Joint Discussion Paper
Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 46-2016

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Geography, Parental Investment, and Comparative Economic Development

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Geography, Parental Investment, and Comparative Economic Development

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July 20, 2016

Abstract

This paper suggests differential parental investment as a theoretical link between geographical conditions and comparative economic development, possibly accounting for the reversal of fortune in the process of development with respect to land productivity. The paper develops an evolutionary growth theory that builds on the trade-off between the quantity and quality of offspring. It advances the hypothesis that individuals living in a society characterized by adverse geographical conditions alter the evolutionary optimal allocation of resources from offspring quantity to offspring quality. Higher parental investment in offspring leads to a lower population density but a higher rate of technological progress in the (initially latent) manufacturing sector. Thus, adverse geographical conditions have a negative impact on economic development in the Malthusian epoch but a positive impact on the timing of the Industrial Revolution. The pattern of parental investment captures the very essence of human capital formation in preindustrial times. It is a slow-changing biological or cultural trait and can therefore be seen as a good candidate for a long-term transmission channel of initial geographical conditions on comparative economic development.

Keywords: Comparative Economic Development, Geographical Conditions, Human Evolution, Industrial Revolution, Parental Investment, Reversal of Fortune.

JEL Classification Numbers: O11, I12, J13

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1. Introduction

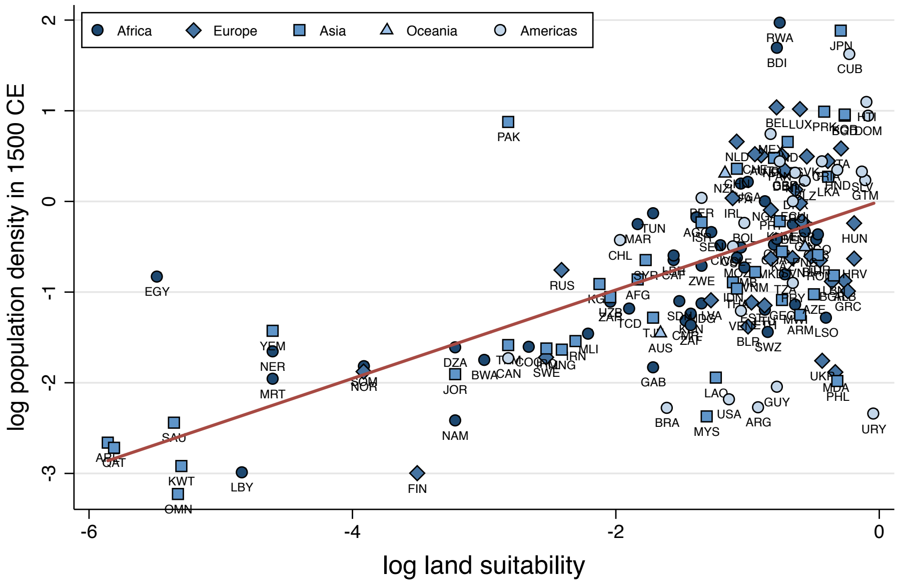
The process of comparative economic development has been profoundly shaped by two remarkable transitions in history. First, the Neolithic transition from hunting and gathering to agriculture more than 10,000 years ago was a necessary condition for human civilization. An earlier onset of the Neolithic Revolution has been associated with a developmental head start that persisted at least until the Middle Ages. Second, the transition from an epoch of Malthusian stagnation to the modern era of sustained economic growth two hundred years ago initiated an unprecedented increase in income per capita. The Industrial Revolution is therefore the foundation of the modern welfare state, but also the origin of a Great Divergence in the distribution of education, health and wealth across the globe.

While early research focused on the proximate determinants of growth such as capital accumulation and technological progress, the literature has shifted gradually toward more fundamental factors. Geographical, institutional, and cultural factors, human capital formation, ethnolinguistic fractionalization, colonization, and globalization have all been debated as determinants that contributed to the pattern of comparative economic development that is prevalent today. Consistent with the profound impact of both transitions, recent research highlights deep-rooted, ultimate factors. History matters because human characteristics have been shaped by geographical conditions since the emergence of *Homo sapiens*, and some key characteristics affecting development are transmitted genetically, epigenetically, or culturally from one generation to the next. A growing body of new empirical work shows that much of the correlation between geographical factors and comparative economic development operates through indirect channels of this kind (for a survey, see Spolaore and Wacziarg 2013).

The distinct characteristics of the agricultural and the industrial era give rise to the idea that certain factors have had a different effect in each stage of development. One such factor is natural land productivity, as documented by Litina (2016). The suitability of land for agriculture and the percentage of arable land are both associated with higher population density in 1500 CE but lower income per capita in 2000 CE (see Figure 1 and Table 1). Both variables together form the so-called *land productivity channel*. Apparently, higher land productivity has been beneficial for growth in the agricultural era but detrimental for growth in the industrial era. This suggests a reversal of fortune in the process of economic development with respect to land productivity. Closely related, Olsson and Paik (2014) document a reversal of fortune within the Western core area, showing that regions that made an early transition to Neolithic agriculture are now poorer than regions that made the transition later. The aim of this paper is to provide a theory that can account for this remarkable reversal of fortune.

The paper proposes that differential parental investment is a key variable, linking initial

(a) The Partial Effect of Land Suitability on Population Density in 1500 CE.



(b) The Partial Effect of Land Suitability on Income Per Capita in 2000 CE.

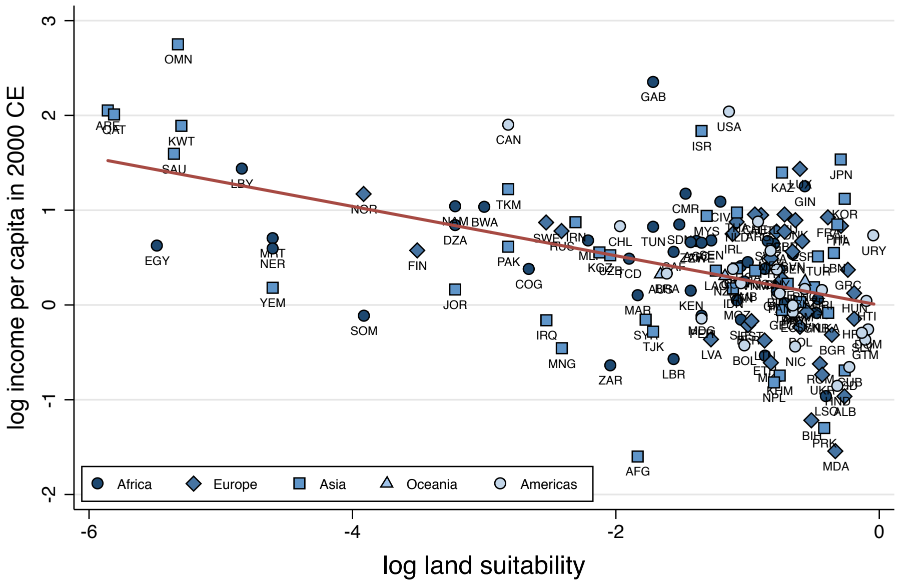


Figure 1: This Figure Depicts the Partial Regression Line for the Effect of Land Suitability on (a) Population Density in the Year 1500 CE and (b) Income Per Capita in the Year 2000 CE, while Controlling for the Influence of Absolute Latitude, Timing of the Neolithic Transition, Access to Waterways, Percentage of Population at Risk of Contracting Malaria, and Continental Fixed Effects.

geographical conditions to comparative economic development in a non-monotonic way. It develops an evolutionary growth theory that builds on the trade-off between the quantity and quality of offspring.[1] The theory uses the term *skill-intensity of the environment* to suggest that exogenous variation in geographical conditions can be a source of variation in the formation of early human capital. Specifically, it advances the hypothesis that individuals living in a society characterized by a higher skill-intensity of the environment alter the evolutionary optimal allocation of resources from offspring quantity to offspring quality. Higher parental investment in offspring leads to a lower population density but a higher rate of technological progress in the (initially latent) manufacturing sector. Thus, adverse geographical conditions have a negative impact on economic development in the Malthusian era but a positive impact on the timing of the Industrial Revolution.

The key hypothesis of this paper is based on the recognition that parental investment lies at the heart of human capital formation in preindustrial times. The demand for human capital was very low in early stages of development. It was arguably higher for societies that were characterized by adverse geographical conditions. Hence, in light of the fundamental trade-off between the quantity and quality of offspring, adverse geographical conditions generated an evolutionary advantage for individuals who were pre-disposed toward higher parental investment, increasing their share in the population, and fostering the formation of early human capital. Thus, if increased parental investment is associated with a higher rate of technological progress, adverse geographical conditions ultimately accelerated the transition to the modern era of sustained economic growth.

The pattern of parental investment is a human trait that is transmitted genetically, epigenetically, or culturally from one generation to the next. It is a natural candidate for a long-term genealogical link that Spolaore and Wacziarg (2013, p. 38) identify as important for very long-run effects of geographical, historical, and cultural factors on productivity and income per capita: "The third message from this literature [. . .] is that long-term genealogical links across populations play an important role in explaining the transmission of technological and institutional knowledge and the diffusion of economic development." In this paper, I assume that the pattern of parental investment is genetically transmitted. This appears plausible as educational achievements in general reflect many genetically influenced traits (Krapohl et al. 2014). However, this assumption is not crucial and the theory is perfectly applicable for either genetic, epigenetic, or cultural transmission of traits, where an epigenetic or cultural

[1] Fitness-maximizing trade-offs have long been studied within the context of life history theory in biology (Charnov 1993; Lessels 1997; Roff 1992, 2002; Stearns 1992) and anthropology (Hawkes and Paine 2006; Hill 1993; Lummaa 2007). In economics, Becker was the first to introduce both a qualitative and a quantitative dimension to the demand for children (Becker 1960; Becker and Lewis 1973; Willis 1973).

Table 1: The Reversal of Fortune With Respect to Land Suitability.

	log population density in 1500 CE	log urbanization rate in 1500 CE	log income per capita in 2000 CE		log urbanization rate in 2000 CE	
	(1)	(2)	(3)	(4)	(5)	(6)
log land suitability	0.503***	0.087	-0.264***		-0.122***	
	(0.078)	(0.062)	(0.061)		(0.029)	
log land suitability (ancestry adjusted)				-0.214**		-0.124***
				(0.087)		(0.037)
Cont. fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	148	81	148	148	148	148
R^2	0.528	0.283	0.534	0.487	0.396	0.363

Notes: This table establishes a reversal of fortune with respect to land suitability for two different indicators of economic development in 1500 CE and 2000 CE. It documents a significant positive effect of land suitability on population density in 1500 CE and a significant negative effect of land suitability on income per capita and urbanization rate in 2000 CE in a 148-country sample while controlling for continent fixed effects. The effect of land suitability on urbanization rate in 1500 CE in a limited 81-country sample is positive but not significant. According to the theory, it is not the direct effect of land suitability that drives the reversal but the embodied component. Hence, tracing the post-1500 worldwide migration flows, columns 4 and 6 follow Putterman and Weil (2010) and establish that an ancestry adjusted measure of land suitability has a significant negative effect on economic development in 2000 CE as well. Heteroskedasticity-robust standard errors are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

transmission is likely to be more rapid.

In the context of this paper, parental investment is understood as investment in human somatic capital. Somatic capital, is—in a physical sense—embodied energy. In a functional sense, somatic capital includes body mass, physical stature, brain size, but also factors like immune function, coordination, and skill, all of which affect the profitability of human activities like resource acquisition (Kaplan et al. 1995). Used in this way, parental investment is associated with the bodily basis of human capital formation.[2] This narrow focus on human physiology is in line with Spolaore and Wacziarg (2009, p. 523) who "have found that linguistic and religious distances, two culturally transmitted characteristics, only slightly reduce the effect of genetic distance on income differences, therefore suggesting a role for other slow-changing biological and/or cultural traits [. . .]". Again, the somatic perspective on parental investment is not crucial. The theory holds for other types of parental investment as well.

The theory contributes to the understanding of a non-monotonic path of comparative economic development. First, it attributes the dominance of some societies during the agricultural

[2]See Dalgaard and Strulik (2015) for a similar perspective. They use a quantity-quality approach to formulate a theory of pre-industrial growth where body size and population size are endogenously determined.

era to favorable geographical conditions that generate an evolutionary advantage for individuals who are genetically pre-disposed toward lower parental investment. Lower parental investment reduces the cost of children and leads to a higher steady state population size. Under the basic assumption of Malthusian-Boserupian interaction between population size and productivity growth (Boserup 1965; Kremer 1993), this is associated with a higher steady state level of economic development in the agricultural era. Second, the theory attributes the earlier industrialization of other societies to adverse geographical conditions that generate an evolutionary advantage for individuals who are genetically pre-disposed toward higher parental investment. Higher parental investment increases the innovation capability of individuals and ultimately accelerates the transition to the industrial stage of development.

The theory is based on two key assumptions. First, it is assumed that the number of efficiency units of labor per adult increases with the amount of parental investment during childhood and decreases with the skill-intensity of the environment.[3] For a fixed level of parental investment, an increase in the skill-intensity of the environment decreases the number of efficiency units of labor per adult. Put differently, adverse geographical conditions can be overcompensated by increased parental investment. This assumption captures the insight that parental investments have to be evaluated in the skill-context of the relevant environment. Second, the theory assumes that the creation of knowledge is more complementary to the level of parental investment in the manufacturing sector as compared to the agricultural sector. This assumption appears plausible as technological progress in the Malthusian epoch, where agriculture was the only mode of production, can be attributed to gradual learning by doing. In contrast, the development of a new production paradigm requires major intellectual developments and something like the Baconian method of inductive reasoning that arguably have a larger degree of complementarity to the level of parental investment. This is in line with Mokyr (2002, p. 29) who writes that "[. . .] the true key to the timing of the Industrial Revolution has to be sought in the scientific revolution of the seventeenth century and the Enlightenment movement of the eighteenth century".

