Distance to the Pre-industrial Technological Frontier and Economic Development

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Abstract

This research explores the effects of the geographical distance to the pre-industrial technological frontier on economic development. It establishes theoretically and empirically that there exists a persistent non-monotonic effect of distance to the frontier on development. In particular, exploiting a novel measure of the travel time to the technological frontier and variations in its location during the pre-industrial era, it establishes a robust persistent U-shaped relation between the distance to the pre-industrial technological frontier and economic development. Moreover, it demonstrates that isolation from the frontier has had a positive cumulative effect on innovation and entrepreneurial activity levels, suggesting isolation may have fostered the emergence of a culture conducive to innovation, knowledge creation, and entrepreneurship.

Key Words: Comparative Development, Geographical Isolation, Culture and Technology, Innovation, Technological Diffusion and Imitation, Patenting Activity, Entrepreneurship
JEL classification: E02, F15, F43, N10, N70, O11, O14, O31, O33, Z10

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1 Introduction

Identifying the ultimate sources of economic development and the distribution of incomes across the world is one of the oldest and most fundamental questions faced by economists and other social scientists. The literature on the subject has focused on deep determinants such as bio-geography, institutions, and culture (Acemoglu et al., 2005; Andersen, Bentzen, Dalgaard and Sharp, 2016; Diamond, 1997; Galor, 2005; Guiso et al., 2009). Among these determinants, geographical distance to the technological frontier, i.e., the most technologically advanced region in the world, has long been considered a fundamental source of economic development and inequality among countries (Smith, 1776). In particular, conventional economic wisdom maintains that larger geographical distances to the technological frontier generate technological backwardness and hinder economic growth. While the effects of the distance to the contemporary technological frontier have been previously studied (Giuliano et al., 2006; Guiso et al., 2009; Spolaore and Wacziarg, 2009), the role of isolation from the pre-industrial technological frontier has been mostly overlooked.

This research explores the effects of the geographical distance to the pre-industrial technological frontier on economic development. It proposes that during the pre-industrial era, while remoteness from the frontier diminished imitation, it fostered the emergence of a culture conducive to innovation, knowledge creation and entrepreneurship, which may have persisted into the modern era. In line with this prediction, the analysis establishes both theoretically and empirically that there exists a persistent non-monotonic effect of distance to the frontier on economic development. In particular, exploiting a novel measure of the travel time to the technological frontier and variations in its location during the pre-industrial era, it establishes a robust persistent U-shaped relation between the distance to the pre-industrial technological frontier and economic development. Moreover, it demonstrates that isolation from the pre-industrial technological frontier has had a positive cumulative effect on innovation and entrepreneurial activity levels, suggesting isolation may indeed have encouraged the emergence of a culture conducive to innovation and entrepreneurship.

The proposed theory suggests that variations in the distance to the technological frontier generated differences in incentives for technological imitation, adaptation and innovation. In particular, since during the pre-industrial era, the usefulness and transferability of technologies decreased with the distance from the technological frontier, distant societies benefitted less from imitation and had to tinker and toil more in order to adapt copied technologies to their own environment. Additionally, geographically distant societies also tended to be culturally different from the frontier, which may have facilitated the application of copied technologies to uses not discovered or intended by the original innovators. Finally, for some societies the process of technological diffusion from the frontier may have been too slow or costly, which may have promoted the generation of native innovations. Thus, these forces diminished the usefulness and availability of foreign technology and increased the incentives for native innovation that distant societies faced. While all societies might have been imitating, adapting and innovating, the degree to which each activity was pursued was affected by their geographical location with respect to the frontier. As successive generations faced similar incentives, the cumulative effect of these differences were conducive to the emergence of variations in innovative and entrepreneurial culture.

The proposed theory generates several testable predictions regarding the effect of the distance to the pre-industrial technological frontier on economic development. The theory suggests that during the pre-industrial era, societies located at intermediate distances from the technological frontier, at the Least Desirable Distances (LDD), were less developed than more isolated societies, located at the More Desirable Distances (MDD). Thus, the theory predicts the existence of a non-monotonic relation between the distance to the frontier and economic development. In particular, it proposes that the LDD is positive and smaller than the maximum distance to frontier. Additionally, the theory predicts that countries that are located farther than the LDD, at the MDD, should be more developed, i.e. the non-monotonicity should be U-shaped. Moreover, the theory implies that the more time an economy spent at the MDD, the more developed it should be. Thus, if the location of the frontier changes, the cumulative time spent at the MDD (across technological frontiers), should be positively associated with development. Furthermore, the theory suggests that isolated economies, which become even more isolated after the change in the location of a frontier should get a boost in their economic performance.

The empirical analysis exploits exogenous sources of variation in the distance to the pre-industrial technological frontier to analyze the effects of the distance to the pre-industrial technological frontier on economic development. Consistent with the predictions of the theory, the empirical analysis establishes the existence of a robust U-shaped relation between the distance to the pre-industrial technological frontier and economic development both in the pre-industrial and modern eras. Moreover, it establishes the positive persistent cumulative effect of isolation from the pre-industrial technological frontier on economic development, as well as on contemporary domestic patenting and entrepreneurial activity.

The analysis establishes these results in various layers: (i) a cross-country analysis of the relation between the distance to the pre-industrial technological frontier and technological sophistication in 1500CE; (ii) a cross-country panel data analysis of the relation between the distance to the pre-industrial technological frontier and population density in the pre-industrial era; (iii) a cross-country panel data analysis of the cumulative effect of isolation from the pre-industrial technological frontier on population density in the pre-industrial era; (iv) a cross-country analysis of the relation between the distance to the last pre-industrial technological frontier and contemporary income per capita; (v) a cross-country analysis of the cumulative effect of isolation from the pre-industrial technological frontier on contemporary income per capita; and (vi) a cross-country analysis of the cumulative effect of isolation from the pre-industrial technological frontier on contemporary patenting and entrepreneurial activities.

The research introduces a novel measure of pre-industrial geographic distance to the pre-industrial technological frontier. This measure estimates the potential minimum travel time to the pre-industrial technological frontier accounting for human biological constraints, as well as geographical and technological factors that determined travel times before the widespread use of steam power. This strategy overcomes the potential mismeasurement of distances generated by using geodesic distances (Özak, 2010), for a period when travel times were the most important determinant of transportation costs (O'Rourke and Williamson, 2001). Additionally, it removes the potential concern that travel times to the frontier reflect a country's stage of development, mitigating further possible endogeneity concerns.

The research validates these measures by (i) analyzing their association to actual historical travel times; (ii) examining their explanatory power for the location of historical trade routes in the Old World; and (iii) analyzing their association to genetic and cultural distances.

The analysis accounts for a wide range of potentially confounding geographical factors that might have directly and independently affected economic development (e.g., elevation, area, malaria burden, share of area in tropical, subtropical or temperate zones, caloric suitability, latitude, island and landlocked regions). Moreover, unobserved geographical, cultural, and historical characteristics at the continental, regional or country level may have codetermined a country's level of economic development. Hence, the analysis accounts for these unobserved characteristics by accounting for continental, historical region, and when possible country and period fixed effects. Furthermore, it accounts for other time-varying pre-industrial country characteristics (e.g. change in caloric suitability due to the Columbian Exchange, colonial status, lagged technology levels, the onset of the Neolithic Revolution). Additionally, the analysis accounts for period-region fixed effects and thus for unobserved time-varying regional factors.

The analysis exploits variations in the location of the pre-industrial technological frontier in order to: (i) mitigate potential concerns relating to omitted country characteristics; (ii) analyze the effects of increases in isolation on isolated economies; and (iii) identify the persistent and cumulative effect of isolation from the frontier. First, changes in the location of the pre-industrial technological frontier permit the analysis to account for omitted time-invariant determinants of economic development. Thus, allowing the analysis to differentiate the effect of distance from the frontier from other unchanging characteristics of a country. Moreover, changes in the distance to the pre-industrial technological frontier across different time periods are potentially less endogenous when exploring their association with differences in development, especially after accounting for period, region and period-region fixed effects. Second, changes in the location of the pre-industrial technological frontier permit the analysis to explore the effects of increasing isolation on isolated economies. Thus, allowing for alternative tests of the theory. Third, changes in the location of the pre-industrial technological frontier generated variations in the time countries spent at the More Desirable Distances (MDD). These variations permit the identification of the cumulative and persistent effect of isolation from the frontier on economic development.

The first part of the empirical analysis examines the effect of distance to the pre-industrial technological frontier on the level of technological sophistication across countries in 1500CE in the Old World. The analysis establishes a robust U-shaped association between the distance to the pre-industrial technological frontier and a country's average level of technological sophistication in 1500CE. The findings are robust to the inclusion of a wide range of confounding geographical characteristics, the years elapsed since the country transitioned to agriculture, and continental fixed-effects. In particular, the estimates suggest that the Least Desirable Distances (LDD) are located at 6.4 weeks of travel from the pre-industrial frontier.

This analysis is robust to accounting for the distance to other technologically advanced regions or for the ancestral origin of populations. Similarly, the results remain qualitatively unchanged when analyzing a country's level of technological sophistication in specific sectors. In particular, the technological sophistication in agriculture, communication, transport, military or industry have similar U-shaped relations with the distance to the pre-industrial technological frontier. Additionally, the analysis suggests that the U-shape is not capturing other forces behind comparative development. In particular, accounting for technological backwardness, european colonization, trade, local technological frontiers or population diversity does not alter the qualitative results.

The second part of the empirical analysis explores the relation between the distance to the pre-industrial technological frontier and population density in the years 1, 1000, 1500, and 1800CE. In particular, by exploiting variations in the location of the technological frontier in the Old World, the analysis accounts for country fixed effects, and thus for the potential confounding effect of invariant country-specific characteristics. Moreover, the analysis accounts for period and region-period fixed effects, as well as time varying pre-industrial country characteristics that may be associated with the change in the distance to the technological frontier. Specifically, the analysis accounts for colonial status, the change in caloric suitability, and the time since the Neolithic Revolution. In line with the theory, the analysis establishes the existence of a robust U-shaped relation between distance to the technological frontier and population density pre-1800CE.

Moreover, the analysis explores the relation between changes in the distance to the pre-industrial technological frontier and its square, and changes in population density pre-1800CE, accounting for region, period, and region-period fixed effects, as well as changes in the number of years since a country transitioned to agriculture, caloric suitability, colonial status, and distances to local technological frontiers. The analysis further demonstrates the existence of a U-shaped relation between distance to the pre-industrial technological and population density. This result is robust to analyzing the growth of population density across various periods and frontiers, suggesting the results are not driven by unobserved characteristics of the country or the frontier in a specific period.

The third part of the empirical analysis explores additional predictions of the theory. In particular, it explores the effect of past levels of isolation from the pre-industrial technological frontier and its changes on changes in population density. In particular, it establishes that countries that were isolated from the frontier in one era tended to have larger increases in population density in the following era. Moreover, isolated countries that became even more isolated tended to grow even more. The findings suggest that for each additional week of travel to the frontier population density increased by 4%, while each additional each week of travel to a new frontier increased population density by an additional 1%. These results are robust to accounting for period, region, and period-region fixed effects, as well as past levels and changes of other time-varying country characteristics.

