation
Log Adjusted Land Suitability	-0.0909***	-0.100***	-0.0966***	-0.0656**		-0.0535**
	(0.0173)	(0.0200)	(0.0220)	(0.0242)		(0.0134)
Log Land Suitability					-0.0540***	
					(0.0165)	
Log Average Ruggedness		0.00677	0.00649	-0.0313	-0.0312	-0.00460
		(0.0427)	(0.0422)	(0.0356)	(0.0403)	(0.0264)
Log Average Elevation		-0.0132	-0.0130	-0.000261	-0.0137	-0.0441
		(0.0716)	(0.0697)	(0.0472)	(0.0488)	(0.0302)
Log Absolute Latitude		-0.00193	-0.0345	0.109**	0.0838	0.0468
		(0.0283)	(0.0442)	(0.0404)	(0.0558)	(0.246)
Distance to Near Coast/River		-0.0895**	-0.0848**	-0.0220	-0.0290	-0.0418
		(0.0345)	(0.0334)	(0.0407)	(0.0487)	(0.0310)
% Land within 100km of Water		-0.0120	-0.0324	0.0111	0.00714	-0.0481
		(0.108)	(0.108)	(0.0878)	(0.109)	(0.0647)
Log Adj. Years Since Neolithic		-0.0506	-0.0585	0.232**	0.209*	0.207**
		(0.0745)	(0.0781)	(0.101)	(0.121)	(0.0612)
Ethnolinguistic Fractionalization			-0.101	0.0850	0.217	0.0757
			(0.104)	(0.110)	(0.139)	(0.0495)
Polity IV			0.00267	-0.0154*	-0.0138*	0.00870
			(0.00520)	(0.00754)	(0.00792)	(0.00641)
% of Pop at Risk of Malaria			-0.0658	0.172	0.0706	-8.575
			(0.114)	(0.120)	(0.122)	(5.515)
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	Yes	No
Observations	57	57	57	57	49	24
R-squared	0.415	0.514	0.537	0.788	0.818	0.985

Summary: This table establishes the significant adverse effect of adjusted land suitability 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 suitability, as an alternative approach to capture the portable component of land productivity, namely the social capital being the outcome of cooperation in the agricultural sector. Column (6) employs an alternative measure of social capital namely the extent of civic participation.

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) civic participation measures the extent of participation in civic activities (La Porta et al., 1997); (iii) log land suitability 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 measure for adjusted land suitability is adjusting the land suitability 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. (v) the set of continent dummies in Columns (1)-(4) includes a fixed effect for Africa, Australia, Europe, North America, South America and Oceania; (vi) 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; (vii) 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; (viii) the set of European colony dummies in columns (4)-(6) includes a fixed effect for British colony, French colony, Portuguese colony, Spanish colony and other European colony; (ix) robust standard error estimates are reported in parentheses; (x) *** 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.

75%.[38]

Figure 14: Adjusted Land Suitability and Trust

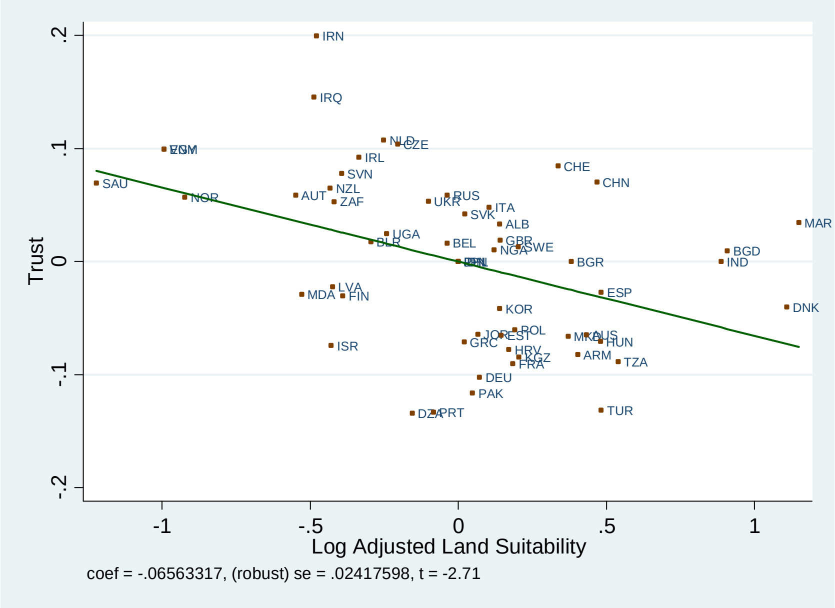
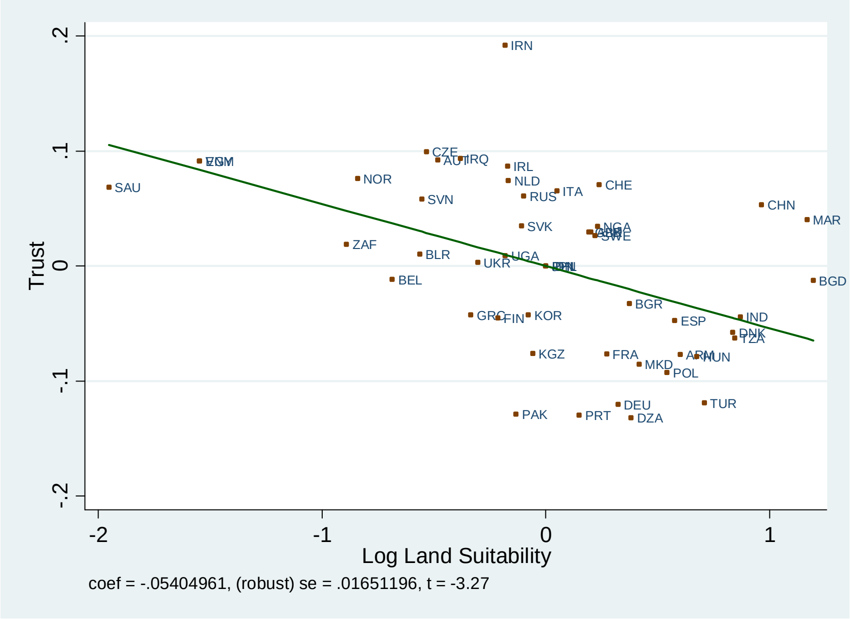