Both assumptions together allow geographical conditions to affect the process of economic development in a non-monotonic way. In early stages of development, the economy is in the Malthusian regime and the manufacturing sector is not operative. Production in the rural sector is subject to decreasing returns to labor. Technological progress is slow but positively affected by the size of the population. Resources generated by technological progress in the rural sector lead to temporary gains in income per capita but are ultimately channeled toward an increase in population size. Thus, the economy dynamically evolves toward a Malthusian

[3] See, e.g., Weil (2007) for evidence on the positive link between somatic investment and labor productivity.

steady state equilibrium where income per capita is stagnant. An economy that is characterized by a relatively high skill-intensity of the environment—and therefore a relatively high level of parental investment—is associated with a relatively inferior Malthusian equilibrium in terms of population density and level of agricultural technology.

The transition from agriculture to industry is the result of constant returns to labor and sustained technological progress in the (latent) manufacturing sector. This leads to the adoption of industrial production in later stages of development. The growth of manufacturing technology is sustained due to a larger degree of complementarity between technological advancements and the existing stock of knowledge in this sector. After the industrial transition, both sectors are operative and the economy emerges into a post-Malthusian regime, where the sustained growth of manufacturing technology generates a pattern of endogenously growing population and income per capita. However, there is also a larger degree of complementarity between the growth of manufacturing technology and the level of parental investment. Hence, an economy that is characterized by a relatively high skill-intensity of the environment tis associated with an earlier transition.

The main contribution of this paper is threefold. First, it suggests differential parental investment as a new theoretical link between geographical conditions and comparative economic development. The pattern of parental investment within a society is a slow-changing genetic, epigenetic, or cultural trait that is intergenerationally transmitted. It captures the very essence of human capital formation in preindustrial times. As a genealogical link, it is a good candidate for a long-term transmission channel of initial geographic conditions suggested by Spolaore and Wacziarg (2013). As such, the pattern of parental investment across societies can be identified as a hitherto neglected, deep-rooted determinant of comparative economic development. Interestingly, higher parental investment in offspring is associated with a higher level of income per capita in the agricultural stage of development. Hence, in contrast to the literature in economics, it is a feature of this paper that income per capita in the Malthusian epoch is not constant but depends on the skill-intensity of the environment. This is entirely in line with Dalgaard and Strulik (2015, p. 50) who show that income per capita is larger and population density is lower in areas where humans are selected to be larger.

Second, the paper suggests that differential parental investment contributes to the reversal of fortune in the process of development with respect to land productivity. This is the case if an increase in land productivity is associated with a decrease in the skill-intensity of the environment, which is very plausible. Consequently, a higher level of parental investment is a burden for a society in the agricultural stage of development because the population density is lower as children are more expensive. In contrast, a higher level of parental investment is a boon for an early industrialization as it is complementary to human capital formation in general and intellectual developments in particular.

Third, this paper opens the possibility that an early Neolithic transition itself might be detrimental for long-term development, a finding that could be related to the Western reversal documented by Olsson and Paik (2014). Specifically, if the Neolithic transition is associated with a decrease in the skill-intensity of the environment because the agricultural mode of production is more complementary to unskilled labor, then an early transition to agriculture has a negative impact on the timing of the industrialization because it triggers a (slow) process of natural selection towards lower parental investment. Interestingly, Robson (2010) shows that the Neolithic transition to agriculture should indeed be associated with a lower level of somatic investment from an bioeconomic point of view. In contrast, however, it is also possible that the (more) complex Neolithic societies stimulate increased parental investment.

This paper is related to several strands of literature. On the one hand, it is associated with the theoretical literature on economic growth in the very long run that models the transition from an epoch of Malthusian stagnation to the modern era of sustained economic growth, specifically Galor and Weil (2000), Galor and Moav (2002), Lucas (2002), Cervellati and Sunde (2005), Cervellati and Sunde (2015); see Galor (2005) or Galor (2011) for a summary. On the other hand, the paper is related to a growing strand of empirical literature that aims to understand the deep-rooted determinants of comparative economic development as recently surveyed by Spolaore and Wacziarg (2013) and by Nunn (2014). Especially relevant are papers that share the physiological focus, i.e., Dalgaard and Strulik (2014a,b, 2015, 2016).

This paper is also related to publications that intend to explain a reversal of fortune in comparative economic development. First, Acemoglu, Johnson, and Robinson (2001, 2002) document a reversal of fortune among former European colonies. They argue that the reversal reflects changes in institutional quality imposed by European colonialists (i.e., extractive vs. inclusive institutions). Chanda, Cook, and Putterman (2014) demonstrate that there is persistence in fortune when accounting for post-1500 migration flows between countries, supporting the view of Glaeser et al. (2004) that human capital is a more fundamental channel of transmission of early developmental advantages. That view is shared in this paper with respect to the transmission of geographical conditions. Second, Olsson and Paik (2014) document a reversal among countries of the Western agricultural core with respect to the timing of the Neolithic transition. They argue that countries that made the transition early also tended to develop autocratic societies whereas late adopters were more likely to have egalitarian societies with stronger private property rights, eventually allowing them to overtake. Third, Dalgaard and Strulik (2014b) document a cross-country reversal with respect to absolute latitude. They build on the fact that individuals in regions further away from the equator are larger due to Bergmann's rule (Bergmann 1847). They argue that the relatively high metabolic costs of larger children acted as a physiological constraint on economic development in preindustrial times, but allowed for an early transition to the modern growth regime. Dalgaard and Strulik (2014b) share the idea of an embodied quantity-quality trade-off. In contrast, however, differences in human physiology are merely understood as passive constraints, whereas this paper argues that the pattern of parental investment is the result of active (albeit persistent) optimizing behavior with respect to initial geographical conditions. Fourth, Litina (2016) focuses on the reversal of fortune with respect to land productivity as well. She argues that variation in land productivity had a persistent effect on the level of cooperation and, therefore, on the evolution of social capital in a country. In contrast, this paper emphasizes the role of geographically induced differences in human capital endowment. Finally, and most interesting, Kelly, Mokyr, and Gráda (2015) document a reversal of fortune between northern and southern counties in England between 1760 and 1830. While wages in the southern counties are relatively high in 1760, reflecting soil quality, the wages in the industrializing counties of the north and midlands have overtaken the wages in the southern counties by 1830. Furthermore, they establish that the strongest predictor for the industrializing counties is the quality of workers shown by body size of the population. This result, and the emphasis on embodied human capital, is exactly in line with the proposed theory in this paper.

The paper proceeds as follows. Section 2 gathers motivating evidence for the theoretical sections of this paper. Section 3 formalizes the key assumptions and develops the basic structure of the model. Section 4 describes the time path of the macroeconomic key variables. Section 5 characterizes the dynamical system. Section 6 analyzes the evolution of the economy in the process of development. Section 7 concludes.

2. Motivating Evidence

In this paper, I introduce two simple concepts: First, I use the term *skill-intensity of the environment* to suggest that exogenous variation in geographical conditions can be a source of variation in the production of early human capital. Second, I use the term *parental investment* to emphasize that—throughout human history—parents (or grandparents) have played a key role in the process of skill-formation of their children. However, as Diamond (2014) notes, operationalizing seemingly intuitive concepts is often hard in social sciences. In the first case, I use the suitability of land for agriculture as an inverse measure for the skill-intensity of the environment because it is exactly the reversal of fortune with respect to land productivity that initiated this paper. In the second case, it is much harder to come up with a measure. The pattern of parental investment has at least two dimensions: a somatic component (i.e., nutrition, feeding) and a cognitive component (i.e., learning, education). Only the first component seems

Table 2: Body Mass as a Proxy for Parental Investment.

	log body mass in 2005 CE		log income per capita in 2000 CE			log urbanization rate in 2000 CE		
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	2SLS (5)	OLS (6)	OLS (7)	2SLS (8)
log body mass in 2005 CE			6.162*** (0.778)	5.672*** (0.823)	19.261** (8.768)	3.098*** (0.380)	3.011*** (0.407)	4.053** (1.820)
log land suitability	-0.028*** (0.006)			-0.097* (0.056)	0.288 (0.272)		-0.029 (0.025)	0.000 (0.060)
log land suitability (ancestry adjusted)		-0.028*** (0.009)	-0.031 (0.071)			-0.027 (0.030)		
Continental fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	148	148	148	148	148	148	148	148
R^2	0.505	0.460	0.642	0.650	—	0.582	0.584	—
Anderson-Rubin *p-value*					0.005			0.077
Kleibergen-Paap *F-statistic*					3.155			3.155

Notes: This table establishes a significant negative effect of either land suitability (column 1) or ancestry adjusted land suitability (column 2) on contemporary body mass in a 148-country sample, while controlling for continent fixed effects. The table further documents a significant positive effect of body mass on two indicators of contemporary economic development, i.e., income per capita in the year 2000 CE (columns 3–5) and urbanization rate in the year 2000 CE (columns 6–8). Columns 3 and 6 show that controlling for ancestry adjusted land suitability renders its direct effect on contemporary development insignificant, indicating that body mass is a relevant channel of transmission. The corresponding effect is ambiguous for unadjusted land suitability, which remains significant in column 4 but insignificant in column 6. Columns 5 and 8 deal with reverse causality and provide IV estimates. The instrument is ancestry adjusted land suitability, and the specifications simultaneously control for unadjusted land suitability. Hence, local geographical conditions have been filtered out. The instrument is clearly relevant. Heteroskedasticity-robust standard errors are reported in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

to be operationalizable for pre-industrial times where formal education was generally absent. However, as long as both dimensions of child quality are imperfect substitutes, measuring one dimension is enough to get an idea of the whole picture.

In this section, I want to operationalize the somatic dimension of parental investment with the help of two approximate variables: *body mass* and *adult survival rate* (i.e., the probability of a 15-year-old to reach age 60). Both variables show considerable variation among human societies. Across taxa, body mass is known to be the most appropriate measure of an animal's overall size (Darveau et al. 2002). Furthermore, both variables can be seen as parameters of the unique human life history, which is—at least partially—understood as the result of embodied parental investment (Charnov 1993; Kaplan 1996; Kaplan and Robson 2002; Kaplan, Lancaster, and Robson 2003). In the following, I use either variable as a proxy for parental investment. That way, I want to explore the link between land suitability, parental investment, and current economic development. It is possible to show that especially body mass seems to be a good candidate for a transmission channel of land suitability on current economic outcomes.

Table 2 uses contemporary *body mass* as a proxy for parental investment.[4] According to the theory, the suitability of land for agriculture should have a significant negative effect on body mass. This is exactly what column 1 reports. In this paper, however, I suggest that the pattern of parental investment is either genetically, epigenetically, or culturally transmitted and should therefore be highly persistent. That is, it is not the direct effect of land suitability that drives the reversal but the embodied component. Hence, it is necessary to trace the post-1500 worldwide migration flows and use *ancestry adjusted* land suitability as the relevant exogenous regressor, which is calculated as the sum of the land suitability index of each country of origin weighted with the population share originating from that country (Putterman and Weil 2010).[5] This is done in column 2. In terms of economic significance the results are very similar to those for unadjusted land suitability in column 1.

The remainder of Table 2 establishes—in line with the theory—a significant positive effect of body mass on contemporary development using two different indicators, i.e., income per capita in the year 2000 CE (columns 3–5) and urbanization rate in the year 2000 CE (columns 6–8), while controlling for either land suitability or ancestry adjusted land suitability. Columns 3 and 6 show that controlling for ancestry adjusted land suitability renders its direct effect on contemporary development insignificant, indicating that body mass is a relevant transmission channel for ancestry adjusted land suitability. Interestingly, unadjusted land suitability remains statistically significant in column 4, showing that a direct effect of land suitability on income per capita in 2000 CE exits. Of course, part of the strong partial correlation between body mass and current economic development is likely reverse causality: a higher income per capita might simply allow for larger people through nutritional improvements. Therefore, columns 5 and 8 deal with reverse causality and provide IV estimates. The instrument is ancestry adjusted land suitability, and the specifications simultaneously control for unadjusted land suitability. Hence, local geographical conditions have been filtered out and identification of body mass runs only through ancestral geographical conditions. The instrument is clearly relevant for both indicators of contemporary development. Although the Kleinbergen-Paap F-statistic seems to be quite low, the null hypothesis of weak identification can be rejected (*p-value* = 0.078). Furthermore, the Anderson-Rubin test, which is robust to weak instruments, indicates a causal impact from body mass on current economic outcomes.

Table 3 uses contemporary *adult survival rate* as a proxy for parental investment. In line with the theory, either land suitability (column 1) or ancestry adjusted land suitability (column

[4] See Appendix C for data sources.

[5] Ancestry adjusted land suitability is constructed as follows: Suppose a country today comprises citizens with ancestry from n countries. Let the land suitability of country i be x_i for $i = 1, \dots, n$. Let further the share of citizens that originate from country i be λ_i. Then, the ancestry adjusted land suitability is given by $\sum_1^n \lambda_i x_i$. The source of the post-1500 worldwide migration flows is a matrix developed by Putterman and Weil (2010).

Table 3: Adult Survival Rate as a Proxy for Parental Investment.

	log adult survival rate in 2000 CE		log income per capita in 2000 CE			log urbanization rate in 2000 CE		
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	2SLS (5)	OLS (6)	OLS (7)	2SLS (8)
log adult survival rate in 2000 CE			1.546**	1.304**	63.948	0.988***	0.918***	12.566
			(0.015)	(0.033)	(0.740)	(0.001)	(0.001)	(0.732)
log land suitability	-0.034***			-0.217***	1.916		-0.089***	0.307
	(0.000)			(0.001)	(0.773)		(0.003)	(0.807)
log land suitability (ancestry adjusted)		-0.039***	-0.150*			-0.085**		
		(0.003)	(0.091)			(0.017)		
Continental fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	149	149	149	149	149	149	149	149
R-squared	0.478	0.468	0.521	0.554	—	0.444	0.463	—
Anderson-Rubin *p-value*					0.005			0.099
Kleibergen-Paap *F-statistic*					0.105			0.105

Notes: This table establishes a significant negative effect of either land suitability (column 1) or ancestry adjusted land suitability (column 2) on contemporary adult survival rate in a 148-country sample, while controlling for continent fixed effects. positive effect of body mass on two indicators of contemporary economic development, i.e., income per capita in the year 2000 CE (columns 3–4) and urbanization rate in the year 2000 CE (columns 6–7). However, the direct effect of either land suitability or ancestry adjusted land suitability on current economic outcomes remains highly significant, indicating that adult survival rate captures something different than the transmission of geographical conditions. Columns 5 and 8 deal with reverse causality and provide IV estimates. The instrument is ancestry adjusted land suitability. Clearly, the instrument is not relevant, raising doubts on the appropriateness of adult survival rate as a transmission channel for land suitability. Heteroskedasticity-robust standard errors are reported in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

2) has a significant negative effect on adult survival rate. Moreover, adult survival rate also has a significant positive effect contemporary economic development (columns 3–4 and 6–7). However, controlling for land suitability (columns 4 and 7) and ancestry adjusted land suitability reveals that the direct influence of both variables on current economic outcomes remains strong, indicating that adult survival rate captures something different than the pure transmission of geographical conditions. This view is strengthened in columns 5 and 8 that deal with reverse causality and provide IV estimates. Again, the instrument is ancestry adjusted land suitability, and the specifications simultaneously control for unadjusted land suitability. Contrary to body mass, however, the null hypothesis of weak identification can't be rejected. Furthermore, the positive effect on current economic outcomes becomes insignificant when adult survival rate is identified with ancestral geographical conditions.