Additionally, the analysis explores the persistent cumulative effect of isolation from the pre-industrial technological frontier on pre-industrial economic development. Specifically, the analysis explores association between the number of years a country spent at the Most Desirable Distances (MDD), i.e. isolated from the pre-industrial technological frontier, and population density. It establishes that each additional century of time spent at the MDD is associated with a 3% increase in population density, after accounting for country, period, and period-region fixed effects, and time-varying pre-industrial country characteristics like colonial status and caloric suitability. The results remain qualitatively similar if instead of the time spent at the MDD one accounts for the number of frontiers for which a country was at the MDD. In particular, the results suggest that for each additional pre-industrial frontier that a country was at the MDD, its population density increased by 18%. These results are statistically and economically significant.

The fourth stage of the empirical analysis explores the relation between the distance to the last pre-industrial technological frontier and contemporary economic development. In particular, it establishes that there exists a U-shaped relation between the distance to the last pre-industrial technological frontier and contemporary income per capita levels, which is statistically and economically significant and suggests an LDD of 6 weeks of travel. Moreover, this result is is robust to the inclusion of a wide range of confounding geographical characteristics, the years elapsed since the country transitioned to agriculture, continental fixed-effects, history of European colonization, pre-industrial distances to China and East Africa and the distance to the contemporary technological frontier.

Finally, the empirical analysis explores the persistent cumulative effect of isolation from the pre-industrial technological frontier on contemporary economic development. In particular, it establishes the positive, statistically and economically significant association between the time spent at the MDD and income per capita, domestic number of patents per capita assigned to residents, and number of new firms per 1,000 people. The analysis accounts for regional fixed effects, a wide range of confounding geographical characteristics, the years elapsed since the country transitioned to agriculture, history of colonization, religious composition, institutional quality, identity of the main colonizer, European ancestry, legal origins, and distance to the contemporary technological frontier. The estimates suggest that each additional century spent at the MDD is associated with a 7% higher GDP per capita, 18% more patents per capita, and 19% more new firms per 1,000 people.

This research is the first attempt to analyze the effects of the geographical distance from the pre-industrial technological frontier on economic development. In particular, it suggests that the distance from the pre-industrial technological frontier may be a deep determinant of innovative and entrepreneurial activities. Although technological progress may have diminished the role of geographical distance in the contemporary period, the theory suggests that cultural and institutional differences from the contemporary technological frontier may be similarly conducive to innovation and entrepreneurship in the modern era. Thus, the research sheds additional light on the geographical origins of comparative development (e.g., Ashraf and Galor, 2013; Diamond, 1997), the changing effects of geography in the course of economic development (Andersen, Dalgaard and Selaya, 2016), and the effects of cultural and institutional differences on economic development (Giuliano et al., 2006).

The rest of the paper is structured as follows: section 2 presents anecdotal evidence supporting the proposed theory. Section 3 rationalizes the theory using an overlapping generations model and establishes the existence of a U-shaped relation between distance and economic development. Section 4 presents the data and the empirical strategy. Section 5 presents the empirical analysis for the pre-industrial era. Section 6 analyzes the persistent effect of isolation from the frontier on contemporary economic development. Section 7 concludes. All additional supporting material is presented in the Appendix.

2 Anecdotal Evidence

This section presents anecdotal evidence for the pre-industrial era that shows (i) the limited role trade could play in technological diffusion before 1850, (ii) the importance of human mobility in technological diffusion, (iii) the difficulty of technological diffusion across space, (iv) the intertemporal links in the imitation and creation of technology, and (v) examples supporting the theory.

2.1 Importance of Trade

Although trade plays a crucial role in the process of economic development in the modern era, historically its role seems to be more restricted, as high transportation costs during the pre-industrial era limited the amount and type of trade being conducted. For example, Maddison (1995) estimates that by 1820 world trade represented only 1% of world GDP. Clearly, trade in technological goods represented an even smaller share, especially since technologies embodied in goods were difficult to transport, as in the case of heavy machinery (e.g. clocks, steam engines, furnaces). Case in point, during its first 25 years of operation, the Boulton and Watt Co. constructed less than one additional steam engine per year in order to fulfill international orders, which represented 4% of their total sales during the period 1775-1800 (Tann, 1978). These low trade volumes in the pre-industrial era suggest that the indirect gains from trade via learning-by-doing or the direct gains from trade in technology were small before 1850.

Furthermore, many technologies could not be embodied in tradable goods (e.g. canal systems, water mills, three-field rotation system, husbandry rules), or required access to tacit knowledge in order to produce them (Epstein, 2006; Jones, 2009; Robinson, 1974). For example, Boulton and Watt had recurring problems securing the services of engineers or skilled mechanics who could travel and install their steam engines overseas (Tann, 1978). To these impediments one must add any kind of state intervention, which forbade the trade in technologies considered fundamental to national security or for the comparative advantage of the nation (Jeremy, 1977). British laws prohibiting the export of machinery and travel of skilled technicians during the 18th and 19th centuries, as well as the current embargo on the trade in nuclear weapons, technology, and knowledge, are examples of these types of measures.[1]

2.2 Transferability across Space and Time

Under such circumstances, most technologies had to be invented *in situ* or imported, not directly through the goods that embodied them, but indirectly through the people who knew the technology. For instance, Epstein (2006) after establishing that neither texts nor patents played a major role in technological diffusion in premodern times, argues that "[i]n practice, technological transfer could only be successfully achieved through human mobility". Mokyr (1990) highlights the importance of master-and-apprentice and father-and-son dynasties in the diffusion of technology, especially in the machine and engineering sector:

[1] Furthermore, during the pre-industrial era most trade was based on goods that could not be produced locally due to agro-climatic, environmental or geological constraints.

> "From Nuremberg and Augsburg the art of instrumentmaking spread to Louvain in the southern Netherlands and from there to London. The London instrumentmaker Humfray Cole was apprenticed to the Liége craftsman Thomas Gemini. [...] Gemini himself had studied in the south of Germany. [...] Another German instrumentmaker, Nicholas Kratzer, lived in England for many years." (Mokyr, 1990, p. 71,fn. 9)

Similarly, Justus von Liebig, the German chemist whose innovations and book on organic chemistry gave birth to the fertilizer industry, studied in Paris under Joseph Louis Gay-Lussac. In turn von Liebig was the professor of August von Hoffman, who moved temporarily to London in order to head the creation of the Royal College of Chemistry and taught there for about twenty years before returning to Germany, teaching the first generation of professionally trained English chemists. Another example is Leonardo Pisano, more commonly known as Fibonacci, who learned mathematics from the Arabs as a boy during his father's trade missions in North Africa, and later introduced Europe to the use of algebra.[2]

Besides the formal networks of scientists and apprentices, the dispersion of technologies was based also on the work of businessmen, merchants, diplomats, and spies, who many times were sent or travelled by their own initiative to the technological frontier in order to gain access to the most advanced products, ideas, processes, and the skilled workers who knew them (Epstein, 2006; Jones, 2009; Mokyr, 1990; Robinson, 1958, 1974). For example, Robinson (1958) notes that

> "Eighteenth-century industry was conducted in an atmosphere of secrecy. The newspapers of Manchester, Birmingham and other industrial centres, during the seventeen-seventies and 'eighties, contain frequent references to foreign spies who were snooping in factories and warehouses to learn the trade secrets of the area and to entice away the workmen who knew them. Committees were formed to protect these trade secrets by warning the locality about foreigners and by enforcing the various acts against the exportation of tools and the enticing of artisans abroad, so that every manufacturer became spy-conscious and perhaps more deliberately secretive than he already was". (Robinson, 1958, p. 3)

Similarly, in 1789, after a notorious spy was caught exporting drawings, plans and objects of industrial interest, the Birmingham industrialist, Samuel Garbett, complained to Matthew Boulton, Watt's partner, that

> "[o]ur country [UK] is certainly considered as a School of the Arts and that great improvements in Manufacture are originating here. And it seems We are a common plunder for all who will take the trouble of coming here. And our Magazine of Secrets at the Patent Office is exposed to all Foreigners" (Robinson, 1974, p. 91).

These examples highlight the two central dimensions through which technology was accumulated, which are central to the mechanism highlighted in this paper. First, technology moved across space, from advanced to less advanced regions, by means of the people who travelled to the first, learning and copying the technology there, and bringing it back to the latter. Second, across time, between generations of innovators, fathers and sons, masters and apprentices.

[2]This last example exemplifies how trade's effect on the diffusion of innovation could be related more to the transmission of information than to the transmission of goods. Pacey (1990, p. vii) holds a similar view and offers as an example the Indian textile industry, "which had a profound influence in Britain during the Industrial Revolution even though there were few 'transfers' of technology. Just the knowledge that Indians could spin fine cotton yarns, weave delicate fabrics, and dye them with bright and fast colours stimulated British inventors to devise new ways of achieving these same results". Another role trade can play is in creating incentives to adopt certain technologies or to invest in certain types of capital which are conducive to economic development.

Clearly the movement along the first dimension is easier the closer the two regions are geographically or culturally. For example, it was easier for Francis Cabott Lowell to visit the textile mills in Lancashire in 1810 and appropriate the new techniques, which would revolutionize manufacturing in the U.S., than it would have been to do so for the contemporaries of Willem Van Ruysbroeck in 13th-century Mongolia, Marco Polo in 13th-century China, Rabban bar Sauma in 13th-century Europe or Matteo Ricci in 16th-century China.[3]

Additionally, if the technology is not generally applicable across space, or requires modification in order to be useful in different locations and environments, the diffusion across space will be facilitated by the proximity to the frontier, requiring less tinkering and toiling in order to adapt the technology to its new location. For instance, the diffusion of the "new husbandry" in the Middle Ages was slowed by these differences, in part because "[d]ifferent crops have different requirements, and the same crop will use different inputs and technology depending on elevation, rainfall, soil type, and so on" (Mokyr, 1990, p. 32).

Similarly, agricultural techniques, windmills, waterwheels, among other machines, required adaptation in order to work in different locations.[4] Jones (2009) mentions the impressions made by the visit of a skilled Welsh ironmaster to Tarnowitz in 1786 on the Prussian Commissioner for Affairs of War, Taxation, Mining and Factories, who concluded that "some ideas were made active in Silesia, old ones improved, some implemented in part, insofar as the differing location of German industry as compared to that of England permits". Similarly, the diffusion of the Bessemer and Siemens-Martin processes of steel production encountered many problems given that they could only be used with phosphorous-free iron ores, which were not abundant (Mokyr, 1990). Also, Epstein (2006) mentions the problems of applying the structural theory for Gothic churches across regions in Europe, as well as other techniques, noting the difficulty of transferring "recipes", adding that "recipes, as opposed to machines, were hard to transfer, because their result depended critically on a combination of material ingredients, and atmospheric and other conditions that could not be easily controlled for, and thus, easily reproduced" (p.23).