Figure 15: Land Suitability and Trust-Restricted Sample



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[38] One concern that may arise is that land productivity is correlated with the degree of land inequality and high land inequality may generate conflict and therefore hinder cooperation and ultimately trust. To address this concern, one could capture this channel by controlling for land inequality. Reassuringly, as established in Appendix C, controlling for land inequality does not affect the qualitative results. In addition, the coefficient of land inequality is positive thereby implying that if indeed conflict emerges, it is not the dominating effect. In particular, it is plausibly suggested by the positive coefficient, that unequal land productivity fostered cooperation and trade among regions, generating positive effects on economic outcomes in the past and the present as well as on the current levels of trust.

6.2.3 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 4, 5, 6 and 7 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.[39]

In the absence of extensive cross-country data on irrigation prior to industrialization, the analysis is based on the fraction of irrigated land for a sample of non-industrial countries in the year 1900. The exclusion of industrialized countries is based upon membership in the OECD in the year 1985, under the assumption that membership was restricted to advanced, and thus early industrialized countries. In the light of the fact that industrialized countries are more advanced technologically, the restriction of the sample is aimed to eliminate the possibility that the extent of irrigation is capturing the stage of development as opposed to the trade-offs associated with the development of infrastructure.

Consistently with the predictions of the theory, Table 4 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 suitability on the fraction of irrigated land in the year 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 4 reports a statistically significant effect, at the 5% level, of land suitability on the fraction of irrigated land, while controlling only for continental fixed effects.

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 suitability 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

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[39] If coordination problems among members of the community dictate a suboptimal level of investment in infrastructure, the qualitative results would be enhanced. Since the complexity of coordination increases with the size of the community, less favorably endowed places, and therefore more sparsely populated places (according to the Malthusian mechanism) would coordinate more easily than more densely populated places. Hence, the sub-optimally level of investment in infrastructure will be larger in favorably endowed places, enhancing the hypothesis the less favorably endowed places invest more in infrastructure.

Table 4: Cooperation in the Agricultural Stage-Irrigation

	(1)	(2)	(3)	(4)	(5)
	Dep. Var.: Irrigation in 1900				
Log Land Suitability	-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

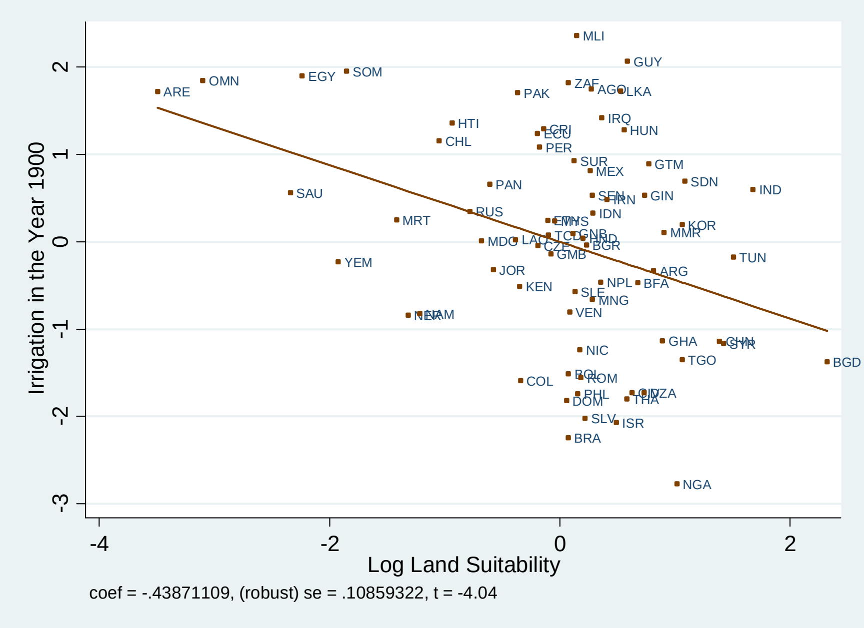
Summary This table establishes the significant adverse effect of land suitability on cooperation, as proxied by the fraction of irrigated land in the year 1900, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, years since the Neolithic transition, 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 the ratio of irrigated land over arable land; (iii) log land suitability 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) includes 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.

could be developed. Nevertheless the coefficient of land suitability remains highly significant and intact.