Overall, the results suggest that body mass is a promising candidate for the (embodied) transmission of initial geographical conditions. Adult survival rate seems to capture something different or the strong correlation is the result of mere reverse causality. The empirical analysis can be summarized in five stylized facts (see Tables 4, 5, and 6 in Appendix B for additional robustness checks with common control variables):

1. Preindustrial economic development was positively correlated with land suitability (Table 1, columns 1 and 2).

2. Contemporary economic development is negatively correlated with adjusted and unadjusted land suitability (Table 1, columns 3 to 6).

3. Body mass and adult survival rate—as proxies for parental investment—are negatively correlated with adjusted and unadjusted land suitability (Columns 1 and 2 of Table 2 and Table 3 respectively).

4. Body mass and adult survival rate—as proxies for parental investment—are positively correlated with contemporary economic development (Table 2 and Table 3, columns 3–4 and 6–7).

5. Using ancestry adjusted land suitability as an instrument for body mass reveals that much of the effect of ancestral geographical conditions on contemporary economic development operates through an indirect transmission channel of this kind (Table 2, columns 5 and 8).

In the remainder of the paper, I develop a model that is consistent with this set of facts. The model thus provides an explanation for the striking reversal of fortune with respect to the suitability of land for agriculture. Contrary to Litina (2016), the main transmission channel is not social capital, but differential somatic investment, which can be understood as an operationalized measure of geographically induced human capital formation in preindustrial times.

3. The Basic Structure of the Model

The following model borrows elements from Ashraf and Galor (2011) to capture the endogenous transition from an epoch of Malthusian stagnation to the modern era of sustained economic growth.

3.1. Individuals

Consider an overlapping generations economy in which economic activity extends over infinite discrete time. In every period t, a new generation of individuals is born. Reproduction is asexual. Therefore, each individual has a single parent. Individuals live for two periods. In the first period of life (childhood), individuals consume a part of their parental income. In the second period of life (adulthood), individuals work and allocate their income between consumption and reproduction.

Individuals differ genetically with respect to the allocation of resources between the number and the quality of offspring. The quality of offspring is measured in terms of units of somatic capital. Somatic capital is, in a physical sense, embodied energy. In a functional sense, somatic capital includes body size, physical stature, and strength, but also factors like coordination, and skill, which affect the profitability of human activities like production and resource acquisition. Therefore, somatic investment during childhood increases an individuals's amount of efficiency units of labor. Variations in the genetically predetermined level of somatic investment manifest themselves in differential human capital endowments.

Let an individual of type i be genetically predetermined to invest $k^i > 0$ units of somatic capital in each child. Somatic investment during childhood is hereditary and transmitted genetically from parent to offspring. That is, individuals within a dynasty are of the same type and the relative size of each dynasty evolves over time by natural selection.

3.2. The Skill-Intensity of the Environment

The land endowment of a society differs with respect to the suitability for agriculture. Farming is comparably easy in certain areas but difficult in others. To capture this fact, I introduce a parameter $\xi \geq 0$ that represents the skill-intensity of an environment with respect to farming. A skill-intensity of zero represents an environment that is perfectly suited for agriculture. Farming becomes more difficult if ξ increases.

3.3. The Production of Final Output

In every period t, a population of L_t adult individuals produce a single homogenous good Y_t. Production occurs in two sectors—a rural (agricultural) sector and a manufacturing (industrial) sector—with aggregate efficiency units of labor H_t and land X as inputs. The supply of land is exogenously given and constant over time. The markets of labor and the final good are perfectly competitive. In early stages of development, the manufacturing sector is not economically viable and production is entirely rural. However, productivity in the manufacturing sector grows relatively faster than productivity in the rural sector. Eventually, in later stages of development, the manufacturing sector becomes economically viable and both sectors are jointly operated.

Let A_t^R be the level of technology and H_t^R the amount of efficiency units of labor employed in the rural sector in period t. The output produced in the rural sector in period t, Y_t^R, is given by the neoclassical production function

$$Y_t^R = \left(A_t^R X\right)^\alpha \left(H_t^R\right)^{1-\alpha}, \tag{1}$$

where $\alpha \in (0,1)$. For simplicity, the supply of land is normalized to one, $X \equiv 1$. In the absence of property rights over land, the return to land is zero. Therefore, the wage rate per efficiency unit of labor in the rural sector in period t, w_t^R, is given by

$$w_t^R = \frac{Y_t^R}{H_t^R} = \left(\frac{A_t^R}{H_t^R}\right)^\alpha. \tag{2}$$

Let A_t^M be the level of technology and H_t^M the amount of efficiency units of labor employed in the manufacturing sector in period t. The output produced in the manufacturing sector in period t is given by the linear production function

$$Y_t^M = A_t^M H_t^M. \tag{3}$$

It follows that the wage rate per efficiency unit of labor in the manufacturing sector in period t, w_t^M, is given by

$$w_t^M = A_t^M. \tag{4}$$

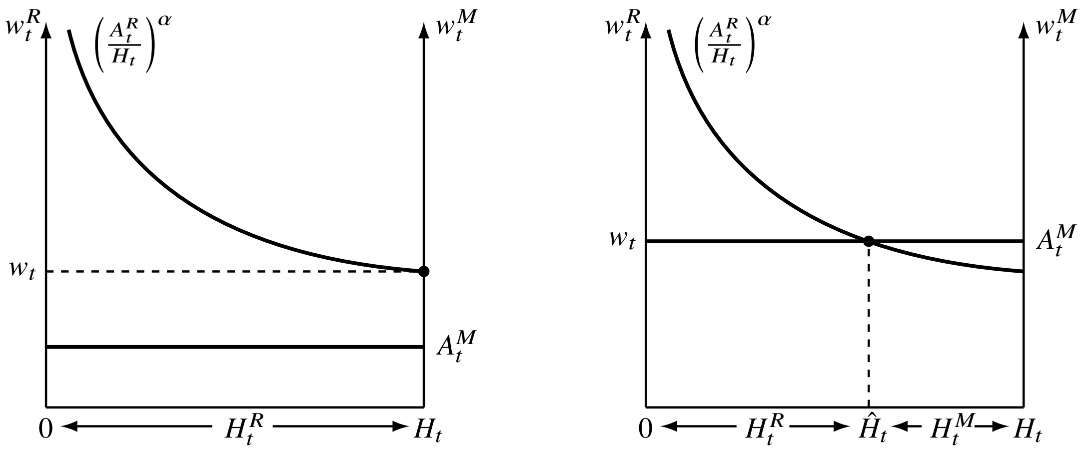
The total supply of efficiency units of labor in period t, H_t, is allocated between both sectors so that

$$H_t = H_t^R + H_t^M, \tag{5}$$

where $H_t > 0$ in every period t.

It is apparent from (2) that the wage rate in the rural sector increases without bound as the amount of efficiency units of labor decreases and approaches zero as the amount of efficiency units of labor increases. This implies that the rural sector will always be operative. In contrast, as follows from (4), the wage rate in the manufacturing sector is finite. Hence, the manufacturing sector will be operative if and only if the manufacturing wage is higher than the rural wage conditional on full labor force participation in the rural sector. Thus, there exists a threshold level of technology in the manufacturing sector so that the manufacturing sector is operative. Put differently, as follows from (2), there exists a threshold level of aggregate efficiency units of labor so that the manufacturing sector is operative in period t.

Lemma 1. *There exists a threshold level of aggregate efficiency units of labor, $\hat{H}_t$, so that the*



(a) $H_t < \hat{H}_t$.

(b) $H_t > \hat{H}_t$.

Figure 2: The Labor Market Equilibrium (a) for Early Stages of Development and (b) for Later Stages of Development, Where the Manufacturing Sector is Operative.

manufacturing sector is operative in period t if and only if

$$H_t \geq \left(A_t^M\right)^{-\frac{1}{\alpha}} A_t^R \equiv \hat{H}\left(A_t^R, A_t^M\right) \equiv \hat{H}_t,$$

where $\frac{\partial \hat{H}_t}{\partial A_t^R} > 0$ *and* $\frac{\partial \hat{H}_t}{\partial A_t^M} < 0$.

Proof. Follows from (2), (4), and (5) and the perfect mobility of aggregate units of labor H_t between both sectors. □

The threshold level of aggregate units of labor, $\hat{H}_t$, decreases with the level of technology in the manufacturing sector, A_t^M. Therefore, as (latent) productivity in the manufacturing sector grows over time, the threshold level of aggregate efficiency units of labor slowly decreases. Ultimately, the manufacturing sector becomes economically viable and both sectors are jointly operated. The equilibrium wage rate in the economy in period t, w_t, is then given by

$$w_t = \begin{cases} \left(\frac{A_t^R}{H_t}\right)^\alpha & \text{if} \quad H_t < \hat{H}_t \\ A_t^M & \text{if} \quad H_t \geq \hat{H}_t, \end{cases} \tag{6}$$

as follows from (2), (4), and Lemma 1. The equilibrium wage rate is depicted in Figure 2 for both cases.

Historically, the agricultural mode of production always preceded the industrial mode of production. Therefore, it is assumed that the manufacturing sector is not economically viable in period 0. Thus, noting (6), the initial level of technology in the manufacturing sector, A_0^M, is below the initial wage rate,

$$A_0^M < \left(\frac{A_0^R}{H_0}\right)^{\alpha}. \tag{A1}$$

3.4. The Production of Human Capital

I assume that a minimum level of somatic investment, $\bar{k}$, is required for participation in the labor market. For $k^i \geq \bar{k}$, let the level of human capital of an individual of type i, h^i, be a strictly concave function of the genetically predetermined level of somatic investment in childhood, k^i, and a strictly convex function of the skill-intensity of the environment, ξ, i.e.,

$$h^i = h\left(k^i, \xi\right) \begin{cases} = 0 & \text{if} \quad k^i < \bar{k} \\ > 0 & \text{if} \quad k^i \geq \bar{k}, \end{cases} \tag{7}$$

with $h_k > 0$, $h_{kk} < 0$, $h_\xi < 0$, $h_{\xi\xi} > 0$ for $k^i \geq \bar{k}$. If the skill-intensity of the environment increases, the level of human capital decreases to zero in the absence of further somatic investment, $\lim_{\xi \to \infty} h\left(k^i, \xi\right) = 0$. In contrast, there is no upper bound on efficiency units of labor if somatic investment increases, $\lim_{k^i \to \infty} h(k^i, \xi) = \infty$.

Importantly, I assume that the adverse effect of a challenging environment on human capital formation is lower for individuals that are genetically predetermined to invest more resources into each child. That is, somatic investment complements skill-intensity of the environment,

$$h_{k\xi}\left(k^i, \xi\right) > 0 \qquad \text{for} \qquad k^i \geq \bar{k}. \tag{A2}$$

Furthermore, I assume that the elasticity, $\eta_{h_k k^i}$, of the effect of somatic investment on human capital production, $h_k(k^i, \xi)$, with respect to somatic investment, k^i, is smaller than one in absolute value. That is, an increase in somatic investment, k^i, generates less than a proportional decrease in the effect of somatic investment on human capital production, $h_k(k^i, \xi)$,

$$\eta_{h_k k^i} \equiv \left|\frac{h_{kk}(k^i, \xi) k^i}{h_k(k^i, \xi)}\right| < 1 \qquad \text{for} \qquad k^i \geq \bar{k}, \tag{A3}$$

which assures that the factor demand for somatic capital in human capital production is elastic.

This human capital production function captures the fundamental idea that investment in the human capital of children always have to be evaluated in the context of the relevant environment. A certain amount of parental investment might be sufficient in terms of output per worker in a moderate environment but not sufficient in a demanding environment. Thus, parental investments in the human capital of their children lead to relatively more efficiency units of labor if the environment is less skill intensive. Put differently, the adverse effect of a challenging environment on output per worker can be overcompensated by higher parental investment in offspring.

3.5. Preferences

Preferences over consumption and reproduction are represented by a simple log-linear utility function. Consider an adult of type i in period t, which was born and raised as a child in period $t-1$. The utility function of the individual is defined over consumption, c_t^i, and the number of children, n_t^i, as

$$u_t^i = (1-\gamma)\ln c_t^i + \gamma \ln n_t^i, \tag{8}$$

where $\gamma \in (0,1)$ is the fraction of income that is allocated to child rearing. The utility function is strictly monotonically increasing in consumption, c_t^i, and the number of children, n_t^i, and strictly quasi-concave.

Let an adult individual of type i be endowed with h^i efficiency units of labor. The adult earns the competitive market wage w_t per efficiency unit. This income is allocated optimally between consumption and reproduction. Since somatic investment per child, k^i, only depends on the type i, an adult individual of type i at time t faces the budget constraint

$$k^i n_t^i + c_t^i \leq w_t h^i. \tag{9}$$

Optimizing (8) with respect to (9) yields

$$c_t^i = (1-\gamma) w_t h^i \tag{10}$$

$$n_t^i = \frac{\gamma w_t h^i}{k^i}. \tag{11}$$

It is apparent from (11) that there is a trade-off between the number of children, n_t^i, and the amount of somatic investment in each child, k^i. For a given income, $w_t h^i$, individuals who are genetically pre-determined to invest more resources in each child give birth to less children. Furthermore, the number of children is an increasing function of parental income. This feature is fundamental to the Malthusian environment, which is at the heart of the proposed theory.