2.3 The Mechanism and Examples

Thus, distance to the technological frontier decreases the diffusion of technology across space by making it more difficult for people to move between their home location and the frontier, and by limiting the usefulness of the acquired knowledge and technology. At the same time, this lower usefulness

[3]Although the motives behind their voyages varied, and so did the circumstances with which they were received, it is clear that Lowell's endeavor was facilitated by him sharing a common language, customs, and religion with his hosts. On the other hand, the difficulties, the hostility, and general lack of trust with which these emissaries and ambassadors were received, gives an idea of how difficult the situation might have been for foreigners lacking their credentials. Van Ruybroeck, also known as Rubruquis, tells of how, in the beginning of his voyage, his guide distrusted him, and how at their arrival at Kûblâi Khân's court, his guide was well received and offered proper accommodations, while the friar and his companions were given a small hut, and they "were called and closely questioned as to the business which had brought" them there [van Ruysbroek 1900, p. 166-167; Polo 1858, p. 66-7]. Marco Polo notes that the people of Maabar distrust sailors [Polo 1858, p. 263; Beazley 1906, p. 138]. Similarly, Rabban bar Sauma, a Christian envoy of the Mongols, was initially treated as a heretic upon his arrival to Rome (Budge, 1928, pp.56-63).

[4]Bazzi et al. (2016) present evidence that the problem of transferability across space in the agricultural sector is still prevalent in the modern period in developing countries.

demands additional innovative work in order to adapt the technologies to local conditions (Epstein, 2006; Immelt et al., 2009; Mokyr, 1990). So, a greater distance to the frontier decreases the offer of directly applicable technologies, but simultaneously increases the innovative effort of the distant receiving society. Additionally, a larger distance to the frontier, which increases the cultural distance to the frontier, expands the possible new uses of any given technology (Ehret, 2002), resulting in more innovation in distant locations.

Moreover, for far enough locations it might be more economical to create the technology at those locations than to go through the process of imitation and adaptation. Thus, one can expect to observe independent innovation in multiple geographical locations, contrary to the diffusionist view (Blaut, 1987, 2012). In particular, this process can potentially increase the innovativeness of distant economies, allowing them to accumulate skills and technology across time. Since the transmission of skills and technologies within a location is easier than across space, and also more efficient and effective the more experienced the master or elder is (Epstein, 2006), the increased demand for innovative effort in distant locations may be accompanied by an improved intergenerational transmission of skills and technology.

All this is conducive to the independent and persistent creation of technologies and innovativeness in locations distant from the technological frontier. Case in point, the Old and New Worlds were mostly incommunicated between the last ice age and the modern discovery voyages, but in both landmasses people independently discovered agriculture and domestication (Diamond, 1997), the compass (Carlson, 1975), and the number zero (Kaplan, 2000), among others. Similarly, research on African medicine has found that kingdoms, like the Bunyoro-Kitara in Uganda, which were isolated from the rest of the world until around the 18$^{\text{th}}$ century, had discovered the use of the Caesarean section, variolation, and inoculation, among other medical technologies (Davies, 1959; Dunn, 1999; Felkin, 1884). Moreover, distant cultures like the kingdoms of Mapungubwe and Great Zimbabwe were some of the most complex societies in Africa (Huffman, 2009). Additionally, ethno-mathematicians have shown that some pre-colonial African and Amerindian cultures had advanced (native) mathematical knowledge in areas like congruences, boolean algebra, fractals, topology, graph theory, etc. (Ascher, 1991, 2002; Bangura and Bangura, 2011; Selin, 2003; Zaslavsky, 1999).[5] Similarly, many ancient Chinese mathematical innovations and results, like solutions to linear, quadratic and cubic equations, Horner's method and Descartes' rule of signs, were much later rediscovered in Europe (Joseph, 2011; Needham and Wang, 2008; Smoryński, 2008).

Further evidence can be found in the improvement of non-native technologies. For example, around the year 1CE African iron-smelting, which had been introduced from the eastern Mediterranean around 500BCE, was technologically superior to European, Middle Eastern, and South Asian smelting techniques (Austen and Headrick, 1983).[6] Analogously, the windmill, which had been invented in central Asia and imported to Europe by its contact with the technologically advanced Islamic world, was

[5]It is interesting to note that some of this knowledge is being currently used to understand modern mathematical problems. For example, the mathematical ideas inherent in the kola designs of the Tamil Nadu in southern India have influenced the development of modern computer science theory (Katz, 2003). See also Selin (1997) and Joseph (2011).

[6]There still exists a debate among archeologists about the possibility of an independent discovery of iron smelting in Sub-saharan Africa (Ehret, 2002), which would provide even stronger support to this paper's theory.

developed and attained its state of perfection in the Netherlands (Mokyr, 1990). These last two examples defy conventional wisdom since it is in locations far away from the technological frontier and from the source of original innovation where these technologies attained their highest expression. Similarly, Great Britain's location made it one of the most distant places relative to the technological frontiers in the Old World until about the 14th century, when the "English had long been known as the perfecters of other people's ideas [...]", to which "[a] Swiss calico painter remarked in 1766 of the English: 'they cannot boast of many inventions, but only of having perfected the inventions of others [...]" (Mokyr 1990, p. 240). Finally, Nicholas (2011), Choi (2011), and Hashino (2012) have recently shown that local innovation played a mayor role in Japan's industrialization process during the 20$^{\text{th}}$ century.

3 A Model of Technology Imitation and Creation

This section introduces a model that highlights the main components of the theory. In particular, using fairly standard conditions it establishes that in a world in which economies can innovate and imitate from at least one technological frontier, there exists a U-shaped relation between the distance to the technological frontiers and economic development.[7]

3.1 Setup

The world consists of a set of economies $\mathcal{E} \subseteq \mathbb{R}^n$ and n technological leaders. Assume that all economies in $\mathcal{E}$ are identical except for their geographical distance $\mathbf{d} = (d_1, \ldots, d_n)$ from these leaders, and thus identify each economy with this distance vector $\mathbf{d}$. Each economy $\mathbf{d} \in \mathcal{E}$, is populated by overlapping generations of two-period lived agents. Population is constant and is normalized so that its size is 1. Each agent is endowed with one unit of time when young and one unit of time when old. For simplicity, assume that young agents can only engage in activities of imitation or creation of technology, and do not engage in consumption. On the other hand, old agents can only engage in production and consumption activities, where their production possibilities are determined by their own technology, which is generated by their decisions when young and the technology left by their parents.[8]

Individuals born in period $t-1$ inherit a level of technology A_{t-1} from their parents. They increase their stock of technology, which will be available for production in period t, using two types of intermediate inputs. The first intermediate input, $\tilde{I}$, is produced by imitation from the technological frontiers, while the second, $\tilde{R}$, is produced through independent creation. Productivity in each activity depends not only on the amount of labor the individual inputs, but also on the amount of labor their parents allocated when they were young. This captures the idea of intertemporal spillovers in imitation and creation of technologies, where the productivity of the current generation depends on

[7] Appendix C presents all the proofs and intermediate steps.

[8] These assumptions are made for convenience and in order to simplify the analysis. Changing them would not alter the main qualitative results since the underlying mechanism does not depend on them. For example, one could allow young agents to produce and consume, or old agents to engage in additional research activities, without affecting the main results. Additionally, allowing for endogenous population growth in a Malthusian framework would generate similar results.

the allocations of previous generations.

In particular, let l_t denote the amount of labor an individual born in period $t-1$ devotes to independent creation. She produces a quantity $\tilde{R}_t = a l_{t-1}^{\alpha'} l_t^{\alpha} A_{t-1}$ of independent knowledge, where $a > 0$, $\alpha', \alpha \in (0,1)$. She devotes the rest of her time, $(1-l_t)$, to creating intermediate knowledge through imitation from the frontiers. Let i_{jt} denote the amount of time she devotes to imitating from frontier j, so that, $\sum_j i_{jt} = 1 - l_t$. Additionally, assume that the intermediate knowledge from each frontier is generated using similar technologies, namely

$$\tilde{I}_{jt} = b(d_j) i_{jt-1}^{\beta'} i_{jt}^{\beta} A_{t-1}, \qquad j = 1, \ldots, n \tag{1}$$

where $\beta', \beta \in (0,1)$, and the function $b : \mathbb{R}_+ \to \mathbb{R}_{++}$ is continuous, decreasing, twice differentiable, and captures the negative effect of distance on the productivity of imitation.

She combines the intermediate knowledge she gained from the frontiers through a constant elasticity of substitution production function to produce her aggregate knowledge from imitation

$$\tilde{I}_t = \left(\sum_{j=1}^{n} \lambda_{2j} \tilde{I}_{jt}^{\rho_2} \right)^{\frac{1}{\rho_2}} \tag{2}$$

where $\sum_{j=1}^{n} \lambda_{2j} = 1$, $\lambda_{2j} \in [0,1]$, $0 \leq \rho_2 \equiv \frac{\eta_2 - 1}{\eta_2} \leq 1$, and $\eta_2 \geq 1$ is the constant elasticity of substitution of knowledge between any two frontiers. The new knowledge she gains from imitation and independent creation are aggregated through another constant elasticity of substitution production function to produce total new knowledge, which is added to her existing stock of technology. Letting $R_t = \tilde{R}_t / A_{t-1}$ and $I_t = \tilde{I}_t / A_{t-1}$, the growth rate of technology can be written as

$$g_t = \frac{A_t - A_{t-1}}{A_{t-1}} = \left[\lambda_1 R_t^{\rho_1} + (1-\lambda_1) I_t^{\rho_1} \right]^{\frac{1}{\rho_1}}, \tag{3}$$

where $\lambda_1 \in (0,1)$, $0 \leq \rho_1 \equiv \frac{\eta_1 - 1}{\eta_1} \leq 1$, and $\eta_1 \geq 1$ is the constant elasticity of substitution between imitation and creation.

From the agent's point of view, the only difference between frontiers is their distance, so, in order to maximize her lifetime expected utility, her time allocations when young, l_t and $\{i_{jt}\}_{j=1}^{n}$, have to equalize the marginal product of labor across sectors. Importantly, increasing the distance d_j lowers the marginal product of labor in imitation from frontier j, without affecting the marginal productivity of labor in any other activity. Thus, increases in d_j generate a reallocation from imitation from j to all other activities. This reallocation process lies at the heart of the mechanism highlighted in this paper.