Given that in the year 1900 mass migration has already taken place in a number of countries, a potential concern would be that irrigation is affected by some sort of specific human capital carried by the migrants, which could reduce the opportunity cost associated with the development of irrigation. Hence in order to capture this aspect, Column (5) is restricting the sample to countries with a percentage of native population higher than 75%, thereby implying that migration has not affected the composition of the human capital of the native population. It is established that the adverse effect of land suitability on the development of irrigation in the year 1900, remains intact, with the coefficient increasing in magnitude and implying that a 1% increase in land suitability would be associated with a 0.48% decrease in the fraction of irrigated land.

The evidence presented in table 4, is thereby establishing the adverse effect of land suitability on the emergence of irrigation. The negative effect of land suitability on the fraction of irrigated land in the year 1900 is illustrated 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 Suitability 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

In the absence of more extensive data on agricultural infrastructure in antiquity, the adverse effect of natural land productivity on cooperation in earlier periods is examined based on several proxies of cooperation: a) communication in the year 1 CE, b) transportation in the year 1 CE, and c) medium of exchange in the year 1 CE. According to the theory, sophisticated means of communication, transportation and medium of exchange have been catalysts in the advancement of large-scale cooperation, and thus, under-development of these technologies reflects the adverse effect of land suitability on the extent of cooperation.

Exploiting variations across a sample of 142 countries for which data on the full set of variables used by the analysis are available, Column (1) in Table 5 establishes, conditional on continental fixed effects, a statistically significant negative effect of land suitability on the development of sophisticated means of communication in the year 1.

It could be argued that the advancement of communication technology captures the degree of trade, associated with higher land suitability, as opposed to the emergence of cooperation in an environment characterized by lower land suitability. Reassuringly however, a more suitable land for agriculture in these societies had an adverse effect on the technological level of this sector, suggesting that the dominating effect was indeed that of reduced cooperation. Moreover, to control for this channel, Column (2) controls for inequality in the land suitability for agriculture, a more direct proxy for trade in early stages of development. Reassuringly, the adverse effect of land suitability on the development of these technologies remains significant, despite the positive and statistically significant effect of land inequality on cooperation technology.

Column (3) enriches the analysis with additional 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 suitability in the development of means of communication remains statistically significant. Column (4) controls for the timing of the Neolithic Revolution that is attested to have affected the emergence of more developed communication means.

Table 5: Cooperation in the Agricultural Stage-Communication

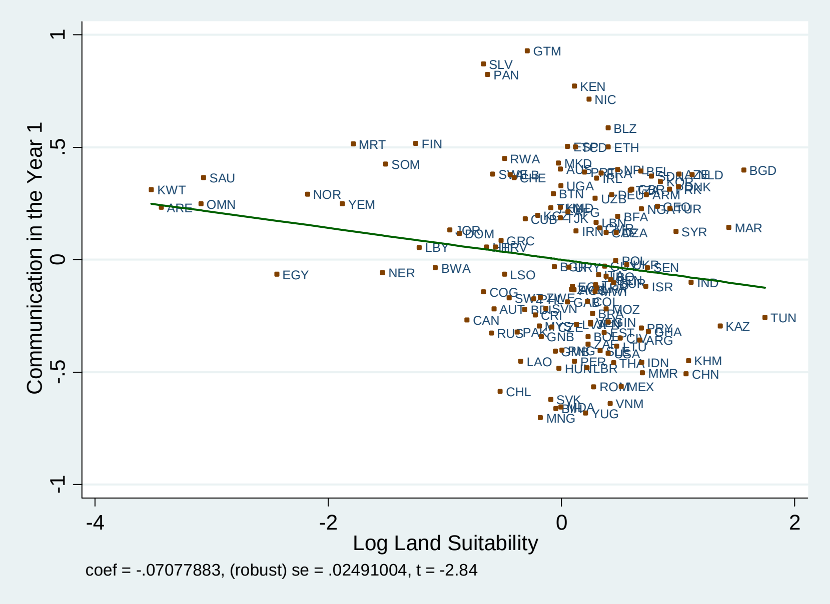
	(1)	(2)	(3)	(4)	(5)
	Dep. Var.: Communication in the Year 1				
Log Land Suitability	-0.0899***	-0.0674***	-0.0775***	-0.0729***	-0.0708***
	(0.023)	(0.024)	(0.026)	(0.025)	(0.025)
Log Land Suitability Gini		0.0679	0.115*	0.112*	0.123*
		(0.052)	(0.067)	(0.065)	(0.064)
Log Average Ruggedness			0.0623	0.0844*	0.076
			(0.050)	(0.050)	(0.048)
Log Average Elevation			0.00125	-0.0346	-0.0377
			(0.051)	(0.050)	(0.046)
Log Absolute Latitude			0.0663	0.0991*	0.0853*
			(0.056)	(0.051)	(0.051)
Mean Distance to Nearest Coast or River			0.0132	0.0257	0.0311
			(0.107)	(0.099)	(0.097)
% of Land within 100 km of Coast or River			0.297	0.262	0.26
			(0.197)	(0.191)	(0.188)
Log Years Since Neolithic				0.322***	0.247**
				(0.093)	(0.097)
Distance to Frontier in the Year 1					-0.0584***
					(0.020)
Continental Dummies	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes
Observations	142	142	142	142	142
R-squared	0.268	0.276	0.338	0.386	0.401

Summary: This table establishes the significant adverse effect of land suitability on cooperation, as proxied by the means of communication in the year 1, while controlling for log land suitability Gini, 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 suitability 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 land suitability Gini coefficient is based on the distribution of a land suitability index, reported at a half-degree resolution by Ramankutty et al. (2002), across grid cells within a country; (iv) the set of continent dummies in Columns (1)-(4) includes 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; (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.