3.6. Evolutionary Optimal Somatic Investment

The skill-intensity of the environment, ξ, is fixed. Hence, a certain type i of individuals has the largest number of offspring and this type will dominate the population in the long run. Let

k be the genetically determined level of somatic investment that generates the evolutionary advantage if the skill-intensity of the environment is ξ. This level of somatic investment is determined by maximizing the number of offspring in (11) with respect to k^i:

$$k = \arg\max \left\{ \frac{\gamma w_t h(k^i, \xi)}{k^i} \right\} \quad \text{s.t.} \quad k^i \geq \bar{k}. \tag{12}$$

Optimizing this expression implies that the implicit functional relationship between optimal somatic investment, k, and the skill-intensity of the environment, ξ, is given by

$$G(k, \xi) \equiv h_k(k, \xi) - \frac{h(k, \xi)}{k} \begin{cases} = 0 & \text{if } k > \bar{k} \\ \leq 0 & \text{if } k = \bar{k}, \end{cases} \tag{13}$$

where $G(k, \xi)$ is the sum of the gain in quality of children and the loss in quantity of children from a marginal increase in somatic investment. For $k \geq \bar{k}$, the derivatives of (13) are readily given as $G_k(k, \xi) < 0$ and $G_\xi(k, \xi) > 0$. Without loss of generality, let $\bar{k}$ be the optimal level of somatic investment if the skill-intensity of the environment is zero, and $\tilde{h}$ the corresponding optimal level of human capital,

$$G(\bar{k}, 0) = 0, \qquad\qquad \tilde{h} \equiv h(\tilde{k}, 0). \tag{A4}$$

Lemma 2. *Under (A2) and (A4), the evolutionary optimal level of somatic investment is a unique single-valued function of the skill-intensity of the environment,*

$$k = k(\xi),$$

where $k(0) = \bar{k}$ *and* $k(\xi) > \bar{k}$ *for all* $\xi > 0$. *Optimal somatic investment increases with the skill-intensity of the environment,*

$$\frac{\partial k(\xi)}{\partial \xi} > 0.$$

Proof. Follows from the properties of (13) and the Implicit Function Theorem together with (A2) and (A4). See the proof of Corollary 1 for an explicit calculation of $k'(\xi)$. □

Corollary 1. *Under (A2), (A3), and (A4), the optimal level of human capital is unique single-valued function of the skill-intensity of the environment,*

$$h = h(k(\xi), \xi) \equiv h(\xi),$$

where $h(0) = \tilde{h}$ *and* $h(\xi) > \tilde{h}$ *for all* $\xi > 0$. *The optimal level of human capital increases with*

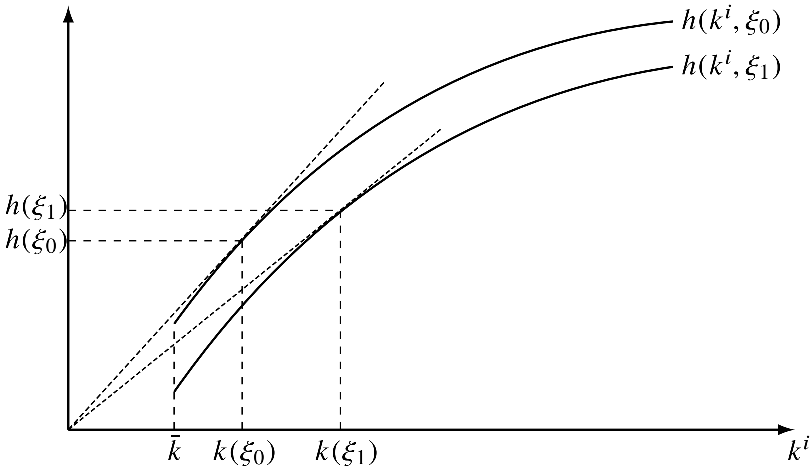


Figure 3: Optimal Somatic Investment for Two Skill-Intensities of the Environment, $\xi_1 > \xi_0$.

the skill-intensity of the environment,

$$\frac{\partial h(\xi)}{\partial \xi} > 0.$$

Proof. See Appendix A. □

Equation 13 is depicted in Figure 3. It shows that the evolutionary optimal level of somatic investment, $k(\xi)$, is given by the unique tangency point between the human capital production function $h(k^i, \xi)$ and a ray from the origin. An increase in the skill-intensity of the environment from ξ_0 to ξ_1 has an adverse impact on human capital formation and the human capital production function shifts downwards. However, as long as (A2) is satisfied, the adverse impact is lower for individuals that are genetically determined to invest more resources into each child. Hence, the evolutionary optimal level of somatic increases. Furthermore, as long as (A3) is satisfied, the evolutionary optimal level of human capital increases as well.

Thus, the theory suggests that an increase in the skill-intensity of the environment triggers a process of natural selection that changes the prevalent type in the population toward individuals who are genetically determined to higher somatic investment. Since human capital formation is assumed to be a function of somatic investment, early human capital increases as well, overcompensating the adverse effect of skill-intensity on efficiency units of labor. This captures the idea that skills become more important for production in a challenging environment and nature selects for individuals with an optimal pattern of skill formation.

The effect of an increase in the skill-intensity of the environment on optimal somatic investment, $k(\xi)$, and optimal human capital endowment, $h(\xi)$, is quantified in the following Corollary:

Corollary 2. *Let* $\varepsilon_{k\xi}$ *and* $\varepsilon_{h\xi}$ *be the elasticities of optimal somatic investment,* $k(\xi)$*, and optimal human capital endowment,* $h(\xi)$*, with respect to the skill-intensity of the environment,* ξ*,*

$$\varepsilon_{k\xi} \equiv \frac{k'(\xi)\xi}{k(\xi)}, \qquad \qquad \varepsilon_{h\xi} \equiv \frac{h'(\xi)\xi}{h(\xi)}.$$

It then follows that $\varepsilon_{k\xi} > \varepsilon_{h\xi} > 0$*. Furthermore, let* ε *be the relative difference between both elasticities. It immediately follows that*

$$\varepsilon \equiv \frac{\varepsilon_{k,\xi} - \varepsilon_{h,\xi}}{\varepsilon_{k,\xi}} < 1.$$

Proof. See Appendix A. □

Hence, an increase in the skill intensity of the environment increases both the evolutionary optimal somatic investment and the evolutionary optimal human capital endowment. As depicted in Figure 3, the increase in somatic investment is larger so that the ratio between human capital and somatic investment decreases.

4. The Time Paths of the Macroeconomic Variables

4.1. The Dynamics of Population Size

The skill-intensity of the environment ξ is fixed. Hence, the type that invests $k(\xi)$ units of somatic capital into each child has an evolutionary advantage and dominates the population after a finite number of generations, τ. Without loss of generality, let this type be the dominant type in the population already in period zero, i.e. $\tau \equiv 0$. An individual of this type is endowed with $h(\xi)$ efficiency units of labor. Since $h(\xi)$ is constant, there exists a linear relationship between the aggregate efficiency units of labor, H_t, and the population size, L_t,

$$H_t = h(\xi)L_t. \tag{14}$$

Hence, I find it convenient to use the term "population size" for both expressions, H_t and L_t.

The adult population size in any period t is determined by the size of the population in the previous generation and the number of children per adult, n_t. It follows from (6), (11), and

(14) that the adult population size evolves over time according to

$$H_{t+1} = n_t H_t = \begin{cases} \frac{\gamma h(\xi)}{k(\xi)} \left(A_t^R\right)^{\alpha} {H_t}^{1-\alpha} \equiv H^R \left(A_t^R, H_t; \xi\right) & \text{if} \quad H_t < \hat{H}_t \\ \frac{\gamma h(\xi)}{k(\xi)} A_t^M H_t \equiv H^M \left(A_t^M, H_t; \xi\right) & \text{if} \quad H_t \geq \hat{H}_t, \end{cases} \tag{15}$$

where the initial size of the population, $H_0 = h(\xi)L_0 > 0$, is given.

Thus, as long as the population size is below the critical threshold from Lemma 1, i.e. for $H_t < \hat{H}_t$, and the manufacturing sector is therefore not operative, the adult population size in period $t + 1$ is determined by the level of technology in the rural sector, A_t^R, and the adult population size in period t, H_t. This changes when the manufacturing sector becomes economically viable, i.e. for $H_t \geq \hat{H}_t$. Then, the labor market equilibrium ensures that the population size in period $t + 1$ is determined by the level of technology in the manufacturing sector, A_t^M, and the size of the adult population in period t, H_t.

4.2. The Dynamics of Technology

The development of the level technology over time in the rural sector, A_t^R, and in the manufacturing sector, A_t^M, is determined by three factors. First, it is influenced positively by the size of the population, H_t, which is a common assumption in a Malthusian framework (Boserup 1965; Kremer 1993). Second, it is influenced positively by an individual's endowment with somatic capital, $k(\xi)$. This reflects the idea that an individual's capacity to innovate increases with parental investment during childhood. Hence, it is not only the quantity but also by the quality of individuals that matters for the creation of new knowledge. Third, it is influenced negatively by the skill-intensity of the environment. That is, adverse environmental conditions act as a negative externality that directly reduces the productivity in each sector. Specifically, technological progress is diminished at a rate $\delta(\xi)$ that captures the erosion in productivity. In particular, I assume the following functional form,

$$\delta(\xi) \equiv e^{-\xi}, \tag{16}$$

which simplifies the exposition of the model.[6]

[6]The concrete functional form is not relevant for the outcome of the model. Rather, it is possible to work with the general function, $\delta(\xi)$, as long as the following additional assumptions,

$$\delta(0) = 1, \qquad \lim_{\xi \to \infty} \delta(\xi) = 0, \qquad \delta'(\xi) < 0, \qquad \lim_{\xi \to \infty} \left| \frac{\delta'(\xi)\xi}{\delta(\xi)} \right| \geq \varepsilon_{k,\xi},$$

are fulfilled. Furthermore, the key results of this paper hold independently of the erosion assumption. However, erosion of productivity allows the derivation of an optimal growth rate of technology in the manufacturing

Overall, the evolution of technology in the rural and manufacturing sector follows the same fundamental law of motion. It is enhanced by the quantity and the quality of individuals and diminished by adverse environmental conditions. In addition, however, I introduce a subtle but important difference between both sectors. I assume that the advancement of knowledge is more complementary to the amount of parental investment and the level of technology in the manufacturing sector as compared to the rural sector.

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

$$A^M_{t+1} = e^{-\xi} H^\lambda_t k(\xi) A^M_t \equiv A(A^M_t, H_t; \xi), \tag{17}$$

where the initial level of manufacturing technology, $A^M_0 > 0$, is given, and

$$0 < \lambda < \frac{\alpha}{\alpha + \varepsilon}, \tag{A5}$$

assuring that the importance of quantity is somewhat restricted in favor of quality in the process of knowledge creation. Note that $\lambda < 1$ follows with $\varepsilon > 0$ from Corollary 2.

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

$$A^R_{t+1} = e^{-\xi_t} H^\lambda_t \left(k(\xi_t) A^R_t\right)^\beta \equiv A^R\left(A^R_t, H_t; \xi_t\right), \tag{18}$$

where the initial level of rural technology, $A^R_0 > 0$, is given, and

$$0 < \beta < \lambda \frac{\varepsilon}{\alpha}. \tag{A6}$$

Again, note that $\beta < 1$ follows from (A5). Note further that assumptions (A5) and (A6) imply

$$\lambda + \beta < 1, \tag{19}$$

assuring that the creation of new knowledge is more complementary to the amount of parental investment and the level of technology in the manufacturing sector as compared to the rural sector, which is crucial for the model.

5. The Dynamical System

The development of the economy is characterized by the evolution of the level of technology in the rural sector, the level of technology in the manufacturing sector, and the population size. It

sector with respect to the skill-intensity of the environment, which is a realistic and desirable feature of the model.

is determined by a sequence $\left\{A_t^R, A_t^M, H_t; \xi\right\}_{t=0}^{\infty}$ that satisfies the following discrete dynamical system in every period t,

$$\begin{cases} H_{t+1} = \begin{cases} H^R\left(A_t^R, H_t; \xi\right) & \text{if} \quad H_t < \hat{H}_t \\ H^M\left(A_t^M, H_t; \xi\right) & \text{if} \quad H_t \geq \hat{H}_t \end{cases} \\ A_{t+1}^R = A^R\left(A_t^R, H_t; \xi\right) \\ A_{t+1}^M = A^M\left(A_t^M, H_t; \xi\right), \end{cases} \tag{20}$$

where the skill-intensity of the environment, ξ, is exogenously given, and the initial values of technology and population, $\left(A_0^R, A_0^M, H_0\right)$, are set to satisfy (A1). The analysis of the dynamical system is based on phase diagrams that characterize the evolution of the economy from an epoch of Malthusian stagnation to the post-Malthusian era of sustained economic growth, and demonstrate the role of the skill-intensity of the environment in the process of development. Each phase diagram consists of three curves that are introduced in the following subsections: the Conditional Malthusian Frontier, the AA locus, and the HH locus.

5.1. The Conditional Malthusian Frontier

Let the *Conditional Malthusian Frontier* be the set of all pairs $\left(A_t^R, H_t\right)$ so that, for a given level of technology in the manufacturing sector, A_t^M, the manufacturing sector just becomes economically viable:

$$MM_{|A_t^M} \equiv \left\{\left(A_t^R, H_t\right) : H_t = \hat{H}\left(A_t^R, A_t^M\right)\right\}. \tag{21}$$

Hence, the Conditional Malthusian Frontier is a geometric locus in the $\left(A_t^R, H_t\right)$ space that separates the phase diagram into two regions: one region where the economy is exclusively agricultural and another region where it is industrial as well. Once the economy's development path crosses the frontier, the Industrial Revolution takes place. The properties of the Conditional Malthusian Frontier are derived in the following lemma.