The steady state growth rate of economy $\mathbf{d}$ generated by the agent's optimal decisions is given by[9]

$$g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = R^*(\mathbf{d}, \lambda_{\mathbf{2}}) \left[\lambda_1 + (1-\lambda_1) \left(\frac{I}{R}(\mathbf{d}, \lambda_{\mathbf{2}}) \right)^{\rho_1} \right]^{\frac{1}{\rho_1}}, \tag{4}$$

[9] See Appendix C for the proof.

where $\lambda_{\mathbf{2}} = (\lambda_{2j})_{j=1}^n$, and $R^*(\mathbf{d}, \lambda_{\mathbf{2}})$ and $I/R(\mathbf{d}, \lambda_{\mathbf{2}})$ are the optimal levels of imitation and of the ratio of imitation to creation. Furthermore, the first factor is increasing and the second one is decreasing in all the components of $\mathbf{d}$. This implies, in particular, that increasing the distance to frontier j, d_j, increases the amount of creation while lowering the aggregate amount of imitation. As shown below, this trade-off, which is caused by agent's desire to equalize the marginal product of labor, can generate under some conditions a U-shape in the level of development.

3.2 Steady-State Growth in a World with a Unique Frontier

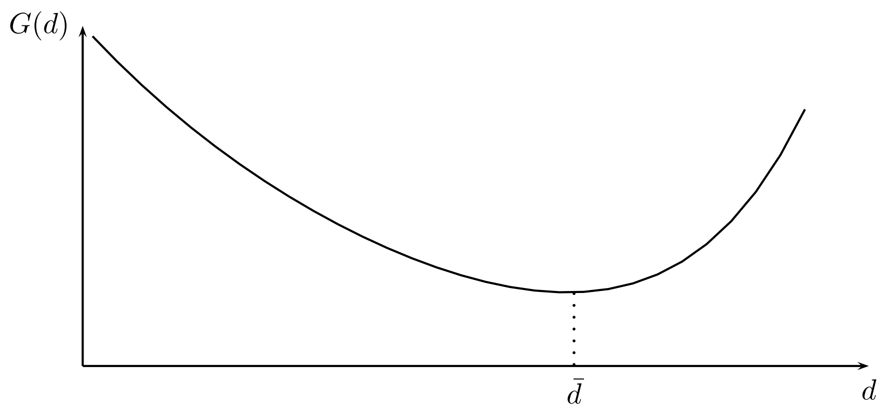
Clearly, economies that are equidistant from all frontiers, effectively only have one frontier. Thus, agents in these economies behave as if they lived in a world with a unique frontier. For these economies, $\mathbf{d} = d \cdot \mathbf{e}$ and $g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = G(d)$, where $\mathbf{e}$ is the n dimensional vector of ones, $d \in \mathbb{R}_+$, and $G(d)$ is the steady state growth rate for an economy at distance d in a world with a unique frontier. If

$$(\alpha' + \alpha)\rho_1 < 1, \qquad (\beta' + \beta)\rho_1 < 1, \tag{ES}$$

$$\frac{\rho_1 \beta \left[\frac{\alpha'}{\alpha} - \frac{\beta'}{\beta}\right] x}{\big(1 - (\alpha' + \alpha)\rho_1\big)(1 - x) + \big(1 - (\beta' + \beta)\rho_1\big)x} = 1 \text{ for some } x \in (0, 1). \tag{U}$$

then in a world with a unique frontier, $G(d)$ is U-shaped with the lowest growth rate attained at the *Least Desirable Distance* $\bar{d} > 0$.[10] Figure 1 depicts the relation between distance d and steady state growth rates in a world with a unique frontier.

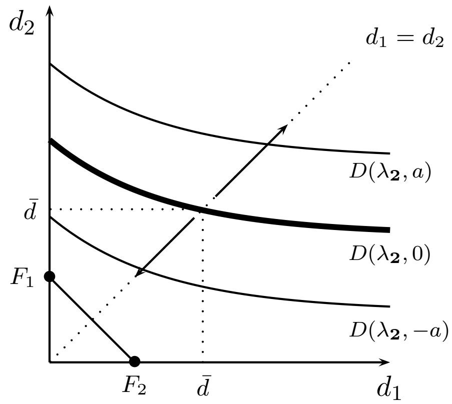
Figure 1: The steady state relationship between distance and economic growth in a world with one frontier.



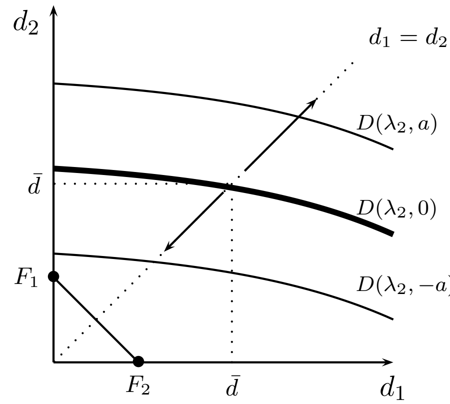
Condition (ES) ensures that the marginal productivity of labor of young and old agents is "jointly" decreasing in the production of intermediate products. Condition (U) gives a measure of the strength of intertemporal spillovers across sectors, and imposes limits on the differences in labor productivities across them. Clearly, $\alpha'/\alpha > \beta'/\beta$ is a necessary condition for (U) to hold, which implies intertemporal spillovers are more important in creation than imitation.

[10] See Appendix D for the proof.

Figure 2: Isogrowth maps in a world with two frontiers.



(a) Convex $b(d)$



(b) Concave $b(d)$

These figure depict the isogrowth maps in a world with two frontiers. F_1 and F_2 denote the locations of frontiers 1 and 2, which are at a distance d_{12} from each other. Every point (d_1, d_2), which does not belong to the triangle generated by the frontiers and the origin, represents an economy located at a distance d_1 from frontier 1 and d_2 from frontier 2. Every isogrowth curve $D(\lambda_2, a)$ represents the set of economies that have the same growth rate. $D(\lambda_2, 0)$ is the set of economies that have the lowest growth rate. The arrows show the direction of increase in the growth rate.

3.3 Steady-State Growth in a World with a Many Frontiers

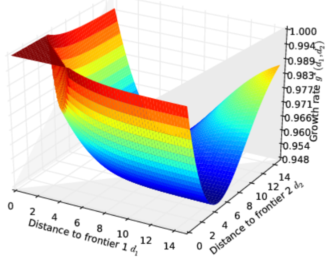
Since any $d \in \mathbb{R}_+$ can be written as $d = \bar{d}+z$, for some $z \in \mathbb{R}$, the previous result implies that in a world with n frontiers, the growth rate of equidistant economies is given by $g^*\Big((\bar{d}+z)\cdot \mathbf{e}, \lambda_{\mathbf{2}}\Big) = G(\bar{d}+z)$, so that the growth rate for these economies is also U-shaped. Also, since the set of economies $\mathcal{E}$ in the world can be partitioned by the z-isogrowth sets

$$D(\lambda_{\mathbf{2}}, z) = \left\{\mathbf{d} \in \mathcal{E} \mid g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = G(\bar{d}+z)\right\}, \tag{5}$$

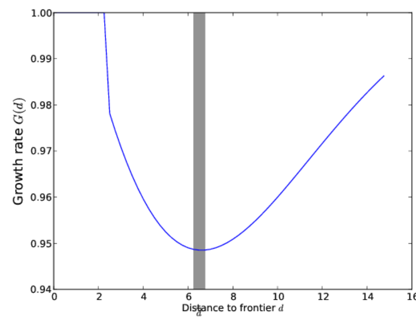
which is the set of economies that grow at rate $G(\bar{d}+z)$, a similar non-monotonicity holds for all other economies as well (see appendix C). These results imply that the steady state profile of growth rates looks like a valley with the economies belonging to $D(\lambda_{\mathbf{2}}, 0)$ at its bottom. Figure 2 depicts two general isogrowth maps in a world with two frontiers when (a) $b(d)$ is convex or (b) $b(d)$ is concave. Clearly, the shape and direction of the valley will depend on the functional forms and parametrization chosen. For example, for the CES functions above, figure 3 plots the $g(\mathbf{d}, \lambda_{\mathbf{2}})$ and $G(\bar{d}+z)$ functions for an artificial economy in which $b(d) = b_0\mathrm{e}^{-b_1 d}$. The distance $\bar{d}$ is the least desirable distance (LDD) from the technological frontiers and is located where the 45-degree line intersects $D(\lambda_{\mathbf{2}}, 0)$.

Notice that the non-monotonicity does not imply that being far from the frontiers *always* increases the growth rate. On the contrary, it only implies that there must exist economies which are farther from the frontiers and have higher growth rates than others which are closer to them. Furthermore, conventional wisdom can be seen as a special case of this theory in which either (i) $\bar{d} = \infty$, so that $D(\lambda_{\mathbf{2}}, z) = \emptyset$ for all $z \geq 0$, or (ii) the observable world is too small, so that $D(\lambda_{\mathbf{2}}, 0)$ is not observable. In either case, any empirical analysis would find a monotonic relation between distance and development.

Figure 3: Artificial world with two frontiers



(a) Steady state growth rates for all economies.



(b) Steady state growth rates for equidistant economies or a world with only one frontier. Least Desirable Distance $\bar{d}$ in gray.

3.4 Testable Predictions

The previous analysis suggests that if the theory proposed in this paper is valid, then for at least one frontier j the Least Desirable Distance, LDD_j, is positive, statistically significant, and smaller than the maximum distance to frontier j in the sample.[11] On the other hand, if conventional wisdom holds, then for all frontiers $j = 1, \ldots, n$, the estimated LDD_j lies outside the sample and is statistically insignificant, i.e. $LDD_j = \infty$.

These predictions and Monte Carlo simulations presented in appendix E suggest using the following empirical specification to explore the relation between economic development and the distance to the technological frontier during the pre-industrial era:

$$y_{it} = \beta_0 + \sum_{j=1}^{n} (\beta_{1j} d_{ijt} + \beta_{2j} d_{ijt}^2) + \gamma' x_{it} + \epsilon_{it} \tag{6}$$

where y_{it} is a measure of economic development in period t, d_{ijt} is the distance to the j-th pre-industrial technological frontier in period t, x_{it} are other covariates in period t, and ϵ_{it} is an error term. The proposed theory implies that for at least one frontier j $\beta_{1j} < 0$, $\beta_{2j} > 0$, and the implied Least Desirable Distance ($LDD_j = -0.5\beta_{1j}/\beta_{2j}$) is positive, statistically significant, and smaller than the maximum distance to frontier j in the sample.

Monte Carlo simulations (appendix E) suggest that this empirical specification over-rejects the proposed theory. In particular, even when the theory proposed in this paper is true, the estimation might not be able to capture this non-monotonic relation, generating over-rejection of the null hypoth-

[11]These conditions need not hold for all frontiers since frontiers can have asymmetric effects on development. In particular, it can be shown that variations in the parameters of the model, e.g. $\boldsymbol{\lambda_2}$ or ρ_2, can disrupt the symmetry of the model and cause estimates not to find a U-shaped effect on development of the distance from certain frontiers. For example, consider the case when $\lambda_{2j} \to 0$ for some j. Additionally, as established in appendix E, even in a symmetric world randomness and sample composition can cause asymmetries in the estimates. Reassuringly, simulations suggest that if the empirical analysis finds at least one frontier with an LDD estimate that satisfies this condition, then the non-monotonicity does in fact exist.

esis of the existence of a non-monotonicity. Thus, the presence of a non-monotonicity in the estimation is strong suggestive evidence that the underlying relation is non-monotonic.