Nevertheless the coefficient remains largely intact and statistically significant. Column (5) controls for the distance from the nearest technological frontier, however the coefficient remains remarkably stable.

The evidence presented in Table 5, is thereby establishing the detrimental effect of land suitability on the emergence of more sophisticated technology of communication during the agricultural stage of development. The positive effect of land suitability on communication in the year 1 is depicted on the scatter plot in Figure (11).

Figure 11: Land Suitability and Communication in the Year 1



Employing a 142 cross country sample, Column (1) in table 6 establishes, conditional on continental fixed effects, a statistically significant negative effect of land suitability on the development of more advanced transportation technology in the year 1.

The concern that the advancement of transportation technology captures the degree of trade, associated with higher land suitability, is more pronounced in the case of transportation. Reassuringly however, a more suitable land for agriculture in these societies had an adverse effect on the technological level of this sector, suggesting that the dominating effect was indeed that of reduced cooperation. Moreover, to control for this channel, Column (2) controls for inequality in the land suitability for agriculture, as a proxy for trade. Reassuringly, the adverse effect of land suitability on the development of these technologies remains significant, despite the positive and statistically significant effect of land inequality on the emergence of transportation technology.

Column (3) further augments the analysis with additional geographical controls. Despite the statistical significance of the additional controls, the persistent effect of land suitability in the development of transportation technology remains statistically significant and largely unaffected. Column (4) enriches the analysis by controlling for the timing of the Neolithic Revolution however the coefficient remains intact. Column (5) establishes similar results even after controlling for the distance from the nearest technological frontier.

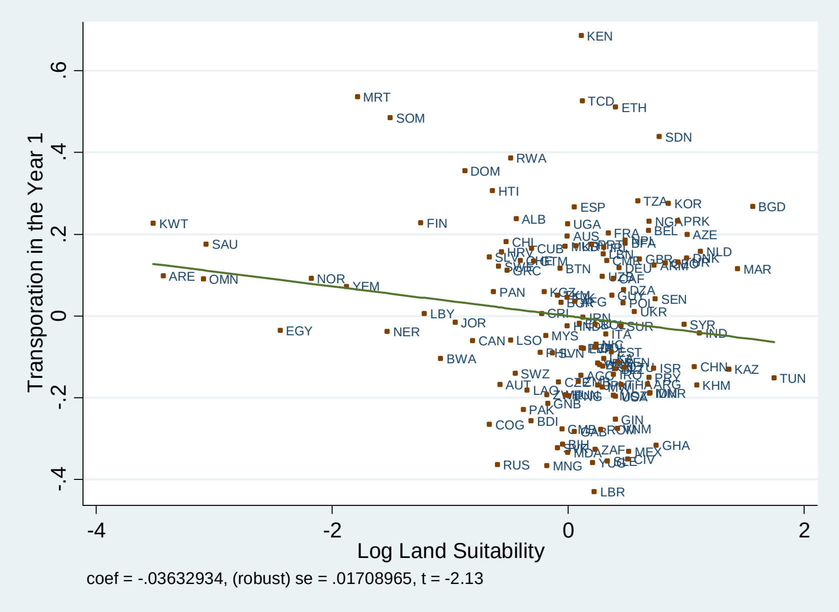
Table 6: Cooperation in the Agricultural Stage-Transportation

	(1)	(2)	(3)	(4)	(5)
	Dep. Var.: Transportation in the Year 1				
Log Land Suitability	-0.0686***	-0.0340*	-0.0412**	-0.0375**	-0.0363**
	(0.017)	(0.019)	(0.019)	(0.017)	(0.017)
Log Land Suitability Gini		0.105***	0.134***	0.131***	0.137***
		(0.030)	(0.038)	(0.035)	(0.035)
Log Average Ruggedness			0.0272	0.0447	0.04
			(0.033)	(0.031)	(0.030)
Log Average Elevation			0.00197	-0.0265	-0.0282
			(0.033)	(0.032)	(0.029)
Log Absolute Latitude			0.0255	0.0516	0.0439
			(0.042)	(0.039)	(0.039)
Mean Distance to Nearest Coast or River			-0.0181	-0.00815	-0.00512
			(0.077)	(0.071)	(0.069)
% of Land within 100 km of Coast or River			0.147	0.119	0.118
			(0.103)	(0.097)	(0.096)
Log Years Since Neolithic				0.256***	0.213***
				(0.063)	(0.066)
Distance to Frontier in the Year 1					-0.0327**
					(0.013)
Continental Dummies	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes
Observations	142	142	142	142	142
R-squared	0.671	0.694	0.708	0.744	0.75

Summary: This table establishes the significant adverse effect of land suitability on cooperation, as proxied by the means of transportation in the year 1, while controlling for log land suitability Gini, 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 suitability 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 land suitability Gini coefficient is based on the distribution of a land suitability index, reported at a half-degree resolution by Ramankutty et al. (2002), across grid cells within a country; (iv) 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 ; (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.

The evidence presented in table 6, is thereby establishing the detrimental effect of land productivity on the emergence of more advanced transportation technology during the agricultural stage of development. The positive effect of land suitability on transportation in the year 1 is depicted on the scatter plot in Figure (12).