Lemma 3. *Let $A_t^M > 0$ be arbitrary but fixed. If $\left(A_t^R, H_t\right) \in MM_{|A_t^M}$, it follows that*

$$H_t = \left(A_t^M\right)^{-\frac{1}{\alpha}} A_t^R = \hat{H}\left(A_t^R, A_t^M\right)$$

where $\frac{\partial \hat{H}\left(A_t^R, A_t^M\right)}{\partial A_t^R} > 0$ and $\frac{\partial \hat{H}\left(A_t^R, A_t^M\right)}{\partial A_t^M} < 0$. Furthermore, given $\xi \geq 0$ and $A_t^R > 0$, for all

$H_t \geq \hat{H}\left(A_t^R, A_t^M\right)$,

$$H_{t+1} - H_t \gtreqless 0 \qquad \textit{if and only if} \qquad A_t^M \gtreqless \frac{k(\xi)}{\gamma h(\xi)}.$$

Proof. The first part follows from (21), Lemma 1, and differentiation. The second part follows immediately from (15). □

The Conditional Malthusian Frontier is an upward sloping ray from the origin in the $\left(A_t^R, H_t\right)$ space. The manufacturing sector is operative on the frontier and in the region above. Moreover, the frontier rotates clockwise in the $\left(A_t^R, H_t\right)$ space as the level of technology in the manufacturing sector, A_t^M, increases in the process of development.

Note that A_t^M equals the wage rate per efficiency unit of labor if the economy is located in the region above the Conditional Malthusian Frontier. Hence, if the manufacturing sector is operative, the adult population grows over time if the wage rate is above the critical threshold, $\frac{k(\xi)}{\gamma h(\xi)}$, and allows fertility to be above replacement level. In contrast, the adult population decreases over time if the wage rate is below the critical threshold, $\frac{k(\xi)}{\gamma h(\xi)}$.

5.2. The AA locus

Let the *AA locus* be the set of all pairs $\left(A_t^R, H_t\right)$ so that the level of technology in the rural sector, A_t^R, is in a steady state:

$$AA \equiv \left\{\left(A_t^R, H_t\right) : A_{t+1}^R - A_t^R = 0\right\}. \tag{22}$$

Hence, the AA locus is a geometric locus in the $\left(A_t^R, H_t\right)$ space that separates the phase diagram into two regions. First, one region where the advancement in the stock of knowledge is large enough to compensate for the erosion in productivity so that the level of technology in the rural sector increases. Second, another region where the advancement in the stock of knowledge is too small to counterbalance the erosion in productivity so that the level of agricultural technology decreases. The properties of the AA locus are derived in the following lemma.

Lemma 4. *If* $\left(A_t^R, H_t\right) \in AA$, *it follows that*

$$H_t = \left(\frac{e^{\xi}}{k(\xi)}\right)^{\frac{1}{\lambda}} \left(A_t^R\right)^{\frac{1-\beta}{\lambda}} \equiv H^{AA}\left(A_t^R, \xi\right),$$

where $\frac{\partial H^{AA}(A_t^R,\xi)}{\partial A_t^R} > 0$, $\frac{\partial^2 H^{AA}(A_t^R,\xi)}{(\partial A_t^R)^2} > 0$, *and* $\frac{\partial H^{AA}(A_t^R,\xi)}{\partial \xi} \gtreqless 0$ *if and only if* $\xi \gtreqless \varepsilon_{k,\xi}$.

Furthermore,

$$A^R_{t+1} - A^R_t \gtreqless 0 \qquad \textit{if and only if} \qquad H_t \gtreqless H^{AA}\left(A^R_t, \xi\right).$$

Proof. The functional form follows with $A^R_{t+1} = A^R_t$ from (18). The derivatives are obtained from differentiation, noting $\lambda + \beta < 1$ and the definition of $\varepsilon_{k,\xi}$ in Corollary 2. □

The AA locus is a strictly convex, upward sloping curve from the origin in the $\left(A^R_t, H_t\right)$ space. The level of agricultural technology increases over time in the region above the locus. For the size of the adult population is large enough to ensure that knowledge advances faster than it erodes. Contrary, the adult population is too small for sufficient knowledge creation in the region below the locus, and the level of rural productivity decreases over time.

Interestingly, the skill-intensity of the environment has an ambiguous effect on the AA locus. The AA locus rotates to the right in the $\left(A^R_t, H_t\right)$ space if the skill-intensity of the environment is smaller than the threshold level, $\xi < \varepsilon_{k,\xi}$. In contrast, the AA locus rotates to the left in the $\left(A^R_t, H_t\right)$ space if the skill-intensity of the environment is larger than the threshold level, $\xi > \varepsilon_{k,\xi}$.

5.3. The HH Locus

Let the economy be in the agricultural stage of development, i.e., the population size is below the threshold level from Lemma 1, $H_t < \hat{H}_t$, and the manufacturing sector is not operative. Then, the *HH locus* is defined as the set of all pairs $\left(A^R_t, H_t\right)$ so that the population size is in a steady state:

$$HH \equiv \left\{\left(A^R_t, H_t\right) : H_{t+1} - H_t = 0 \mid H_t < \hat{H}\left(A^R_t, A^M_t\right)\right\}. \tag{23}$$

Hence, the HH locus is a geometric locus in the $\left(A^R_t, H_t\right)$ space that separates the phase diagram into two regions. First, one region where fertility is above replacement level, and the size of the adult population increases. Second, another region where fertility is below replacement level, and the size of the adult population decreases.

Lemma 5. *If* $\left(A^R_t, H_t\right) \in HH$*, it follows that*

$$H_t = \left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{1}{\alpha}} A^R_t \equiv H^{HH}\left(A^R_t, \xi\right),$$

where $\frac{\partial H^{HH}(A^R_t,\xi)}{\partial A^R_t} > 0$, $\frac{\partial^2 H^{HH}(A^R_t,\xi)}{(\partial A^R_t)^2} = 0$, *and* $\frac{\partial H^{HH}(A^R_t,\xi)}{\partial \xi} < 0$. *Furthermore, for all* $H_t <$

$\hat{H}(A_t^R, A_t^M)$,

$$H_{t+1} - H_t \gtreqless 0 \qquad \textit{if and only if} \qquad H_t \lesseqgtr H^{HH}\left(A_t^R; \xi\right).$$

Proof. The first part follows with $H_{t+1} = H_t$ from (15) and differentiation, noting $k = k(\xi)$ and assumption (A3). The second part follows from (11) and (6) since $n_t = 1$ along the HH locus. □

The HH locus is an upward sloping ray from the origin in the $\left(A_t^R, H_t\right)$ space. As long as the manufacturing sector is not operative, the size of the population increases over time in the region below the locus. For the wage rate increases if the population size is smaller than the steady state value, allowing fertility to be above replacement level. In contrast, the size of the population decreases over time in the region above the locus. For the wage rate decreases if the population size is larger than the steady state value, reducing fertility below replacement level.

Contrary to the AA locus, the skill-intensity of the environment has a distinct effect on the HH locus. The HH locus rotates clockwise in the $\left(A_t^R, H_t\right)$ space if the skill-intensity of the environment increases.

5.4. Global Dynamics of Population Size

Lemma 5 suggests a steady state level of population size as long as the adult population is below the threshold level, i.e., for $H_t < \hat{H}_t$. In contrast, Lemma 3 indicates a growing population if the manufacturing sector is operative, i.e., for $H_t \geq \hat{H}_t$. Hence, at some point in time, the qualitative characteristic of the dynamical system changes with respect to population size. To see this, note that the Conditional Malthusian Frontier rotates clockwise in the $\left(A_t^R, H_t\right)$ space as the level of technology in the manufacturing sector, A_t^M, increases in the process of development, while the HH locus does not. Thus, there exists a critical level of manufacturing technology, $\frac{k(\xi)}{\gamma h(\xi)}$, so that the two loci coincide. The Conditional Malthusian Frontier drops below the HH locus if the level of technology in the manufacturing sector, A_t^M, grows even further. This qualitative change in the dynamical system marks the transition from the Malthusian to the post-Malthusian regime. It is summarized in the following lemma.

Lemma 6. *Given $A_t^M > 0$ and $\xi \geq 0$, for all $A_t^R > 0$,*

$$\hat{H}\left(A_t^R, A_t^M\right) \gtreqless H^{HH}\left(A_t^R, \xi\right) \qquad \textit{if and only if} \qquad A_t^M \lesseqgtr \frac{k(\xi)}{\gamma h(\xi)}.$$

Furthermore, if the Conditional Malthusian Frontier is above the HH locus, i.e., for $A_t^M < \frac{k(\xi)}{\gamma h(\xi)}$,

$$H_{t+1} - H_t \gtreqless 0 \qquad \text{if and only if} \qquad H_t \lesseqgtr H^{HH}\left(A_t^R, \xi\right).$$

If the Conditional Malthusian Frontier is below the HH locus, i.e., for $A_t^M > \frac{k(\xi)}{\gamma h(\xi)}$,

$$H_{t+1} - H_t > 0 \qquad \text{for all} \qquad H_t > 0.$$

Proof. The first part follows from comparing the functional forms of the Cond. Malthusian Frontier, $\hat{H}\left(A_t^R, A_t^M\right)$, and the HH locus, $H^{HH}\left(A_t^R, \xi\right)$. The second part follows immediately from Lemma 3 and 5. □

6. The Process of Development

6.1. The Agricultural Stage of Development

Let the level of technology in the manufacturing sector, A_t^M, be fixed so that production is exclusively agricultural, i.e., $A_t^M < \frac{k(\xi)}{\gamma h(\xi)}$. Then, the conditional evolution of agricultural technology and population size is characterized by a sequence $\left\{A_t^R, H_t; \xi\right\}_{t=0}^{\infty}$ that satisfies the following two-dimensional discrete dynamical system:

$$\begin{cases} H_{t+1} = \frac{\gamma h(\xi)}{k(\xi)}\left(A_t^R\right)^{\alpha} H_t{}^{1-\alpha} = H^R\left(A_t^R, H_t; \xi\right) \\ A_{t+1}^R = e^{-\xi} H_t^{\lambda}\left(k(\xi) A_t^R\right)^{\beta} = A^R\left(A_t^R, H_t; \xi\right). \end{cases} \tag{24}$$

This conditional dynamical system is characterized by a globally stable steady state equilibrium $\left(A_{ss}^R, H_{ss}\right)$. To see this, consider the phase diagram in Figure 4. The phase diagram contains the Conditional Malthusian Frontier, the AA locus and the HH locus. The Conditional Malthusian Frontier lies above the HH locus, as established in Lemma 6. Furthermore, the AA locus and the HH locus intersect at a point $\left(A_{ss}^R, H_{ss}\right)$. This point of intersection forms the globally stable steady state equilibrium of the conditional dynamical system. The steady state values of rural technology, A_{ss}^R, and population size, H_{ss}, are readily calculated as

$$A_{ss}^R = \left[e^{-\xi} k(\xi)^{\beta}\left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{\lambda}{\alpha}}\right]^{\frac{1}{1-\lambda-\beta}} \equiv A_{ss}^R(\xi) \tag{25}$$

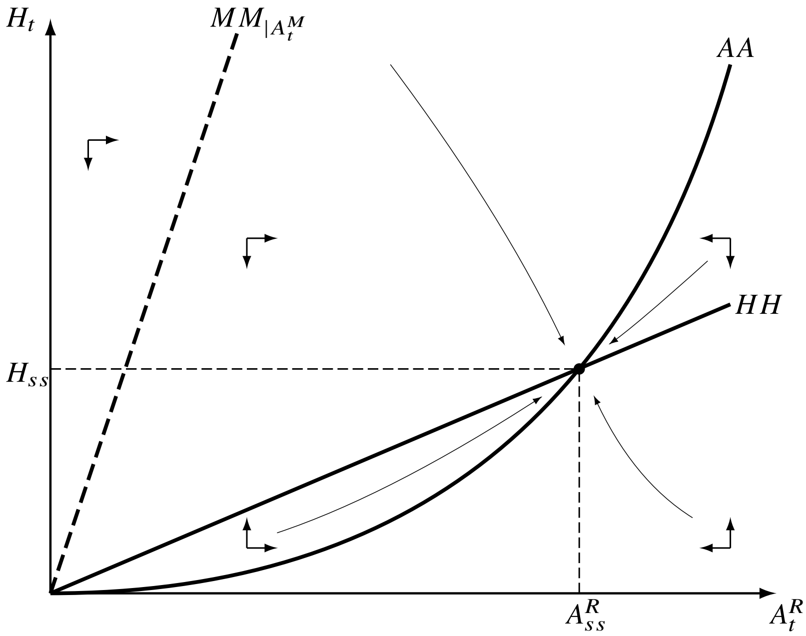


Figure 4: The Agricultural Stage of Development, $A_t^M < \frac{k(\xi)}{\gamma h(\xi)}$.

and

$$H_{ss} = \left[e^{-\xi} k(\xi)^{\beta} \left(\frac{\gamma h(\xi)}{k(\xi)} \right)^{\frac{1-\beta}{\alpha}} \right]^{\frac{1}{1-\lambda-\beta}} \equiv H_{ss}(\xi), \tag{26}$$

as follows from Lemma 4 and 5. The conditional dynamical system has a second steady state equilibrium at the origin of the $\left(A_t^R, H_t\right)$ space. This equilibrium is trivial, unstable, and irrelevant, as the non-trivial steady state equilibrium is globally stable for $A_0^R > 0$ and $H_0 > 0$.

The conditional dynamical system converges to the globally stable steady state equilibrium in a typical Malthusian fashion. In the region above the HH locus, the adult population is too large so that the wage rate restricts fertility to sub-replacement levels. Hence, the population size decreases over time. In the region below the HH locus, the adult population is too small so that the wage rate allows fertility to be above replacement level. Thus, the population size increases over time. In the region above the $MM_{|A_t^M}$ locus, the manufacturing sector would be active. However, the population size would decrease over time and would eventually drop below the $MM_{|A_t^M}$ locus. Therefore, industrial production is not sustainable in the agricultural stage of development.

Convergence to the conditional Malthusian steady state equilibrium could be monotonically or oscillatory in principle. Convergence is oscillatory if at least one of the eigenvalues of the Jacobian matrix of the dynamical system in (24) is negative. The stability properties of the conditional steady state equilibrium are established in the following lemma.