Additionally, a corollary of the theory suggests that countries that are located farther than the Least Desirable Distance (LDD) at the More Desirable Distances (MDD) should be more developed. This in turn implies that if the location of the frontier changes exogenously, the more time an economy spends at the MDD (across technological frontiers), the more developed it should be. Furthermore, the theory suggests that isolated economies, which become even more isolated after the change in the location of a frontier should get a boost in their economic performance.

4 Data and Empirical Strategy

This section develops the empirical strategy and describes the data used to explore the existence of a U-shaped relation between the pre-industrial distance to the technological frontier and economic development.

4.1 Identification Strategy

The analysis surmounts significant hurdles in the identification of a U-shaped effect of pre-industrial distance to the technological frontier on economic development. First, the results may be biased due to potential measurement error in historical data on economic development. In order to address this concern, the analysis explores the relation using different measures of economic development for the pre-industrial era. In particular, the research explores the relation using the level of technological sophistication in 1500CE and also population density levels for the years 1CE, 1000CE, 1500CE and 1800CE. This allows it to analyze the relation in data constructed from independent sources, over different samples, minimizing the potential effects of mismeasurement and sample selection on the analysis. Additionally, it permits the analysis to exploit cross-country and cross-period variation to identify the non-monotonic effect of distance to the frontier.

Second, the results may be biased by omitted geographical, institutional, cultural, or human characteristics that might have determined economic development and are correlated with the pre-industrial distance to the technological frontier. This research employs various strategies to address this potential concern. In particular, the analysis accounts for a large set of possible confounding geographical characteristics (e.g., elevation, area, malaria burden, share of area in tropical, subtropical or temperate zones, average caloric suitability, latitude and its square, being an island or landlocked). Moreover, it accounts for continental fixed effects capturing any unobserved time-invariant heterogeneity at the continental level. In addition, it accounts for common history fixed effects capturing any unobserved time-invariant heterogeneity due to common historical experience within a region. Additionally, when possible it accounts for country fixed effects and thus unobserved time-invariant country-specific factors. Furthermore, it accounts for other time-varying country characteristics (e.g. change in caloric suitability due to the Columbian Exchange, colonial status, lagged technology levels), as well as period-region fixed effects and thus for unobserved time-varying regional factors.

Third, the analysis further addresses the potential concern that the results may partially reflect the effect of omitted geographical, institutional, cultural, or human characteristics, by exploiting the variation in the location of the western technological frontier in the Old World. In particular, changes in the location of the technological frontier permit the research to account for country fixed effects and thus for time-invariant characteristics of a country. Moreover, it is plausible that the change in a country's distance to the frontier is exogenous to its characteristics, especially once region-period fixed effects are accounted for. In this case, the first difference estimator of equation (6) should be unbiased.

Fourth, variations in the location of the western frontier permit the analysis to address various potential concerns by exploring the effects of changes in the distance to the frontier on changes in population densities. In particular, as mentioned above, differences across periods in equation (6) account for omitted time-invariant determinants of population density. Additionally, analyzing changes across different periods addresses the potential concern that a particular period or technological frontier drives the results. Another potential concern is that the results may reflect movement of economies that were distant from the frontier in one period and become closer to it in another period. Exploration of the differential effect of larger distances (to the technological frontiers) on population density in economies located far from the technological frontiers addresses this concern.

Fifth, the analysis exploits the variation in the location of the western frontier in order to identify the cumulative and persistent effect of the distance to the pre-industrial frontier on development. In particular, the theory suggests that being far from the frontier generates a persistent positive effect on economic development as it promotes culture and institutions that are conducive to economic development. Thus, the more time a country spends far from the pre-industrial technological frontiers, farther than the Least Desirable Distance (LDD) at the More Desirable Distances (MDD), the more developed it should be.

Finally, the results may reflect the European expansion in the post-1500CE era or other time-varying characteristics of a country. The analysis addresses this potential concern by using various strategies. In particular, it restricts the analysis to the Old World, where European population replacement was less prevalent. Additionally, it establishes that the results hold for the pre-colonial period, before European expansion. Furthermore, it accounts for time-varying characteristics of a country (years since the Neolithic Revolution, lagged technological sophistication) as well as other changes generated in the Old World during the colonial period (e.g. changes in colonial status, changes in caloric suitability). In addition, it accounts for the interaction between region and period fixed effects, which capture the effects of time-varying region-specific unobserved heterogeneity, and thus partially account for the potential effects of European expansion and other omitted time-varying characteristics of a country.

4.2 Independent Variable: An Economic Measure of Pre-industrial Distance[12]

This section introduces a novel measure of the pre-industrial distance to the technological frontier in the pre-industrial era, which is the main independent variable employed in the analysis. This distance

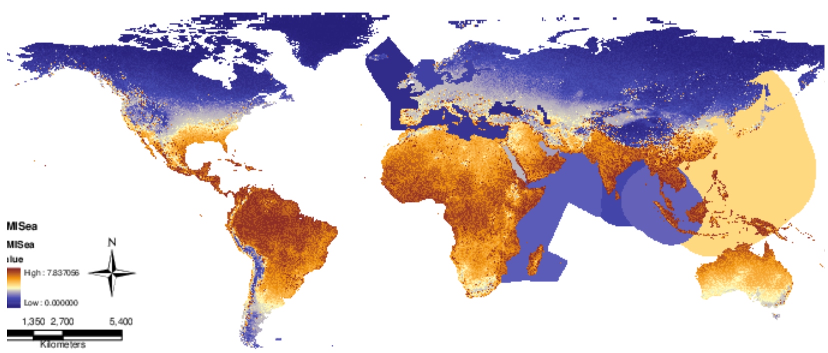
[12]Given space limitations, a more complete presentation of the material covered in this section is given in Appendix A. The interested reader can find additional material regarding the construction and testing of the measure there.

is based on a novel measure of geographical distance during pre-industrial times: the Human Mobility Index with Seafaring (HMISea). The HMISea measures the time required to cross any square kilometer on land and on some seas accounting for human biological constraints, as well as geographical and technological factors that determined travel times before the widespread use of steam power. Based on HMISea, the analysis estimates distances as the potential minimum travel times between locations (measured in weeks of travel). This strategy overcomes the potential mismeasurement of distances generated by using geodesic distances (Özak, 2010), for a period when travel times were the most important determinant of transportation costs (O'Rourke and Williamson, 2001).

The estimated time required to cross each square kilometer on land is based on data on the maximal sustainable speeds of dismounted infantry movement under different climatic, topographical, and terrain conditions (Hayes, 1994). In particular, Hayes (1994) estimates the maximal sustainable speeds of dismounted infantry movement under different temperature, relative humidity, slope, and terrain conditions. Hayes focused on the levels of metabolic rates and speeds that can be sustained for long periods of time without causing a soldier to become a victim of heat-exhaustion.

Based on this data, the analysis estimates the relation between the maximum sustainable travel speeds and these conditions using Ordinary Least Squares (OLS). Given these OLS coefficients, the analysis proxies the time required to cross any square kilometer on land, given the average geographical conditions prevalent in it. Additionally, it complements this Human Mobility Index (HMI) by estimating the time required to cross any square kilometer on seas in the Old World, by constructing average times for each sea from primary and secondary historical sources (see appendix A for a more complete description). Figure 4 depicts the resulting HMISea cost surface.

Figure 4: Human Mobility Index with Seafaring (HMISea) cost surface.



The figure depicts the number of hours required to cross each square kilometer on land and on seas in the Old World. Low values in dark lila, high values in dark brown, intermediate values in intermediate tones. See text or Özak (2010) for construction.

In order to validate this index, Appendix A applies the HMISea measure to estimate distances during the pre-industrial era (see also Özak, 2010). In particular, it estimates the total time required to travel along the optimal paths that connect all modern day capitals and the average optimal time required to travel to each capital from all locations on a contiguous continental mass. Using these estimates, the analysis validates the measures by comparing them with data on ancient trade routes (Ciolek, 2004). As established in Appendix A, these optimal paths among capitals explain well the locations of ancient trade routes in the Old World (500BCE-1900CE). Additionally, it explores the relation between these historical migratory distances and genetic, religious, and linguistic distances (Spolaore and Wacziarg, 2009; Fearon, 2003; Mecham et al., 2006). Reassuringly, the optimal time required to travel among regions is strongly positively associated with these cultural distances.[13] Finally, using data on the historical speed of diffusion of news to Venice between the 16$^{\text{th}}$ and 18$^{\text{th}}$ century from a sample of cities (Braudel, 1972), the analysis establishes that HMISea travel times to Venice approximate these historical data.

These results suggest that HMISea based migratory routes are good proxies for the minimum total travel times between the capital of each technological frontier in the pre-industrial era and the capitals of countries in the Old World. Economic historians suggest that during the pre-industrial, the eastern technological frontier in the Old World era was located in China. On the other hand, the western technological frontier changed location during this era from the Eastern Mediterranean (≈1CE), to Iraq (≈1000CE), to the Netherlands (≈1500CE), and to the UK (≈1750CE) (Abu-Lughod, 1989; Blaut, 2012; Findlay and O'Rourke, 2007; Maddison, 1995, 2003; Mokyr, 1990; Pomeranz, 2000). For each country the analysis estimates the HMISea migratory distance to all technological frontiers. Figure 5 depicts the travel times to each western pre-industrial technological frontier in the Old World. In particular, for each western frontier it depicts the iso-chronic lines generated by the HMISea measure, where each line corresponds to half a week of continuous uninterrupted travel.