Figure 12: Land Suitability and Transportation in the Year 1



coef = -.03632934, (robust) se = .01708965, t = -2.13

Employing a 142 cross country sample, Column (1) in Table 7 establishes, conditional on continental fixed effects, a statistically significant negative effect of land suitability on the development of advanced medium of exchange in the year 1.

Similarly to the case of transportation technology, the concern that the advancement of the medium of exchange captures the degree of trade, associated with higher land suitability, is more pronounced. Reassuringly however, a more suitable land for agriculture in these societies had an adverse effect on the medium of exchange, suggesting that the dominating effect was indeed that of reduced cooperation. Moreover, to control for the trade channel, Column (2) controls for inequality in the land suitability for agriculture. Reassuringly, the adverse effect of land suitability on the development of a medium of exchange remains significant, despite the positive and statistically significant coefficient of land inequality.

Column (3) further augments the analysis with additional geographical controls, reassuringly though the coefficient of land suitability remains intact. Column (4) controls for the timing of the Neolithic Revolution, whereas Column (5) 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 suitability in the development of medium of exchange remains statistically significant.

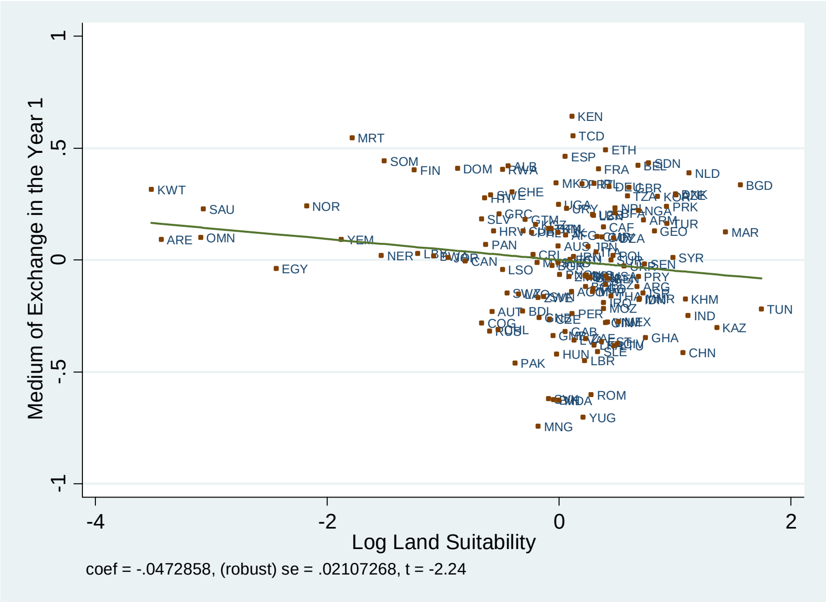
The evidence presented in Table 7, is thereby establishing the detrimental effect of land productivity on the emergence of more sophisticated medium of exchange during the agricultural stage of development. The positive effect of land suitability on the medium of exchange in the year 1 is depicted on the scatter plot in Figure (13).

Table 7: Cooperation in the Agricultural Stage-Medium of Exchange

	(1)	(2)	(3)	(4)	(5)
	Dep. Var.: Medium of Exchange in the Year 1				
Log Land Suitability	-0.0777***	-0.0377*	-0.0529**	-0.0490**	-0.0473**
	(0.020)	(0.021)	(0.022)	(0.021)	(0.021)
Log Land Suitability Gini		0.0969***	0.152***	0.149***	0.158***
		(0.037)	(0.047)	(0.045)	(0.044)
Log Average Ruggedness			0.0792*	0.0978**	0.0909**
			(0.043)	(0.042)	(0.041)
Log Average Elevation			-0.0434	-0.0736*	-0.0762**
			(0.038)	(0.037)	(0.035)
Log Absolute Latitude			0.0169	0.0446	0.0332
			(0.043)	(0.040)	(0.040)
Mean Distance to Nearest Coast or River			-0.0563	-0.0457	-0.0413
			(0.091)	(0.085)	(0.083)
% of Land within 100 km of Coast or River			0.0983	0.0686	0.0671
			(0.142)	(0.138)	(0.137)
Log Years Since Neolithic				0.271***	0.209***
				(0.072)	(0.078)
Distance to Frontier in the Year 1					-0.0481***
					(0.0173)
Continental Dummies	Yes	Yes	Yes	Yes	Yes
Landlocked Dummy	No	Yes	Yes	Yes	Yes
Island Dummy	No	Yes	Yes	Yes	Yes
Observations	142	142	142	142	142
R-squared	0.491	0.523	0.546	0.583	0.594

Summary: This table establishes the significant adverse effect of land suitability on cooperation, as proxied by the medium of exchange in the year 1, while controlling for log land suitability Gini, 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 suitability 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 land suitability Gini coefficient is based on the distribution of a land suitability index, reported at a half-degree resolution by Ramankutty et al. (2002), across grid cells within a country; (iv) the set of continent dummies in Columns (1)-(4) includes 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; (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.