Lemma 7. *Let* $A_t^M < \frac{k(\xi)}{\gamma h(\xi)}$ *be fixed. The conditional Malthusian steady state equilibrium,* $\left(A_{ss}^R, H_{ss}\right)$*, is locally asymptotically stable. It is characterized by local monotonic evolution of both state variables,* A_t^R *and* H_t*, if and only if the Jacobian matrix,*

$$J\left(A_{ss}^R, H_{ss}\right) = \begin{pmatrix} \frac{\partial A^R(A_{ss}^R, H_{ss};\xi)}{\partial A_t^R} & \frac{\partial A^R(A_{ss}^R, H_{ss};\xi)}{\partial H_t} \\ \frac{\partial H^R(A_{ss}^R, H_{ss};\xi)}{\partial A_t^R} & \frac{\partial H^R(A_{ss}^R, H_{ss};\xi)}{\partial H_t} \end{pmatrix},$$

has eigenvalues that are real and positive, i.e., if and only if

$$\alpha < \frac{\beta}{\beta + \lambda}.$$

Proof. See Appendix A. □

If the parametric condition in Lemma 7 holds, the conditional dynamical system is locally nonoscillatory in the vicinity of the conditional steady state equilibrium. The trajectories in Figure 4 are drawn under this assumption. However, the analysis of the present model would not change if the conditional dynamical system is characterized by oscillatory behavior. In fact, oscillations seem to be a feature of the Malthusian epoch (Lagerlöf 2006).

As long as the economy is exclusively agricultural, the wage rate per efficiency unit of labor in the conditional steady state equilibrium is given by

$$w_{ss}(\xi) = \frac{k(\xi)}{\gamma h(\xi)}, \tag{27}$$

as follows from (6), (25), and (26). The steady state level of income per worker is then readily calculated as

$$y_{ss}(\xi) = \frac{k(\xi)}{\gamma}. \tag{28}$$

Hence, income per worker is independent of the level of technology in the agricultural sector, which is a well-established property of the Malthusian epoch. A higher level of agricultural technology is counterbalanced by a larger population size.

Interestingly, the model predicts some variation in income per capita in response to differing environmental conditions. If optimal somatic investment increases due to a rise in the skill-intensity of the environment, the steady state level of income per worker increases as well. Intuitively, children are more expensive if somatic investment increases. Thus, income per worker has to be higher to raise a single child, which is necessary to keep the population size constant.

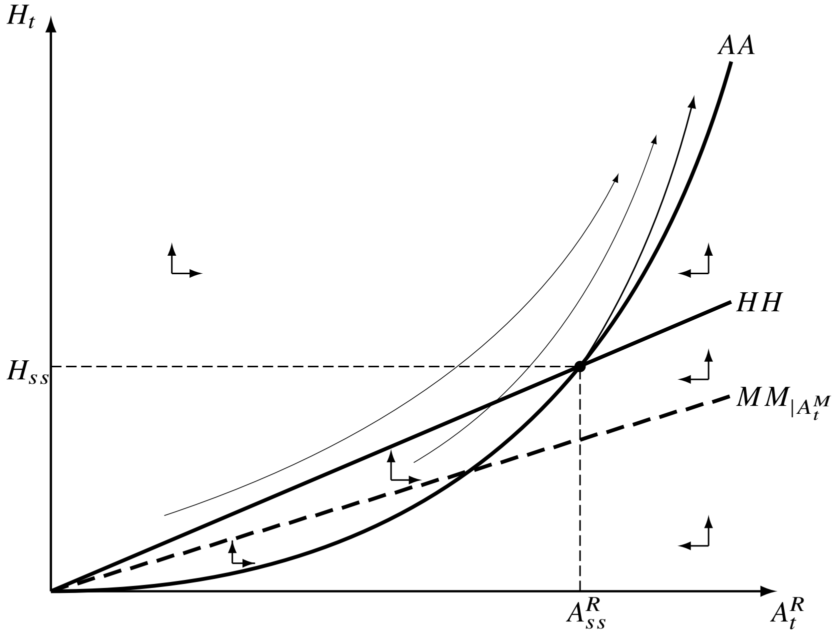


Figure 5: The Industrial Stage of Development, $A_t^M > \frac{k(\xi)}{\gamma h(\xi)}$.

6.2. The Industrial Stage of Development

Suppose a level of technology in the manufacturing sector above the critical threshold, $A_t^M > \frac{k(\xi)}{\gamma h(\xi)}$, so that the manufacturing sector is economically viable. The economy is in the industrial stage of development, and the dynamical system differs qualitatively with respect to its characteristics in the agricultural stage of development, as depicted in Figure 5.

The phase diagram shows that the Conditional Malthusian Frontier is located below the HH locus. Therefore, as established in Lemma 6, the growth rate of population size is positive. This in turn reinforces the growth rate of technology in the manufacturing sector, increasing the wage rate over time, and allowing fertility to be constantly above replacement level. Thus, feedback effects between population size and manufacturing technology lead to increasing growth rates over time, and the unconditional dynamical system in (20) is characterized by hyperbolic growth (i.e. faster than exponential growth) in population and technology. This behavior is well in line with the characteristics of the post-Malthusian era.

6.3. The Transition from Agriculture to Industry

Consistent with the historical path of economic development it is important to ensure that the manufacturing sector becomes economically viable for at least some environmental conditions. The transition from agricultural to industrial production occurs if the level of technology in the manufacturing sector, A_t^M, grows and crosses the critical threshold, $\frac{k(\xi)}{\gamma h(\xi)}$. Let g_t be the growth rate of productivity in the manufacturing sector between periods t and $t+1$. It is given by

$$g_t \equiv \frac{A_{t+1}^M - A_t^M}{A_t^M} = e^{-\xi} H_t^{\lambda} k(\xi) - 1 \equiv g(H_t, \xi), \tag{29}$$

as follows from (17). Specifically, the growth rate has to be positive at the conditional Malthusian steady state equilibrium, $\left(A_{ss}^R, H_{ss}\right)$. The growth rate of manufacturing productivity at the conditional Malthusian steady state equilibrium, as follows from (26), is given by

$$g\left(H_{ss}(\xi), \xi\right) = \left[e^{-\xi} k(\xi)^{1-\lambda} \left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{\lambda}{\alpha}}\right]^{\frac{1-\beta}{1-\lambda-\beta}} - 1 \equiv g_{ss}(\xi). \tag{30}$$

This growth rate depends on the skill-intensity of the environment. It can be positive or negative in general. In order to permit a positive growth rate of productivity in the (latent) manufacturing sector at least for small values of the skill-intensity of the environment, ξ, it as assumed that

$$g_{ss}(0) = \left[\left(\tilde{k}\right)^{1-\lambda} \left(\frac{\gamma \tilde{h}}{\tilde{k}}\right)^{\frac{\lambda}{\alpha}}\right]^{\frac{1-\beta}{1-\lambda-\beta}} - 1 > 0, \tag{A7}$$

where $\tilde{k} = k(0)$ and $\tilde{h} = h(0)$ are defined in assumption (A4).

The properties of the growth rate of manufacturing productivity at the conditional Malthusian steady state equilibrium are established in the following lemma.

Lemma 8. *1. Under (A5) and (A6), it follows that*

$$\frac{\partial g_{ss}(\xi)}{\partial \xi} \gtreqless 0 \qquad \textit{if and only if} \qquad \xi \lesseqgtr \xi^*,$$

where $\xi^* \equiv \varepsilon_{k,\xi}\left(1 - \frac{\alpha+\varepsilon}{\alpha}\lambda\right)$ *with* $0 < \xi^* < \varepsilon_{k,\xi}$.

2. *Under (A5), (A6), and (A7), it follows that* $\lim_{\xi\to\infty} g_{ss}(\xi) = -1$. *Moreover, there exists a unique* $\hat{\xi} > \xi^*$ *so that*

$$g_{ss}(\xi) \gtreqless 0 \qquad \textit{if and only if} \qquad \xi \lesseqgtr \hat{\xi}.$$

Proof. See Appendix A. □

Hence, the growth rate of manufacturing productivity at the conditional Malthusian steady state equilibrium has a unique root, $\hat{\xi}$, in the domain (ξ^*, ∞). It is positive for all values

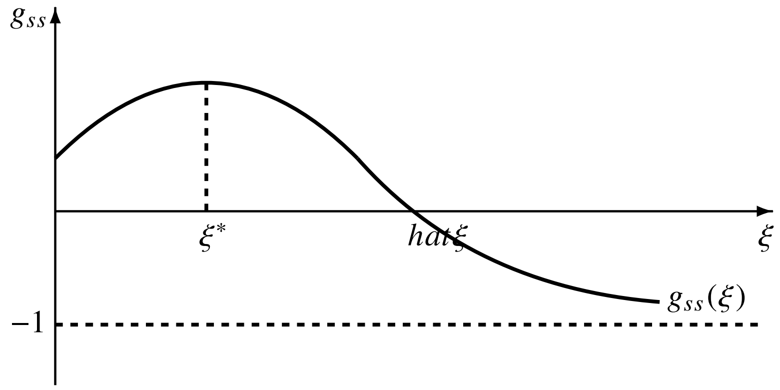


Figure 6: The Effect of the Skill-Intensity on the Growth Rate of Manufacturing Productivity at the Conditional Steady State Equilibrium.

below the root and negative for all values above the root. As depicted in Figure 6, it has a hump-shaped relationship with respect to the skill-intensity of the environment. Note that the growth rate is monotonically increasing for $\xi \in (0, \xi^*)$. Hence, a rise in the skill-intensity of the environment leads to higher growth rates of manufacturing productivity as long as the skill-intensity is not too large. This property of $g_{ss}(\xi)$ is important and forms the basis for the key result of this paper.

6.4. Skill-Intensity and Comparative Economic Development

The skill-intensity of the environment has two major effects in the agricultural stage of development. First, it changes the location of the conditional Malthusian steady state equilibrium, $\left(A^R_{ss}(\xi), H_{ss}(\xi)\right)$. Second, it has an effect on the growth rate of productivity in the (latent) manufacturing sector, $g_{ss}(\xi)$, and therefore influences the timing of the transition to the industrial stage of development. Both effects are analyzed in this subsection.

The effect of an increase in the skill-intensity on the conditional Malthusian steady state equilibrium is summarized in the following proposition.

Proposition 1. *Consider an economy in the agricultural stage of development. Under assumptions (A5) and (A6), an increase in the skill-intensity of the environment has an adverse effect on the steady state levels of population size and rural technology, but a beneficial effect on the steady state level of income per capita, i.e.,*

$$\frac{\partial A^R_{ss}(\xi)}{\partial \xi} < 0, \qquad \frac{\partial H_{ss}(\xi)}{\partial \xi} < 0, \qquad \frac{\partial y_{ss}(\xi)}{\partial \xi} > 0.$$

Proof. Follows immediately from differentiating (25), (26), and (28) with respect to ξ while

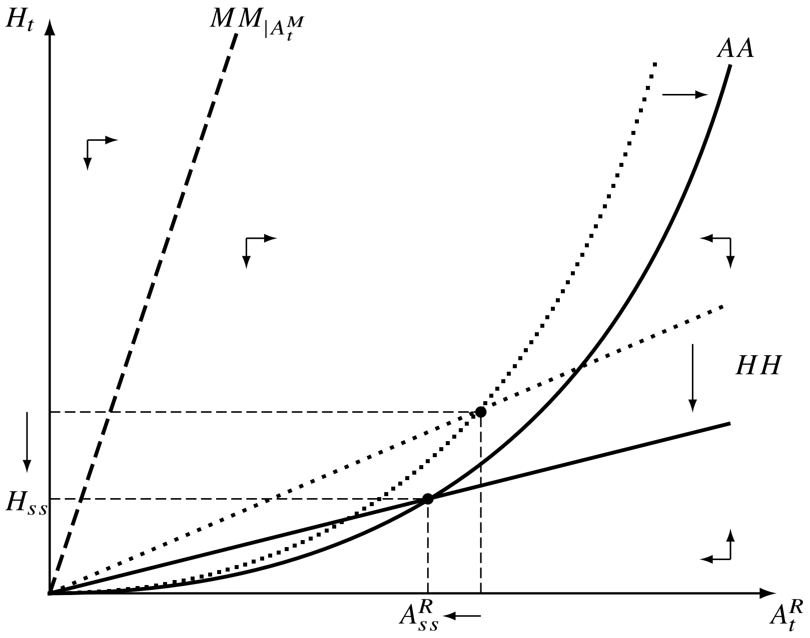


Figure 7: The Effect of an Increase in the Skill-Intensity on the Conditional Malthusian Steady State Equilibrium for a Low Skill-Intensity, $\xi < \varepsilon_{k,\xi}$.

noting (A5), (A6), and Lemma 2. □

Hence, as depicted in Figure 7, an increase in the skill-intensity of the environment causes the HH locus to rotate clockwise in the $\left(A_t^R, H_t\right)$ space. In contrast, as follows from Lemma 4, the effect on the AA locus is ambiguous. If the skill-intensity is large, $\xi > \varepsilon_{k,\xi}$, the AA locus rotates counterclockwise in the $\left(A_t^R, H_t\right)$ space, leading to a lower steady state level of rural technology and population size. If the skill-intensity is small, $\xi < \varepsilon_{k,\xi}$, the AA locus rotates clockwise in the $\left(A_t^R, H_t\right)$ space, still leading to lower steady state level of rural technology and population size as long as (A6) is fulfilled. Therefore, the new conditional Malthusian steady state equilibrium is inferior and characterized by a lower level of technology in the rural sector and a smaller population size, as depicted in Figure 7.

A close look at equations (25) and (26) reveals three opposing effects of environmental conditions on the Malthusian steady state equilibrium. First, a negative *quantity* effect via $\frac{\gamma h(\xi)}{k(\xi)}$, i.e., the steady state level of population size decreases with a rise in the skill-intensity, reducing the rate of knowledge creation. Second, a positive *quality* effect via $k(\xi)$, i.e., the steady state level of parental investment increases with a rise in the skill-intensity, leading to a higher innovation capability of individuals. Third, a negative *erosion* effect via $e^{-\xi}$, i.e., adverse environmental conditions act as a negative externality that directly hampers the advancement of the knowledge frontier. Clearly, the erosion effect dominates if the skill-intensity of the environment is large. In contrast, the quantity effect and the quality effect are more important if the skill-intensity is small. The relative size of both effects depends on the elasticities λ and β. Under (A6), the steady state levels of population size and rural technology are unambiguously dominated by the negative quantity effect, leading to an inferior conditional Malthusian steady state equilibrium for a society with a larger skill-intensity.