5 Pre-industrial Distance to the Frontier and Development

This section analyses the relation between the pre-industrial distance to the technological frontiers in the Old World and economic development.[14] In particular, the predictions of the theory and Monte Carlo simulations (section 3 and 4.1, Appendix E) suggest that the theory can be tested using variations of the following empirical specification

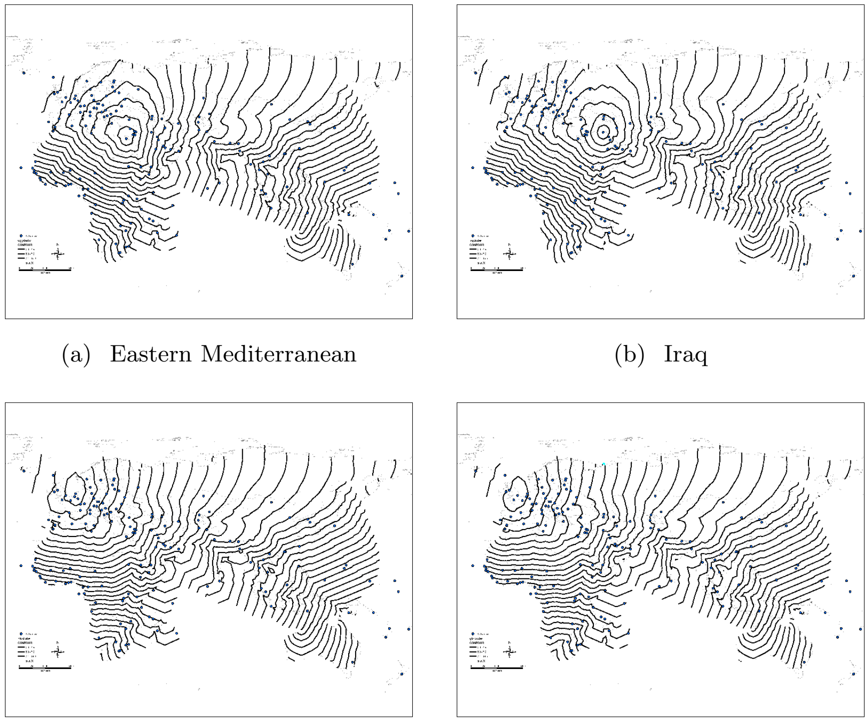
$$y_{it} = \beta_0 + \sum_{j=1}^{n}(\beta_{1j} d_{ijt} + \beta_{2j} d_{ijt}^2) + \sum_j \gamma_{0j} x_{ijt} + \sum_c \gamma_{ci}\delta_c + \sum_t \gamma_t \delta_t + \sum_{ct} \gamma_{ct}\delta_{ci}\delta_t + \epsilon_{it} \tag{7}$$

where y_{it} is a measure of economic development in period t for country i, d_{ijt} is the number of weeks of travel to the j-th pre-industrial technological frontier in period t, x_{ijt} are additional characteristics of country i in period t (including geography), $\{\delta_{ci}\}$ are a complete set of continen-

[13] Further supportive evidence of the validity of this method has been provided elsewhere. In particular, as predicted by the Out-of Africa Theory of the dispersion of modern humans, estimated HMI and HMISea migratory distances to East Africa have been shown to have a high explanatory power for the level of expected heterozygocity both at the ethnic and country levels (Ashraf and Galor, 2013; Depetris-Chauvin and Özak, 2015). Similarly, differences in other cultural values have been linked to these estimated migratory distances (Becker et al., 2014; Depetris-Chauvin and Özak, 2015; Spolaore and Wacziarg, 2014).

[14] As explained in section 4.1, the analysis excludes the New World and Oceania in order to overcome various concerns. In particular, since the development process in both the New World and Oceania was strongly affected by other forces during the pre-1500 and post-1500 eras, their exclusion overcomes potential concerns due to, e.g., the potential confounding effects of population replacement and colonization, as well as the extinction of great mammals. Additionally, the lack of interaction between the Old and New World raises methodological issues regarding the estimation of distances. Reassuringly, Appendix F establishes the robustness of the inclusion of these regions into the analysis. In particular, it establishes the presence of a non-monotonicity when the New World has its own technological frontiers or when distances between the Old and New World are assumed to be larger than within each region.

Figure 5: Travel time along optimal paths to technological frontiers.



(a) Eastern Mediterranean

(b) Iraq

(c) Netherlands

(d) UK

Note: Each panel depicts iso-chronic lines of travel times to a western pre-industrial technological frontier in the Old World. Each iso-chronic line represents half a week of continuous travel time along the optimal path to the frontier.

tal/regional/historical/country fixed effects, $\{\delta_t\}$ are a complete set of period fixed effects, and ϵ_{it} is an error term.[15] If the theory is valid, then $\beta_{1j} < 0$, $\beta_{2j} > 0$, and the implied Least Desirable Distance ($LDD_j = -0.5\beta_{1j}/\beta_{2j}$) is positive, finite and statistically significant for at least one frontier j. On the other hand, if the theory is invalid, then the LDD is not significant or is outside the maximum distance in the sample.[16]

5.1 Historical Evidence I: Technological Sophistication (Cross-Sectional Analysis)

This section explores the relation between a country's level of technological sophistication in 1500CE and the distance to the technological frontiers in the Old World during that period, namely the Netherlands and China. The technology indices for the year 1500 proxy a country's stock of technology and innovativeness.[17] Thus, the dependent variable in these regressions measures the relevant channel

[15]The analysis includes the largest set of countries in the Old World for which all the data in the most general specification being studied is available. Appendix B contains the descriptive statistics for all the samples and variables used in the analysis.

[16]Monte Carlo simulations presented in appendix E suggest that this specification has high power. In particular, it can correctly reject the null-hypothesis of the existence of a U-shape, when countries only imitate from the closest frontier, or from only one frontier, or if conventional wisdom holds. Moreover, *only* simulations in which the proposed theory is true, did the regression find a statistically and economically significant U-shape. Still, even when the theory was true, the empirical test tended to reject the null hypothesis of the existence of a U-shape.

[17]These measures were constructed independently of historical or contemporaneous income levels, covering a wide range of sectors, technologies, and countries. Thus, these measures try to prevent biases caused by a country's develop-

through which remoteness affects economic development according to the proposed theory.

Table 1 explores the existence of a non-monotonic relation between the pre-industrial distance to the technological frontier and development. In particular, it uses ordinary least-squares (OLS) regressions to analyze the empirical association between pre-industrial distance, its square and technological sophistication in 1500CE. Column (1) shows the unconditional relation between the distance to the western technological frontier in the Old World and technological sophistication. In particular, the estimated Least Desirable Distance (LDD) is statistically and economically significant, and is located at 8.3 weeks. The estimates suggest that an economy located 1-standard deviation (SD) away from the LDD has a technological sophistication 19% higher than at the LDD.

Table 1: Technology in 1500 CE and Pre-industrial Distance from the Technological Frontier

	Technological Sophistication in 1500CE							
	Unadjusted						Migration Adjusted	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-industrial distance to NLD	-0.15***	-0.10***	-0.10***	-0.10***	-0.13***	-0.13***	-0.13***	-0.13***
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Sq. Pre-industrial distance to NLD	0.01***	0.01***	0.01***	0.01**	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to CHN					-0.03***	-0.04	-0.03***	-0.04
					(0.01)	(0.04)	(0.01)	(0.04)
Sq. Pre-industrial distance to CHN						0.00		0.00
						(0.00)		(0.00)
LDD NLD	8.25***	5.37***	5.63***	6.42***	7.66***	7.73***	7.28***	7.41***
	(0.89)	(0.50)	(0.36)	(1.25)	(1.26)	(1.62)	(1.13)	(1.52)
LDD CHN						124.61		61.21
						(1456.00)		(325.44)
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Continental FE	No	No	No	Yes	Yes	Yes	Yes	Yes
AET		1.87	2.15	3.51	13.05	14.95	10.24	12.88
δ		1.35	1.37	1.26	1.08	1.07	1.10	1.08
β^*		3.97	4.78	5.86	7.51	7.59	7.09	7.26
R^2	0.48	0.83	0.87	0.88	0.89	0.89	0.89	0.89
Adjusted-R^2	0.46	0.80	0.85	0.85	0.86	0.86	0.86	0.86
Observations	84	84	84	84	84	84	84	84

Notes: This table establishes the statistically and economically significant U-shaped relation between technological sophistication and the distance to the frontier. Estimation by OLS. It additionally shows the Altonji et al. (2005) AET ratio as extended by Bellows and Miguel (2009). It also shows the δ and $\beta^*(1,1)$ statistics suggested by Oster (2014). All statistics suggest that the results are not driven by unobservables. Pre-industrial distance to Netherlands/China is the minimum total travel time (in weeks) along the optimal path between a country's capital and the Netherlands/China (see text for construction). Additional controls include latitude and latitude squared of the country's capital, Pre-1500CE caloric suitability, percentage of land area in tropics and subtropics, mean elevation above sea level, land area, island and landlocked dummies, and malaria (falciparum) burden. Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Column (2) accounts for the confounding effect of a country's geographical characteristics. In particular, it accounts for a country's latitude and its square, pre-1500CE caloric suitability, percentage

ment. Still, they may be subject to Eurocentric biases due to the choice of technologies and knowledge on which they focus (Blaut, 2012; Selin, 1997).

of land area in tropics and subtropics, mean elevation above sea level, land area, malaria burden, and dummies for being landlocked or an island. Reassuringly, the estimated LDD remains statistically and economically significant. The estimated location of the LDD is 5.4 weeks and implies that an economy located 1-SD away from the LDD has a technological sophistication 44% higher than at the LDD.

Columns (3) and (4) consider the confounding effects of the advent of sedentary agriculture and of unobserved time-invariant omitted variables at the continental level on technological sophistication. In particular, column (3) accounts for the years elapsed since the onset of the Neolithic Revolution, which previous research has suggested had a positive impact on economic development (Diamond, 1997). Additionally, column (4) accounts for continental fixed effects and therefore for any unobserved time-invariant omitted variable at the continental level. The estimated LDD remains statistically significant at the 1% and implies an economically significant effect of the distance to the technological frontier. In particular, after accounting for a country's geography, the advent of the Neolithic Revolution, and continental fixed effects, the estimated LDD is 6.4 weeks and implies that an economy located 1-SD away from the LDD has a technological sophistication 31% higher than at the LDD.

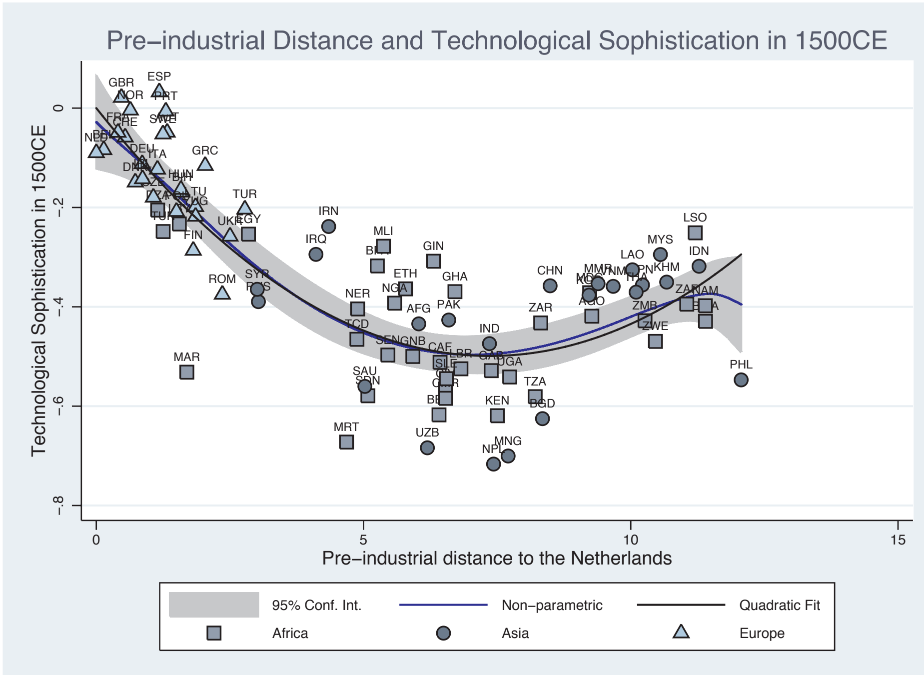
Furthermore, columns (5) and (6) account for the distance to the eastern technological frontier in the Old World. If conventional wisdom were valid, then accounting for the distance to China should eliminate the non-monotonicity with respect to the distance to the western technological frontier (see Appendix E). Reassuringly, the U-shape remains statistically and economically significant. In particular, the estimated LDD is 7.7 weeks and implies that an economy located 1-SD away from the LDD has a technological sophistication 22% higher than at the LDD.