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



coef = -.0472858, (robust) se = .02107268, t = -2.24

Reassuringly, as is evident from Tables 4, 5, 6 and 7, there is a statistically significant adverse effect of land suitability 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.[40]

7 Concluding Remarks

This research argues that reversal of fortune in the process of economic development can be traced to the effect of natural 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 natural 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

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[40] One could potentially argue that threat of war and the fear of being invaded could enforce cooperation in the past. However, the presence of this plausible effect would suggest that the identified adverse effect of land productivity on cooperation represents an upper bound of the actual effect. First, if one plausibly assumes that the more fertile places faced an increased risk to be invaded then land productivity would generate a positive effect on cooperation via this channel, mitigating the actual adverse effect identified in the regression analysis. Moreover, even if implausibly, less fertile places were faced with an increased probability of being invaded, it would only constitute a complementary channel through which land productivity is affecting cooperation and trust, since as the established effect of low land productivity on cooperation, via irrigation, medium of exchange, and communication technologies are tangential to cooperation for defensive purposes.

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 natural 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 fortune in the process of development can be traced to variation in land suitability for agriculture 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 suitability in the past is associated with higher levels of contemporary social capital.

Interestingly, the proposed mechanism could also capture the emergence of risk mitigating social networks in remote and harsh climatic environments and thus potentially the forces behind the emergence of the welfare state. The advent of the welfare state in the region of Scandinavia, for instance, could be partly traced to the long lasting effects of this form of cooperation, that had characterized this region in the past.

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

$$\begin{aligned} J\left(A_t^A, L_t\right) &= \begin{bmatrix} \partial A_{t+1}^A/\partial A_t^A & \partial A_{t+1}^A/\partial L_t \\ & \\ \partial L_{t+1}/\partial A_t^A & \partial L_{t+1}/\partial L_t \end{bmatrix} \\ &= \begin{bmatrix} \beta + b(L_t)^{\lambda}(A_t^A)^{b-1} & \lambda(L_t)^{\lambda-1}(A_t^A)^{b} \\ & \\ \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)}\xi^{2-a} & \frac{1-\gamma}{\tau}a^a(1-a)^{(1-a)}\xi^{-a} \end{bmatrix}, \end{aligned} \tag{A.1}$$

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

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

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 $Det\left(J_{ss}\right) > 0$, $\xi < \xi < \left[\frac{(1-\gamma)v}{\tau}\frac{[\beta(1-\beta)^{\frac{b}{1-b}} + b(1-\beta)^{\frac{1}{1-b}} + \lambda(1-\beta)^{\frac{1}{(1-b)}}]}{\lambda}\right]^{1/a}$ 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* 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 Suitability. 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. This index was initially reported at a half-degree resolution by Ramankutty et al. (2002). Formally, Ramankutty et al. (2002) calculate the land suitability index (S) as the product of climate suitability (Sclim) and soil suitability (Ssoil), i.e., S = Sclim Ssoil. The climate suitability component is estimated to be a function of growing degree days (GDD) and a moisture index (α) gauging water availability to plants, calculated as the ratio of actual to potential evapotranspiration, i.e., Sclim = f1(GDD)f2(α). The soil suitability component, on the other hand, is estimated to be a function of soil carbon density (Csoil) and soil pH (pHsoil), i.e. Ssoil = g1(Csoil)g2(pHsoil). The functions, f1(GDD), f2(α), g1(Csoil), and g2(pHsoil) are chosen by Ramankutty et al. (2002) by empirically fitting functions to the observed relationships between cropland areas, GDD, α, Csoil, and pHsoil. For more details on the specific functional forms chosen, the interested reader is referred to Ramankutty et al. (2002). Since Ramankutty et al. (2002) report the land suitability index at a half-degree resolution, Michalopoulos (2011) aggregates the index to the country level by averaging land suitability across grid cells within a country. This study employs the country-level aggregate measure reported by Michalopoulos (2011) as the control for land suitability in the baseline regression specifications for both historical population density and contemporary income per capita.

Land Suitability (Adjusted). The cross-country weighted average of the land suitability 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).

Land Suitability Gini. The land suitability Gini coefficient is based on the distribution of a land suitability index, reported at a half-degree resolution by Ramankutty et al. (2002), across grid cells within a country. This variable is obtained from the data set of Michalopoulos (2011).

Land Suitability Gini (Adjusted). The cross-country weighted average of the land suitability Gini 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 Suitability 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 Suitability	-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 Suitability 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	8.336	1.241	6.145	10.440	1.000										
(2)	Log Adjusted Land Suitability	-1.413	1.250	-5.686	-0.177	-0.075	1.000									
(3)	Log Average Ruggedness	4.260	1.078	1.282	6.371	0.135	0.271	1.000								
(4)	Log Average Elevation	5.962	1.006	3.051	7.950	-0.269	-0.020	0.622	1.000							
(5)	Log Absolute Latitude	3.058	0.966	0.000	4.159	0.573	-0.030	0.192	-0.135	1.000						
(6)	Distance to Near Coast/River	0.390	0.498	0.023	2.386	-0.405	-0.217	-0.059	0.393	-0.091	1.000					
(7)	% of Land within 100 km of Coast or River	0.419	0.376	0.000	1.000	0.558	0.308	0.063	-0.607	0.334	-0.667	1.000				
(8)	Log Adjusted Years Since Neolithic	8.453	0.496	7.213	9.250	0.476	-0.077	0.326	-0.060	0.450	-0.120	0.357	1.000			
(9)	Ethnolinguistic Fractionalization	0.454	0.267	0.002	0.930	-0.637	-0.106	-0.300	0.100	-0.570	0.253	-0.445	-0.412	1.000		
(10)	Polity IV	3.765	3.740	0.000	10.000	0.693	0.262	0.143	-0.230	0.448	-0.361	0.527	0.241	-0.480	1.000	
(11)	% of Pop at Risk of Malaria	0.372	0.444	0.000	1.000	-0.724	0.013	-0.338	0.023	-0.749	0.142	-0.406	-0.621	0.668	-0.499	1.000

Note: Number of observations = 107.