The skill-intensity of the environment, however, also has an effect on the growth rate of technology in the (latent) manufacturing sector and, thus, on the timing of the industrialization. This effect is summarized in the following proposition.

Proposition 2. *Consider an economy in a conditional Malthusian steady state equilibrium. Under assumptions (A5), (A6), and (A7), an increase in the skill-intensity of the environment, as long as the skill-intensity is not too large, has a beneficial effect on the growth rate of technology in the (latent) manufacturing sector and, thus, on the timing of the industrialization, i.e.,*

$$\frac{\partial g_{ss}(\xi)}{\partial \xi} \gtreqless 0 \qquad \textit{if and only if} \qquad \xi \lesseqgtr \xi^{*}.$$

Proof. Follows immediately from Lemma 8. □

Hence, the growth rate of technology in the (latent) manufacturing sector at the conditional Malthusian steady state equilibrium is positive and monotonically increasing in the skill-intensity of the environment up to the threshold level, ξ^{*}, and monotonically decreasing thereafter. Again, a close look at equation (30) reveals that the steady state growth rate of manufacturing technology is governed by a quantity, quality, and erosion effect. Under (A5), the quality effect unambiguously dominates the quantity effect, leading to an earlier transition to the industrial era by a society with a larger but still moderate skill-intensity of the environment. In contrast, if the skill-intensity of the environment is too large, an increase in the skill-intensity still raises the rate of knowledge creation, which is, however, dominated by the negative erosion effect. The net rate of knowledge creation is therefore diminished.

It is clear from Propositions 1 and 2 that variation in the skill-intensity of the environment across societies can be associated with a reversal of fortune in the process of development if the skill-intensity is not too large, i.e., for $\xi < \xi^{*}$. On the one hand, a higher skill-intensity of the environment generates an inferior Malthusian steady state equilibrium in the agricultural stage of development. On the other hand, it stimulates an earlier transition to the industrial stage of development and, thus, an earlier take-off to the modern era of sustained economic growth. Initial geographical conditions can therefore have a profound effect on the process of development. This is summarized in the following corollary.

Corollary 3. *Consider two societies indexed by $i \in \{N, S\}$. Suppose that society N is characterized by a higher skill-intensity of the environment so that $\xi^S < \xi^N < \xi^*$, where ξ^i is the skill-intensity of society i. Society N will then be characterized by a smaller population size and a lower level of technology in the Malthusian era, but it will overtake society S via an earlier transition to the modern era of sustained economic growth.*

Proof. Follows immediately from Propositions 1 and 2. □

7. Conclusion

This paper argues that variation in the skill-intensity of the environment has played a significant role for the prevalent pattern of economic development across the globe. It develops an evolutionary growth theory that suggests differential parental investment as a new theoretical link between geographical conditions and comparative economic development. The theory contributes to the understanding of the process of economic development that is characterized by a reversal of fortune with respect to land productivity.

First, it attributes the dominance of some societies in the Malthusian era to favorable geographical conditions. Societies that were characterized by higher land productivity and, therefore, by lower skill-intensity of the environment generated a fertility advantage for individuals who were pre-disposed toward lower parental investment, increasing their share in the population. Lower parental investment reduced the cost of children, leading to a larger population size and a higher level of economic development in the Malthusian era.

Second, it attributes the earlier industrialization of other societies to adverse geographical conditions. Societies that were characterized by lower land productivity and, therefore, a higher skill-intensity of the environment generated a fertility advantage for individuals who were pre-disposed toward higher parental investment, increasing their share in the population. Higher parental investment increased the innovation capability of individuals, leading to a faster rate of technological progress in the latent manufacturing sector and an earlier transition to the modern era of sustained economic growth.

The theory proposes the pattern of parental investment as a natural candidate for a long-term genealogical link between geographical, historical, and cultural factors on productivity and income per capita. According to Spolaore and Wacziarg (2013), such a genealogical link is important in explaining the transmission of technological knowledge and the diffusions of development. The pattern of parental investment is a slow-changing biological and/or cultural trait that is transmitted between generations and therefore highly persistent. Arguably, it captures the very essence of human capital formation in historic and prehistoric times. As such, it is a good candidate for the long-term transmission of initial geographical conditions on comparative economic development.

Appendix A Proofs

Proof of Corollary 1. It follows from the properties of (13) and the Implicit Function Theorem that the derivate of evolutionary optimal somatic investment is positive and given by

$$k'(\xi) = -\frac{h_{k\xi}(k,\xi)k - h_{\xi}(k,\xi)}{h_{kk}(k,\xi)k} > 0. \tag{31}$$

Using (31) to calculate the derivate of evolutionary optimal human capital with respect to the skill-intensity of the environment ξ yields

$$\begin{aligned}
h'(\xi) &= \frac{\partial h(k(\xi),\xi)}{\partial \xi} \\
&= h_k(k^i,\xi)k'(\xi) + h_{\xi}(k^i,\xi) \\
&= -h_k(k^i,\xi)\frac{h_{k\xi}(k^i,\xi)k^i - h_{\xi}(k^i,\xi)}{h_{kk}(k^i,\xi)k^i} + h_{\xi}(k^i,\xi) \\
&= -h_k(k^i,\xi)\frac{h_{k\xi}(k^i,\xi)}{h_{kk}(k^i,\xi)} + h_{\xi}(k^i,\xi)\left[1 + \frac{h_k(k^i,\xi)}{h_{kk}(k^i,\xi)k^i}\right] \\
&= -h_k(k^i,\xi)\frac{h_{k\xi}(k^i,\xi)}{h_{kk}(k^i,\xi)} + h_{\xi}(k^i,\xi)\left[1 - \frac{1}{\eta_{h_k k^i}}\right] > 0,
\end{aligned}$$

where the positive sign follows from the properties of (7), the positivity of $h_{k\xi}(k,\xi)$ from (A2), and the fact that $\eta_{h_k k^i}$ is smaller than one in absolute value from (A3). Finally, $h(\xi) > 0$ for $\xi \geq 0$ follows from the properties of (7) and (A4). □

Proof of Corollary 2. To simplify the proof, I define the following elasticities:

$$\eta_{h_k\xi} \equiv \frac{h_{k\xi}(k,\xi)\xi}{h_k(k,\xi)} > 0, \qquad \eta_{h\xi} \equiv \left|\frac{h_{\xi}(k,\xi)\xi}{h(k,\xi)}\right| < 1, \qquad \eta_{hk} \equiv \frac{h_k(k,\xi)k}{h(k,\xi)} < 1.$$

They are positive by definition and the latter two are smaller than one in absolute value.

Then, using $k'(\xi)$ from the proof of Corollary 1, the elasticity $\varepsilon_{k\xi}$ is given by

$$\begin{aligned}\varepsilon_{k\xi} &= \frac{k'(\xi)\xi}{k}\\ &= -\frac{h_{k\xi}(k,\xi)k - h_\xi(k,\xi)}{h_{kk}(k,\xi)k}\frac{\xi}{k}\\ &= -\frac{h_k(k,\xi)}{h_{kk}(k,\xi)k}\left[\frac{h_{k\xi}(k,\xi)\xi}{h_k(k,\xi)} - \frac{h_\xi(k,\xi)\xi}{h(k,\xi)}\frac{h(k,\xi)}{h_k(k,\xi)k}\right]\\ &= \frac{1}{\eta_{h_k k}}\left[\eta_{h_k\xi} + \frac{\eta_{h\xi}}{\eta_{hk}}\right] > 0,\end{aligned}$$

which is positive.

Furthermore, using $h'(\xi)$ from the proof of Corollary 1, the elasticity $\varepsilon_{h\xi}$ is given by

$$\begin{aligned}\varepsilon_{h\xi} &= \frac{h'(\xi)\xi}{h(\xi)}\\ &= \left[h_k(k,\xi)\frac{h_{k\xi}(k,\xi)}{h_{kk}(k,\xi)} + h_\xi(k,\xi)\left(1-\frac{1}{\eta_{h_k k^i}}\right)\right]\frac{\xi}{h(\xi)}\\ &= \frac{h_k(k,\xi)}{h_{kk}(k,\xi)k}\frac{h_{k\xi}(k,\xi)\xi}{h_k(k,\xi)}\frac{h_k(k,\xi)k}{h(k,\xi)} + \frac{h_\xi(k,\xi)\xi}{h(k,\xi)}\left(1-\frac{1}{\eta_{h_k k}}\right)\\ &= \frac{\eta_{h_k\xi}\eta_{hk}}{\eta_{h_k k}} - \eta_{h\xi}\left(1-\frac{1}{\eta_{h_k k}}\right)\\ &= \eta_{hk}\left[\frac{1}{\eta_{h_k k}}\left(\eta_{h_k\xi} + \frac{\eta_{h\xi}}{\eta_{hk}}\right)\right] - \eta_{h\xi}\\ &= \eta_{hk}\varepsilon_{k\xi} - \eta_{k\xi} < \varepsilon_{k\xi},\end{aligned}$$

which is positive and smaller than $\varepsilon_{k\xi}$ since η_{hk} is smaller than one. □

Proof of Lemma 7. Under $A_t^M < \frac{k(\xi)}{\gamma h(\xi)}$, the Jacobian matrix of the conditional dynamical system in (24) is given by

$$\begin{aligned}J\left(A_t^R, H_t\right) &= \begin{pmatrix}\frac{\partial A^R(A_t^R,H_t;\xi)}{\partial A_t^R} & \frac{\partial A^R(A_t^R,H_t;\xi)}{\partial H_t}\\ \frac{\partial H^R(A_t^R,H_t;\xi)}{\partial A_t^R} & \frac{\partial H^R(A_t^R,H_t;\xi)}{\partial H_t}\end{pmatrix}\\ &= \begin{pmatrix}\frac{\beta}{A_t^R}A^R\left(A_t^R,H_t;\xi\right) & \frac{\lambda}{H_t}A^R\left(A_t^R,H_t;\xi\right)\\ \frac{\alpha}{A_t^R}H^R\left(A_t^R,H_t;\xi\right) & \frac{1-\alpha}{H_t}H^R\left(A_t^R,H_t;\xi\right)\end{pmatrix}.\end{aligned}$$

Evaluating this system at the conditional steady state given by (25) and (26) yields

$$J\left(A^R_{ss}, H_{ss}\right) = \begin{pmatrix} \beta & \lambda\left(\frac{k(\xi)}{\gamma h(\xi)}\right)^{\frac{1}{\alpha}} \\ \alpha\left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{1}{\alpha}} & 1-\alpha \end{pmatrix} \equiv J_{ss}$$

The steady state equilibrium of a two-dimensional system can be characterized in terms of trace and determinant of the matrix J_{ss}. The trace of this matrix is positive,

$$Tr(J_{ss}) = \beta + (1-\alpha) > 0.$$

As follows from Galor (2007, p. 90), to show that $\left(A^R_{ss}, H_{ss}\right)$ is locally asymptotically stable, it is then sufficient to show that $Det(J_{ss}) \in \left(Tr(J_{ss}) - 1, \frac{1}{4}Tr(J_{ss})^2\right)$. The determinant of the matrix J_{ss} is given by

$$Det(J_{ss}) = \beta(1-\alpha) - \alpha\lambda.$$

The upper boundary holds since

$$4Det(J_{ss}) < Tr(J_{ss})^2 \quad \Longleftrightarrow \quad -4\alpha\lambda < [\beta - (1-\alpha)]^2$$

and $\alpha\lambda > 0$. The lower boundary holds since

$$Det(J_{ss}) > Tr(J_{ss}) - 1 \quad \Longleftrightarrow \quad \alpha(1-\lambda-\beta) > 0,$$

where $\lambda + \beta < 1$. Thus, the steady state equilibrium is locally asymptotically stable.

As follows from Galor (2007, p. 88), both eigenvalues are real since $4Det(J_{ss}) < Tr(J_{ss})^2$. One eigenvalue is definitely positive since $Tr(J_{ss}) > 0$. The second eigenvalue is positive if $Det(J_{ss}) > 0$. This is the case for

$$Det(J_{ss}) > 0 \quad \Longleftrightarrow \quad \alpha < \frac{\beta}{\beta + \lambda},$$

and the state variables, A^R_t and H_t, are characterized by local monotonic evolution to the steady state equilibrium if this condition is satisfied. □

Proof of Lemma 8. 1. Let the function $\kappa_{ss}(\xi) \equiv k(\xi)^{1-\lambda}\left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{\lambda}{\alpha}}$ be defined, and let ε_κ be the elasticity of $\kappa_{ss}(\xi)$ with respect to the skill-intensity of the environment, $\varepsilon_\kappa \equiv \frac{\kappa'_{ss}(\xi)\xi}{\kappa_{ss}(\xi)}$.

Under (A5), calculating the first derivative of $\kappa_{ss}(\xi)$ yields

$$\frac{\partial \kappa_{ss}(\xi)}{\partial \xi} = \left[(1-\lambda)\frac{k'(\xi)}{k(\xi)} + \frac{\lambda}{\alpha}\left(\frac{h'(\xi)}{h(\xi)} - \frac{k'(\xi)}{k(\xi)}\right)\right]\kappa_{ss}(\xi).$$

Noting Corollary 2, the elasticity of $\kappa_{ss}(\xi)$ with respect to ξ is then readily given as

$$\varepsilon_\kappa = \frac{\partial \kappa_{ss}(\xi)}{\partial \xi}\frac{\xi}{\kappa_{ss}(\xi)} = (1-\lambda)\varepsilon_{k,\xi} + \frac{\lambda}{\alpha}\left(\varepsilon_{h,\xi} - \varepsilon_{k,\xi}\right) = \varepsilon_{k,\xi}\left(1 - \frac{\alpha+\varepsilon}{\alpha}\lambda\right),$$

where $0 < \varepsilon_\kappa < \varepsilon_{k,\xi}$ follows from $0 < \lambda < \frac{\alpha}{\alpha+\varepsilon}$.