Finally, columns (7) and (8) use an alternative measure of technological sophistication that corrects for possible migration in the pre-1500 era. Reassuringly, the results remain qualitatively similar, with the estimated LDD at 7.3 weeks, which implies that an economy located 1-SD away from the LDD has a technological sophistication 24% higher than at the LDD.

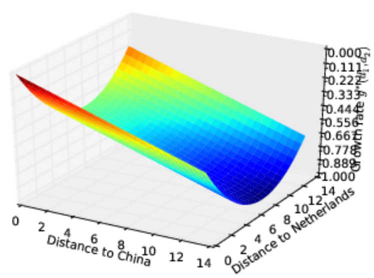
Table 1 suggests that after accounting for a country's geography, onset of the Neolithic Revolution and continental fixed effects there exists a U-shaped effect of the pre-industrial distance to the technological frontier on economic development. One potential concern with these results is that omitted factors might bias the results. In order to address this issue, Table 1 additionally analyzes the possibility of bias generated by selection on unobservables (Altonji et al., 2005; Bellows and Miguel, 2009; Oster, 2014). The results shown in the table imply that the selection on unobservables would have to be stronger than selection on observables in order to explain the results. Furthermore, the bias-adjusted estimated LDD remains strictly positive, smaller than the sample maximum, and economically significant (Oster, 2014). These results suggest that it is unlikely that omitted country characteristics are significantly biasing the results.

Figures 6(a) and 6(b) depict the relation between technological sophistication and distance implied by column (5). The figures show that the estimates generate a U-shape and a valley as predicted by the theory. Importantly, as shown in Figure 6(a), the semi-parametric regression and the fitted quadratic relation are almost identical, suggesting that the quadratic functional form is a good approximation to the non-monotonicity. One potential concern with these estimates is that the location of the LDD with respect to the Netherlands might depend on the distance from China. Reassuringly, including the

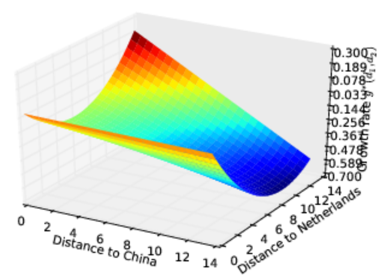
Figure 6: Technology and Pre-industrial Distance to Technological Frontier in 1500CE.



(a) Average Technology



(b) Growth valley based on column 7 of table 1.



(c) Growth valley (interaction).

interaction between the (linear) distances does not affect the results. Figure 6(c) plots the estimated relation when this interaction is included in the specification of column (5).

Another potential concern is that these results may reflect the aggregation of the sophistication measure across sectors. In order to address this concern, Table 2 replicates the analysis for individual sectors. Reassuringly, as established in Table 2, the results remain qualitatively similar and suggest that the U-shape is not generated by aggregation and on the contrary holds for all sectors.

5.2 Robustness to Alternative Theories

This section explores the robustness of the results to alternative theories of development, omitted variables and mismeasurement. In particular, if the distance from the technological frontier correlates with

Table 2: Sectorial Technology in 1500 CE and Pre-industrial Distance from the Technological Frontier

	Technological Sophistication in 1500CE						
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.M.)
Pre-industrial distance to NLD	-0.14***	-0.06	-0.13***	-0.21***	-0.12*	-0.13***	-0.13***
	(0.05)	(0.05)	(0.04)	(0.07)	(0.06)	(0.03)	(0.03)
Sq. Pre-industrial distance to NLD	0.01**	0.00	0.01**	0.01**	0.01**	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to CHN	-0.03	-0.02	-0.05***	-0.05**	-0.03**	-0.03***	-0.03***
	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
LDD NLD	8.87***	8.83*	8.32***	7.60***	5.90***	7.66***	7.28***
	(2.21)	(4.82)	(1.90)	(1.82)	(1.02)	(1.26)	(1.13)
Continental FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.64	0.80	0.74	0.69	0.67	0.86	0.86
Observations	84	84	84	84	84	84	84

Notes: This table establishes the statistically and economically significant U-shaped relation between sectorial technological sophistication and the distance to the frontier. All columns include the same set of controls as column (5) in Table 1. Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

other cultural, historical or institutional characteristics of a country, the estimated U-shaped relation may reflect these alternative mechanisms or theories. Specifically, Table 3 explores the confounding effects of lagged technological sophistication, European colonization, pre-industrial trade, local technological frontiers, and population diversity. Column (1) replicates the specification in column (5) of Table 1. As before the LDD is highly statistically and economically significant.

A potential concern is that the results in column (1) omit a country's lagged technology levels. In particular, if conventional theory holds, then countries that are far from the frontier should be technologically backward and, thus, could potentially benefit from the advantages of backwardness (Gerschenkron, 1962). So, countries that are lagging technologically should be able to take advantage of larger productivity and technological gains as they imitate from the technological frontier. Thus, according to this alternative theory, lagged levels of technology should be negatively correlated with technological sophistication in 1500CE. Column (2) accounts for a country's lagged technological sophistication levels in order to address the potential concern generated by the advantages of backwardness (Gerschenkron, 1962). Reassuringly, accounting for past technology levels does not alter the results. In particular, the estimated LDD remains statistically and economically significant with an estimated value of 7.6.

Another potential concern is that the results reflect the effect of the European expansion of the 16th century. In particular, if regions far from the technological frontier were colonized by (more developed) Europeans, who brought their technology, human capital, institutions, and culture, then regions far from the frontier would be more developed, but the cause would not be the one suggested by the theory. The analysis addresses this potential concern in two ways. First, and importantly, technological sophistication in 1500CE is measured *before* the large technological transfers generated by European conquest (Comin et al., 2010). Thus, the positive effects of remoteness should not reflect the dispersion of Europeans, but conditions *preceding* it. Additionally, it accounts for countries' post-1500CE colonial history. In particular, it accounts for a dummy that is equal to 1 if post-1500CE a country will be colonized by an European power (including Turkey) and 0 otherwise. This accounts for any potentially unobservable time-invariant country characteristics that might jointly determine development around 1500CE and future colonization. Reassuringly, as established in column (3), the results remain mostly unchanged.

Table 3: Technology in 1500 CE, Pre-industrial Distance from the Technological Frontier (Alternative Theories)

	Technological Sophistication in 1500CE						
	Base	Back	Colony	Trade	Local	OOA	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pre-industrial distance to NLD	-0.13***	-0.13***	-0.14***	-0.13***	-0.14***	-0.14***	-0.15***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)
Sq. Pre-industrial distance to NLD	0.01***	0.01***	0.01***	0.01***	0.01***	0.01**	0.01**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to CHN	-0.04***	-0.03**	-0.04***	-0.04***	-0.04***	-0.05***	-0.06***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
Lagged technological sophistication		0.05					0.07
		(0.11)					(0.10)
European colony			-0.06				-0.08
			(0.06)				(0.07)
Pre-industrial distance to major trade routes				-0.00			0.02
				(0.03)			(0.04)
Pre-industrial distance to local frontier					0.01		0.01
					(0.02)		(0.02)
Pre-industrial distance to East Africa						0.01	0.02
						(0.01)	(0.01)
LDD NLD	7.77***	7.57***	7.83***	7.69***	7.84***	8.69***	9.83***
	(1.27)	(1.37)	(1.26)	(1.33)	(1.34)	(2.10)	(2.96)
Continental FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.87	0.86	0.87	0.86	0.86	0.86	0.86
Observations	82	82	82	82	82	82	82

Notes: This table establishes the robustness of the U-shaped relation between technological sophistication and the distance to the frontier to accounting for lagged technology levels, European colonization, trade, local technological frontiers, and the Out-of-Africa hypothesis. Estimation by OLS. See table 1 for list of additional controls. Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2\cdot\beta_{Sq.Distance})$. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

A further potential concern is that the results reflect the effect of trade. In particular, if the distance from the technological frontier were negatively correlated with the distance to major pre-industrial trade, pilgrimage, or other routes through which information and goods were transported, then the relevant distance would be mismeasured. Moreover, regions far from the frontier would be developed due to trade and information flows arriving through these routes, and not the channel suggested by the theory. In order to address this issue, the analysis accounts for a country's pre-industrial distance to the location of pre-industrial trade, pilgrimage, banking and mail routes (Ciolek, 2004). Column (4) establishes that accounting for the pre-industrial distance to these networks does not alter the results.

Another potential concern is that the distance to the global technological frontiers is not as relevant for imitation and innovation as the distance to some local technological frontier. In particular, if the distance from the global technological frontier is negatively correlated with the distance to a local technological frontier, then regions far from the global frontier would be close to their local frontier. Thus, if conventional theory holds true, they would be developed, but not through the channel suggested by the theory. The analysis addresses this potential concern by accounting for the pre-industrial distance to the local technological frontiers identified by Ashraf and Galor (2013). Column (5) shows that accounting for the pre-industrial distance to the local technological frontiers does not affect the results.[18]

An additional concern is that the results reflect the effect of the Out-of-Africa (OOA) hypothesis on economic development (Ashraf and Galor, 2013). In particular, the OOA hypothesis suggests that economic development in the Old World is positively correlated with the pre-industrial distance to the Cradle of Civilization (East Africa). If the distance to the technological frontier is correlated with the distance to East Africa, then its omission may bias the results. Reassuringly, as established in column (6) accounting for the pre-industrial distance to East Africa does not alter the results.

Moreover, accounting jointly for all these other potential channels does not alter the results. This suggests that the U-shaped effect of the pre-industrial distance to the frontier on economic development does not capture the effect of these other theories. Finally, as established in Appendix F, including the New World, splitting the sample by regions, including the minimum distance to either frontier, or analyzing the alternative theories at the sectorial level does not alter the qualitative results.