Table C.3: Descriptive Statistics for the Analysis of the Impact of Land Suitability 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 Suitability	-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.4: Descriptive Statistics for the Analysis of the Impact of Land Suitability 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 Suitability	-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.5: Descriptive Statistics for the Analysis of the Impact of Land Suitability on Communication in the Year 1

		Summary Statistics				Pairwise Correlations									
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Communication in the Year 1	0.481	0.461	0.000	1.000	1.000									
(2)	Log Land Suitability	-1.317	1.223	-5.686	-0.050	-0.315	1.000								
(3)	Log Land Suitability Gini	-1.231	0.744	-3.402	-0.139	0.252	-0.551	1.000							
(4)	Log Average Ruggedness	4.393	1.043	1.282	6.616	0.140	0.287	-0.130	1.000						
(5)	Log Average Elevation	5.963	1.113	-0.650	7.950	0.120	-0.070	0.338	0.546	1.000					
(6)	Log Absolute Latitude	3.004	0.934	0.000	4.159	0.321	-0.040	0.021	0.192	-0.083	1.000				
(7)	Distance to Nearest Coast or River	0.348	0.456	0.020	2.386	0.043	-0.254	0.421	-0.079	0.344	-0.011	1.000			
(8)	% of Land within 100 km of Coast or River	0.432	0.362	0.000	1.000	0.030	0.342	-0.535	0.096	-0.565	0.236	-0.658	1.000		
(9)	Log Years Since Neolithic	8.376	0.573	5.991	9.259	0.492	-0.149	0.131	0.264	0.173	0.364	-0.033	0.130	1.000	
(10)	Distance to Frontier in the Year 1	7.347	1.303	0.000	9.067	-0.377	0.010	0.041	-0.243	-0.044	-0.359	0.182	-0.239	-0.501	1.000

Note: Number of observations = 142.

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

		Summary Statistics				Pairwise Correlations									
		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Transportation in the Year 1	0.542	0.422	0.000	1.000	1.000									
(2)	Log Land Suitability	-1.317	1.223	-5.686	-0.050	-0.329	1.000								
(3)	Log Land Suitability Gini	-1.231	0.744	-3.402	-0.139	0.316	-0.551	1.000							
(4)	Log Average Ruggedness	4.393	1.043	1.282	6.616	0.161	0.287	-0.130	1.000						
(5)	Log Average Elevation	5.963	1.113	-0.650	7.950	0.121	-0.070	0.338	0.546	1.000					
(6)	Log Absolute Latitude	3.004	0.934	0.000	4.159	0.467	-0.040	0.021	0.192	-0.083	1.000				
(7)	Distance to Nearest Coast or River	0.348	0.456	0.020	2.386	0.069	-0.254	0.421	-0.079	0.344	-0.011	1.000			
(8)	% of Land within 100 km of Coast or River	0.432	0.362	0.000	1.000	0.041	0.342	-0.535	0.096	-0.565	0.236	-0.658	1.000		
(9)	Log Years Since Neolithic	8.376	0.573	5.991	9.259	0.702	-0.149	0.131	0.264	0.173	0.364	-0.033	0.130	1.000	
(10)	Distance to Frontier in the Year 1	7.347	1.303	0.000	9.067	-0.406	0.010	0.041	-0.243	-0.044	-0.359	0.182	-0.239	-0.501	1.000

Note: Number of observations = 142.

Table C.7: Descriptive Statistics for the Analysis of the Impact of Land Suitability. 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)	(10)
(1)	Medium of Exchange in the Year 1	0.480	0.443	0.000	1.000	1.000									
(2)	Log Land Suitability	-1.317	1.223	-5.686	-0.050	-0.362	1.000								
(3)	Log Land Suitability Gini	-1.231	0.744	-3.402	-0.139	0.329	-0.551	1.000							
(4)	Log Average Ruggedness	4.393	1.043	1.282	6.616	0.146	0.287	-0.130	1.000						
(5)	Log Average Elevation	5.963	1.113	-0.650	7.950	0.138	-0.070	0.338	0.546	1.000					
(6)	Log Absolute Latitude	3.004	0.934	0.000	4.159	0.327	-0.040	0.021	0.192	-0.083	1.000				
(7)	Distance to Nearest Coast or River	0.348	0.456	0.020	2.386	0.064	-0.254	0.421	-0.079	0.344	-0.011	1.000			
(8)	% of Land within 100 km of Coast or River	0.432	0.362	0.000	1.000	-0.028	0.342	-0.535	0.096	-0.565	0.236	-0.658	1.000		
(9)	Log Years Since Neolithic	8.376	0.573	5.991	9.259	0.587	-0.149	0.131	0.264	0.173	0.364	-0.033	0.130	1.000	
(10)	Distance to Frontier in the Year 1	7.347	1.303	0.000	9.067	-0.349	0.010	0.041	-0.243	-0.044	-0.359	0.182	-0.239	-0.501	1.000

Note: Number of observations = 142

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

	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in the Year 1000			
Log Land Suitability	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 suitability 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 suitability 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) includes 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 Suitability on Population Density in the Year 1000

Table C.9: Descriptive Statistics for the Analysis of the Impact of Land Suitability 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 Suitability	-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 = 142.