Under (A5) and (A6), the first derivate of $g_{ss}(\xi)$,

$$\frac{\partial g_{ss}(\xi)}{\partial \xi} = \frac{1-\beta}{1-\lambda-\beta}\left[e^{-\xi}k(\xi)^{1-\lambda}\left(\frac{\gamma h(\xi)}{k(\xi)}\right)^{\frac{\lambda}{\alpha}}\right]^{\frac{1-\beta}{1-\lambda-\beta}}\frac{\varepsilon_\kappa - \xi}{\xi},$$

is positive for $\xi < \varepsilon_\kappa$ and negative for $\xi > \varepsilon_\kappa$. Thus, $g_{ss}(\xi)$ has a global maximum at $\xi^* \equiv \varepsilon_\kappa$.

2. It follows from (A7) that $g_{ss}(0) > 0$. Moreover,

$$\lim_{\xi\to\infty} g_{ss}(\xi) = \left(\lim_{\xi\to\infty}\frac{\kappa^{HH}(\xi)}{e^{\xi}}\right)^{\frac{1-\beta}{1-\lambda-\beta}}\left(A_t^R\right)^{-\frac{\lambda(1-\beta)}{1-\lambda-\beta}} - 1 = -1,$$

since ε_κ is restricted from above by $\varepsilon_{k,\xi}$, whereas the elasticity of e^{ξ} with respect to ξ, $\frac{e^{\xi}\xi}{e^{\xi}} = \xi$, grows without bound as $\xi \to \infty$. Therefore, the existence of a unique root follows immediately from the continuity of $g_{ss}(\xi)$. The unique root has to be larger than ε_κ since $g_{ss}(\varepsilon_\kappa) > g_{ss}(0) > 0$.

□

Appendix B Robustness

Table 4: Robustness of the Reversal of Fortune With Respect to Land Suitability.

	log population density in 1500 CE	log urbanization rate in 1500 CE	log income per capita in 2000 CE		log urbanization rate in 2000 CE	
	(1)	(2)	(3)	(4)	(5)	(6)
log land suitability	0.488***	0.033	-0.260***		-0.117***	
	(0.056)	(0.051)	(0.051)		(0.027)	
log land suitability (ancestry adjusted)				-0.235***		-0.130***
				(0.065)		(0.034)
log absolute latitude	-0.210	-0.262	-0.064	-0.040	0.039	0.046
	(0.140)	(0.177)	(0.105)	(0.110)	(0.069)	(0.070)
log Neolithic transition timing	1.052***	0.159	-0.421***	-0.370**	-0.067	-0.053
	(0.225)	(0.225)	(0.135)	(0.144)	(0.098)	(0.101)
Mean distance to nearest waterway	-0.822***	-0.254**	-0.440***	-0.433***	-0.225***	-0.230***
	(0.130)	(0.118)	(0.148)	(0.158)	(0.082)	(0.083)
Percentage of pop. at risk of malaria	0.272	-0.428	-1.517***	-1.567***	-0.532***	-0.552***
	(0.326)	(0.414)	(0.233)	(0.254)	(0.151)	(0.156)
Cont. fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	146	81	146	146	146	146
R^2	0.684	0.343	0.685	0.650	0.520	0.500

Notes: This table establishes that the reversal of fortune with respect to land suitability from Table 1 is robust to alternatives. It documents a significant positive effect of land suitability on population density in 1500 CE and a significant negative effect of either land suitability or ancestry adjusted land suitability on income per capita and urbanization rate in 2000 CE in a 146-country sample, while controlling for absolute latitude, timing of the Neolithic transition, mean distance to nearest waterway, percentage of population at risk of contracting malaria, and continent fixed effects. Again, using identical control variables, the effect of land suitability on urbanization rate in 1500 CE in a limited 81-country sample is positive but not significant. Heteroskedasticity-robust standard errors are reported in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 5: Robustness of Body Mass as a Proxy for Parental Investment.

	log body mass in 2005 CE		log income per capita in 2000 CE			log urbanization rate in 2000 CE		
	OLS	OLS	OLS	OLS	2SLS	OLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log body mass			1.439*	1.376*	5.907*	2.526***	2.533***	7.631**
			(0.078)	(0.097)	(0.060)	(0.000)	(0.000)	(0.018)
log land suitability	-0.016***		-0.050			-0.074		
	(0.007)		(0.256)			(0.140)		
log land suitability (ancestry adjusted)		-0.017**		-0.078*			-0.088*	
		(0.019)		(0.099)			(0.069)	
log absolute latitude	0.026***	0.027***	0.060	0.061	-0.061	0.016	0.019	-0.119
	(0.000)	(0.000)	(0.275)	(0.265)	(0.556)	(0.811)	(0.777)	(0.319)
log Neolithic transition timing	0.052***	0.055***	-0.153	-0.146	-0.395*	-0.068	-0.056	-0.336*
	(0.004)	(0.002)	(0.282)	(0.309)	(0.057)	(0.515)	(0.613)	(0.090)
Mean distance to nearest waterway	-0.043**	-0.034**	-0.235*	-0.226*	-0.074	-0.222	-0.184	-0.013
	(0.020)	(0.049)	(0.081)	(0.087)	(0.656)	(0.180)	(0.217)	(0.938)
Percentage of population at risk of malaria	-0.052**	-0.055**	-0.748***	-0.756***	-0.506	0.053	0.039	0.321
	(0.034)	(0.025)	(0.004)	(0.002)	(0.131)	(0.800)	(0.851)	(0.293)
Social infrastructure	0.056	0.066*	1.409***	1.445***	1.144***	-0.027	0.021	-0.317
	(0.104)	(0.055)	(0.000)	(0.000)	(0.002)	(0.899)	(0.919)	(0.389)
Years of schooling	0.010***	0.010***	0.104***	0.106***	0.059	0.057**	0.058**	0.006
	(0.009)	(0.008)	(0.001)	(0.001)	(0.149)	(0.017)	(0.016)	(0.889)
Continental fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	91	91	91	91	91	91	91	91
R^2	0.759	0.757	0.903	0.904	0.867	0.675	0.676	0.432
Anderson-Rubin *p-value*					0.028			0.010
Kleibergen-Paap *F-statistic*					5.766			5.766

Notes: This table shows that the results from Table 2 are robust to alternatives. First, it establishes a significant negative effect of either land suitability (column 1) or ancestry adjusted land suitability (column 2) on contemporary body mass in a 91-country sample, while controlling for absolute latitude, timing of the Neolithic transition, mean distance to nearest waterway, percentage of population at risk of contracting malaria, and continent fixed effects. Second, under the same control variables, the table documents a significant positive effect of body mass on two indicators of contemporary economic development, i.e., income per capita in the year 2000 CE (columns 3–5) and urbanization rate in the year 2000 CE (columns 6–8). Columns 3, 4, 6, and 7 show that the significance of the direct effect of (ancestry adjusted) land suitability on current economic outcomes is greatly diminished or rendered insignificant when body mass is introduced, indicating that body mass is a relevant channel of transmission. Columns 5 and 8 deal with reverse causality and provide IV estimates. The instrument is ancestry adjusted land suitability. The instrument is clearly relevant. However, it is not possible to control for unadjusted land suitability in the extended specification. Heteroskedasticity-robust standard errors are reported in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 6: Robustness of Adult Survival Rate as a Proxy for Parental Investment.

	log adult survival rate in 2000 CE		log income per capita in 2000 CE			log urbanization rate in 2000 CE		
	OLS	OLS	OLS	OLS	2SLS	OLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log adult survival rate			0.159	0.119	1.730***	0.645**	0.642**	2.472***
			(0.703)	(0.769)	(0.009)	(0.036)	(0.042)	(0.002)
log land suitability	-0.050***		-0.068			-0.100*		
	(0.000)		(0.110)			(0.076)		
log land suitability (anc. adjusted)		-0.060***		-0.097**			-0.111**	
		(0.000)		(0.025)			(0.050)	
log absolute latitude	0.035*	0.037*	0.093	0.096	0.036	0.068	0.073	0.005
	(0.071)	(0.058)	(0.120)	(0.112)	(0.618)	(0.292)	(0.252)	(0.937)
log Neolithic transition timing	0.188***	0.197***	-0.112	-0.096	-0.413*	-0.078	-0.058	-0.418**
	(0.004)	(0.002)	(0.442)	(0.501)	(0.066)	(0.476)	(0.615)	(0.040)
Mean distance to nearest waterway	-0.103*	-0.079	-0.294**	-0.274**	-0.146	-0.347*	-0.290*	-0.145
	(0.100)	(0.219)	(0.040)	(0.045)	(0.390)	(0.058)	(0.076)	(0.420)
Percentage of population at risk of malaria	0.077	0.068	-0.835***	-0.841***	-0.950***	-0.127	-0.148	-0.273
	(0.384)	(0.422)	(0.001)	(0.001)	(0.000)	(0.483)	(0.416)	(0.152)
Social infrastructure	0.174**	0.207**	1.457***	1.509***	1.176***	-0.026	0.041	-0.338
	(0.045)	(0.018)	(0.000)	(0.000)	(0.000)	(0.906)	(0.852)	(0.214)
Years of schooling	0.010	0.011	0.117***	0.119***	0.101***	0.077***	0.079***	0.059***
	(0.301)	(0.244)	(0.000)	(0.000)	(0.004)	(0.001)	(0.001)	(0.010)
Continental fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	92	92	92	92	92	92	92	92
R^2	0.688	0.692	0.902	0.904	0.870	0.657	0.655	0.450
Anderson-Rubin *p-value*					0.023			0.007
Kleibergen-Paap *F-statistic*					17.130			17.130

Notes: This table shows that the results from Table 3 are only partially robust to alternatives. First, it establishes a significant negative effect of either land suitability (column 1) or ancestry adjusted land suitability (column 2) on contemporary adult survival rate in a 92-country sample, while controlling for absolute latitude, timing of the Neolithic transition, mean distance to nearest waterway, percentage of population at risk of contracting malaria, and continent fixed effects. Second, the table shows that the significant positive effect of adult survival rate income per capita in the year 2000 CE (columns 3–5) is not robust to the control variables, casting further doubt on the suitability of adult survival rate as a transmission channel for ancestral geographic conditions. Columns 5 and 8 deal with reverse causality and provide IV estimates. The instrument is ancestry adjusted land suitability. The instrument is clearly relevant. However, it is not possible to control for unadjusted land suitability in the extended specification. Heteroskedasticity-robust standard errors are reported in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Appendix C Data Definitions and Sources

Table 7: Descriptive Statistics.

	Obs	Mean	Std. Dev.	Min	Max
log population density in 1500 CE	184	.883	1.424	-3.817	4.135
log urbanization rate in 1500 CE	84	1.869	.817	0	3.367
log income per capita in 2000 CE	187	8.521	1.177	5.884	10.783
log urbanization rate in 2000 CE	205	3.87	.545	2.11	4.605
log body mass in 2005 CE	176	4.177	.112	3.904	4.47
log adult survival rate in 2000 CE	195	-.302	.196	-1.324	-.091
log land suitability	154	-1.476	1.362	-5.857	-.041
log land suitability (ancestry adjusted)	151	-1.25	.985	-5.857	-.21
log absolute latitude	205	2.916	.956	0	4.277
log Neolithic transition timing	164	8.313	.642	5.892	9.259
Mean distance to nearest waterway	160	.342	.471	.008	2.386
Percentage of pop. at risk of malaria	164	.307	.421	0	1
Social infrastructure	125	.47	.252	.113	1
Years of schooling	134	4.862	2.813	.409	10.862

Population density in 1500 CE The data on population density in 1500 CE is taken from Ashraf and Galor (2013). Population density (in persons per square km) 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*.

Urbanization rate in 1500 CE The percentage of a country's total population residing in urban areas (each with a city population of at least 5,000), as reported by Acemoglu, Johnson, and Robinson (2005).

Income per capita in 2000 CE The data on income per capita in 2000 CE is taken from Ashraf and Galor (2013). It reflects real GDP per capita, in constant 2000 international dollars, as reported by the *Penn World Table*, version 6.2.

Urbanization rate in 2000 CE The data on urbanization rate in 2000 CE is taken from the World Bank's *World Development Indicators*.

Body mass in 2005 CE The cross-country data on average body mass is from Walpole et al. (2012).

Adult survival rate in 2000 CE The adult survival rate in 2000 CE (asr) reflects the probability of a 15-year-old to survive to the age of 60. It is calculated from the adult mortality rate in 2000 CE (amr) as reported by the World Bank's *World Development Indicators*. The calculation is done as follows: asr = 1 − amr/1000.

Land suitability for agriculture The data on land suitability for agriculture is taken from Ashraf and Galor (2013). It reflects 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). Michalopoulos (2012) aggregates the index to the country level by averaging land suitability across grid cells within a country.

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

Neolithic transition timing The number of years elapsed, until the year 2000 CE, since the majority of the population within a country's modern national borders began practicing sedentary agriculture as the primary mode of subsistence. This measure is reported by Putterman (2008).

Mean distance to nearest waterway The distance, in thousands of km, from a GIS grid cell to the nearest ice-free coastline or sea-navigable river, averaged across the grid cells of a country. This variable was originally constructed by Gallup, Sachs, and Mellinger (1999) and is part of Harvard University's CID Research Datasets on *General Measures of Geography*.

Percentage of the population at risk of contracting malaria The percentage of a country's population in 1994 CE residing in regions of high malaria risk, multiplied by the proportion of national cases involving the fatal species of the malaria pathogen *P. falcipraum* (as opposed to other largely nonfatal species). This variable was originally constructed by Gallup, Sachs, and Mellinger (1999) and is part of Harvard University's CID Research Datasets on *General Measures of Geography*.

Social infrastructure An index, calculated by Hall and Jones (1999), that quantifies the wedge between private and social returns to productive activities. This measure is computed as the average of two separate indices. The first is a government anti-diversion policy (GADP) index, based on data from the *International Country Risk Guide* that represents the average across five categories, each measured as the mean over the 1986–1995 period: (i) law and order, (ii) bureaucratic quality, (iii) curruption, (iv) risk of expropriation, and (v) government repudiation of contracts. The second is an index of openness, based on Sachs and Warner (1995) that represents the fraction of years in the time period 1950–1994 that the economy was open to trade with other countries.

Years of schooling The mean—over the 1960–2000 time period—of the 5-yearly reported figure on average years of schooling amongst the population aged 25 and over. The data is taken from Barro and Lee (2001).

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