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

	(1)	(2)	(3)	(4)
	Dep. Var.: Log Population Density in the Year 1			
Log Land Suitability	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 suitability 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 suitability 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) includes 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 Suitability 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 Suitability	-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.

Table C.12

	(1)	(2)	(3)	(4)
	Log Pop. Dens. in 1500	Log Pop. Dens. in 1000	Log Pop. Dens. in 1	Irrigation in 1900
Log Land Suitability	0.483***	0.439***	0.351***	-0.386***
	(0.0567)	(0.0637)	(0.0872)	(0.116)
Log Adjusted Land Gini	0.244*	0.116	0.0782	0.373
	(0.135)	(0.129)	(0.129)	(0.384)
Log Average Ruggedness	0.284***	0.293**	0.250*	0.587
	(0.109)	(0.121)	(0.130)	(0.353)
Log Average Elevation	-0.203**	-0.251**	-0.267**	0.232
	(0.0974)	(0.116)	(0.119)	(0.386)
Log Absolute Latitude	-0.368**	-0.329**	-0.0172	0.113
	(0.145)	(0.159)	(0.138)	(0.208)
Mean Distance to Nearest Coast or River	-0.439**	-0.421**	-0.624***	-0.531
	(0.174)	(0.201)	(0.194)	(0.446)
% of Land within 100 km of Coast or River	0.929***	0.562	0.387	2.618**
	(0.335)	(0.406)	(0.399)	(1.071)
Log Years Since Neolithic	0.868***	1.143***	1.754***	0.499
	(0.219)	(0.260)	(0.312)	(0.723)
Distance to Frontier in 1500	-0.192***	-0.207***	-0.206***	-0.164*
	(0.0398)	(0.0761)	(0.0589)	(0.0916)
Continental-Landlocked-Island Dummies	Yes	Yes	Yes	Yes
Observations	147	142	129	72
R-squared	0.758	0.689	0.723	0.702

Summary This table establishes the significant positive effect of land suitability on population density in the years 1500, 1000 and 1 as well as the adverse effect of land suitability on the fraction of irrigated land, while controlling for land inequality, 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 suitability 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) land inequality is the Gini coefficient based on the distribution of a land suitability index, reported at a half-degree resolution by Ramankutty et al. (2002), across grid cells within a country; (iii) The regression on irrigation 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; (iv) 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; (v) the set of continent dummies in Columns (1)-(4) includes 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; (vi) a single continent dummy is used to represent the Americas, which in natural given the historical period examined; (vii) robust standard error estimates are reported in parentheses; (viii) *** 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 C.13

	(1)	(2)
	Log Per Capita GDP in 2000	Trust
Log Adjusted Land Suitability	-0.260**	-0.0467*
	(0.101)	(0.0252)
Log Adjusted Land Gini	0.00907	0.0659
	(0.167)	(0.0505)
Log Average Ruggedness	-0.0000139	-0.0239
	(0.127)	(0.0406)
Log Average Elevation	-0.142	-0.00231
	(0.148)	(0.0495)
Log Absolute Latitude	0.0247	0.0979**
	(0.159)	(0.0410)
Mean Distance to Nearest Coast or River	-0.226	-0.0478
	(0.193)	(0.0504)
% of Land within 100 km of Coast or River	-0.218	0.0359
	(0.379)	(0.0908)
Log Adj. Years Since Neolithic	0.0316	0.232**
	(0.310)	(0.0995)
Ethnolinguistic Fractionalization	-0.526	0.0399
	(0.389)	(0.117)
Polity IV	0.0623**	-0.0184**
	(0.0301)	(0.00828)
% of Pop at Risk of Malaria	-1.137**	0.194
	(0.486)	(0.127)
Continental-Landlocked-Island Dummies	Yes	Yes
Legal Origin - European Colony Dummies	Yes	Yes
Major Religion Shares	Yes	Yes
Observations	107	57
R-squared	0.840	0.801

Summary: This table establishes the significant adverse effect of adjusted land suitability on income per capita in year 2000 and on the level of generalized trust, while controlling for average ruggedness, average elevation, absolute latitude, access to navigable waterways, adjusted years since the Neolithic transition, ethnic fractionalization, quality of institutions, disease environment, and fixed effects for landlocked country, island, legal origin, European colony, and unobserved continental fixed effects. Notes: (i) Data on trust come from five different waves of the WVS (1981-2008); (ii) log land suitability is a geospatial index of the suitability of land for agriculture based on ecological indicators of climate and soil suitability for cultivation; (iii) land inequality is the Gini coefficient based on the distribution of a land suitability index; (iv) Adj. land suit. and adj. land inequality is using the migration matrix of Putterman and Weil (2010);. (v) the set of continental dummies includes a fixed effect for Africa, Australia, Europe, N. America, S. America and Oceania; (vi) legal origins dummies includes a fixed effect for British, French, German, Scandinavian and Socialist origin; (vi) major religion shares dummies includes a fixed effect for Catholic, Muslim Protestant and other religious shares; (vii) European colony dummies include a fixed effect for British, French, Portuguese, Spanish and other European colony; (viii) robust standard error estimates are reported in parentheses; (ix) *** denotes statistical significance at the 1 % ** at the 5%, and * at the 10%, all for two-sided hypothesis tests.

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