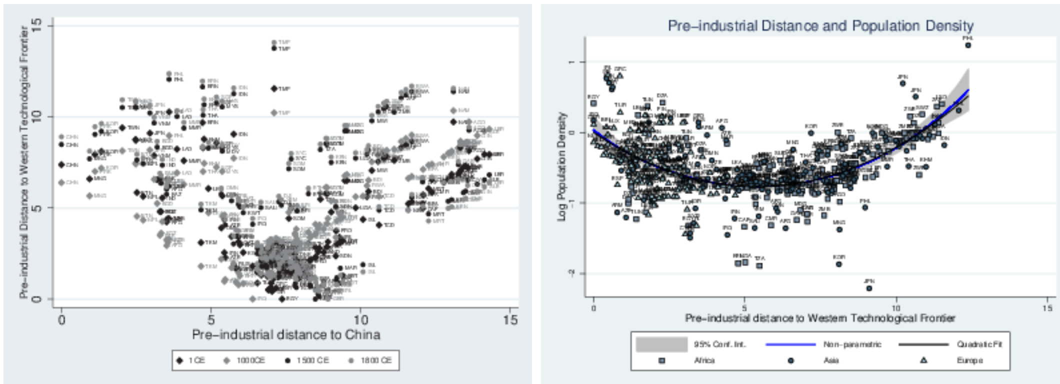
5.3 Historical Evidence II: Population Density (Panel-Data Analysis)

This section further explores the existence of a non-monotonic relation between the pre-industrial distance to the technological frontier and population density. In particular, the analysis exploits the movement in the location of the western pre-industrial technological frontier in the Old World in order to identify the effect of distance to the frontier. Thus, the analysis can exploit inter-temporal within-country variations to explore this relation, mitigating possible concerns about the confounding effect of country-specific characteristics. Figure 7(a) depicts the location of Old World countries in the two-dimensional space defined by their distance to China and the western technological frontier in the years 1CE, 1000CE, 1500CE, and 1800CE. It illustrates the existence of large variations in distances with respect to the frontiers both between and within countries.

Table 4 explores the existence of a U-shaped relation between the distance to the technological frontier and population density. In particular, column (1) uses Pooled OLS to establish that population

[18] This does not imply that local technological frontiers played no role. In particular, technology might have diffused from the global to the local technological frontiers and then to the countries. But this implies that the *relevant* distance from the source of innovation is still the global technological frontier, since imitation can only happen from the local frontier once enough time has passed for the innovation to diffuse or be created there.

Figure 7: Population Density and Variations in the Location of the Frontier



(a) Countries' locations relative to China and the Western Technological Frontier in 1CE, 1000CE, 1500CE, and 1800CE.

(b) Population Density and Distance to the Technological Frontier.

density between 1CE and 1800CE had a U-shaped relation with the distance to the pre-industrial technological frontier. The analysis in column (1) accounts for the distance to China as well as the geographical controls included in Table 1. The results suggest that the Least Desirable Distance, LDD, is economically and statistically significant, located at 5.9 weeks of travel from the pre-industrial frontier.

Column (2) additionally accounts for fixed effects for regions that share a common history, religion, or language (Findlay and O'Rourke, 2007), and thus, for the potential effects of any time-invariant characteristic of regions that shared a common history. Furthermore, column (3) accounts for period fixed effects and thus for any period-specific unobserved heterogeneity. Column (4) also includes the interaction of period and region fixed effects in the analysis, thus accounting for the potential effect of any period-region-specific omitted factors. Reassuringly, the LDD remains statistically and economically significant, and is estimated to be located at 5.8 weeks of travel from the frontier.

Column (5) additionally accounts for the potential confounding effects of other sources of comparative development. In particular, it accounts for the potential confounding effect of (i) trade by controlling for a country's distance to a major trade route; (ii) population diversity as determined during the Out-of-Africa migration of modern humans by controlling for a country's pre-industrial distance to East Africa; (iii) the transition to agriculture by controlling for the number of years since a country experienced the Neolithic Revolution; (iv) European expansion by controlling for a country's colonial status in a period; (v) local technological frontiers by controlling a country's pre-industrial distance to a local technological frontier in a period; and (vi) agricultural productivity by controlling for the country's average caloric suitability in a period. Reassuringly, the U-shape remains statistically and economically significant with the LDD estimated to be located at 4.6 weeks of travel from the frontier.

By exploiting variations in the location of the technological frontier, the analysis mitigates concerns that omitted characteristics of the country that correlate with the distance to the frontier bias

Table 4: Pre-industrial Population Density and Distance from the Technological Frontier

	Log Population Density in Period							
	Pooled OLS					FE		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-industrial distance to frontier	-0.41***	-0.39***	-0.33***	-0.24**	-0.18**	-0.38***	-0.15***	-0.13**
	(0.10)	(0.08)	(0.07)	(0.10)	(0.08)	(0.07)	(0.05)	(0.05)
Sq. Pre-industrial distance to frontier	0.04***	0.04***	0.03***	0.02**	0.02***	0.05***	0.02***	0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
Pre-industrial distance to China	-0.06	-0.18***	-0.14**	-0.14**	-0.03			
	(0.04)	(0.07)	(0.07)	(0.07)	(0.09)			
Pre-industrial distance to major trade routes					-0.35*			
					(0.19)			
Pre-industrial distance to East Africa					-0.01			
					(0.06)			
Colonial status					0.32**			0.10
					(0.16)			(0.12)
Pre-industrial distance to local frontier					0.00			-0.13*
					(0.10)			(0.08)
Caloric Suitability					-0.00			0.00
					(0.00)			(0.00)
LDD	5.90***	4.37***	6.12***	5.78***	4.59***	3.89***	4.16***	3.61***
	(0.53)	(0.44)	(0.68)	(1.24)	(0.98)	(0.40)	(0.69)	(0.81)
Country FE	No	No	No	No	No	Yes	Yes	Yes
Geographical Controls	Yes	Yes	Yes	Yes	Yes	No	No	No
Region FE	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Period FE	No	No	Yes	Yes	Yes	No	Yes	Yes
Region × Period FE	No	No	No	Yes	Yes	No	Yes	Yes
Time Since Neolithic Revolution	No	No	No	No	Yes	No	No	Yes
Adjusted-R^2	0.49	0.59	0.74	0.76	0.78	0.21	0.86	0.86
Observations	463	463	463	463	463	463	463	463

Notes: This table establishes the statistically and economically significant U-shaped relation between population density and the distance to the frontier. Column names denote the estimator used: (POLS) pooled OLS estimator, (FE) fixed effects estimator. Additional controls as in Table 1. Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the technological frontier. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. Heteroskedasticity robust standard error estimates clustered at the country level are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

the results. Columns (6)-(8) further addresses this concern by accounting for country fixed effects. Moreover, the analysis accounts for period and period-region fixed effects (column 7), as well as other time-varying pre-industrial characteristics of a country (column 8), in order to additionally mitigate concerns that time-varying country characteristics of a country drive the results. Reassuringly, results remain qualitatively similar, mitigating concerns that they are driven by omitted factors. Figure 7(b) depicts the relation in column 8.

Table 5 further explores the existence of a non-monotonic relation between the distance to the frontier and economic development. In particular, equation 6 suggests that changes in economic development should be associated with changes in the distance to the frontier and its square. Importantly, by taking differences in equation 6, the analysis accounts for any time-invariant country-specific heterogeneity. Columns (1)-(3) establish that population density indeed has an economically and statistically significant U-shaped relation with the distance to the technological frontier. This result is robust to

Table 5: Pre-industrial Population Density and Distance from the Technological Frontier

	Change in Log Population Density					
	All Periods			1000CE-1800CE	1CE-1500CE	1CE-1800CE
	(1)	(2)	(3)	(4)	(5)	(6)
ΔPre-industrial distance to frontier	-0.18***	-0.08*	-0.07*	-0.08	-0.23***	-0.33***
	(0.03)	(0.04)	(0.04)	(0.06)	(0.09)	(0.09)
ΔSq. Pre-industrial distance to frontier	0.01***	0.01***	0.01***	0.01**	0.03***	0.03***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)
Δyears since transition to agriculture			-0.72***			
			(0.13)			
ΔCaloric suitability			0.00			
			(0.00)			
ΔColonial status			0.03			
			(0.12)			
ΔPre-industrial distance local frontier			-0.06			
			(0.06)			
LDD	5.91***	4.34***	4.04***	3.83**	3.70***	4.68***
	(0.45)	(1.03)	(1.21)	(1.49)	(0.75)	(0.63)
Region FE	No	Yes	Yes	Yes	Yes	Yes
Period FE	No	Yes	Yes	No	No	No
Region × Period FE	No	Yes	Yes	No	No	No
Adjusted-R^2	0.08	0.43	0.43	0.48	0.56	0.60
Observations	346	346	343	117	108	107

Notes: This table establishes the statistically and economically significant U-shaped relation between population density and the distance to the frontier. (i) Columns (1)-(3) use panel of all changes in log population density and changes in frontier location (First Differences). Columns (4)-(6) use long differences (two periods columns (4)-(5), column (6) three periods). (ii) Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the technological frontier. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (iv) Heteroskedasticity robust standard error estimates clustered at the country level are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

accounting for region, period, and region-period fixed effects, as well as changes in the number of years since a country experienced the Neolithic Transition, changes in a country's caloric suitability, changes in a country's colonial status, and changes in a country's distance to a local technological frontier.

A potential concern is that these results are driven by a specific period or frontier. Although period, region and period-region fixed effects ought to account for any unobserved heterogeneity at the region, period, or period-region levels, columns (4)-(6) further address this concern. While the analysis in columns (1)-(3) employed the first-difference of equation 6 to explore the relation, the analysis in columns (4)-(6) uses long-differences for the 1-1800CE era. In particular, column (4) explores the change in population density between 1000CE and 1800CE, column (5) between 1CE and 1500CE, and column (6) between 1CE and 1800CE. Reassuringly, the analysis in all three columns suggests that there exists a statistically and economically significant U-shaped relation between population density and the distance to the frontier.

5.4 Alternative Tests of the Theory

This section explores additional predictions of the theory in order to test its validity. In particular, the theory predicts that countries located farther than the Least Desirable Distance (LDD) from the technological frontier should grow faster, and increasing their distance to the technological frontier should boost economic development during the pre-industrial era. Additionally, the theory predicts a cumulative positive effect of being isolated from the technological frontier, reflecting its beneficial effect on the emergence of institutional and cultural characteristics conducive to innovation and entrepreneurship.

Table 6: Pre-industrial Population Density Growth and Distance from the Technological Frontier

	Change in Log Population Density					
	Western Frontier				Local Frontier	Closest Frontier
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged Pre-industrial distance to frontier	0.04**	0.04**	0.04**	0.04**	0.08***	0.03*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
ΔPre-industrial distance to frontier		-0.03		-0.03	-0.27***	-0.04
		(0.04)		(0.04)	(0.08)	(0.04)
(Lag $\times\Delta$)Pre-industrial Distance to frontier		0.01**		0.01*	0.10***	0.01**
		(0.01)		(0.01)	(0.02)	(0.01)
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
Region $\times$ Period FE	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls and Interactions	No	No	Yes	Yes	Yes	Yes
Adjusted-R^2	0.43	0.43	0.43	0.43	0.47	0.43
Observations	346	346	346	346	343	346

Notes: This table establishes that during the pre-industrial era, economies located far from the technological frontier had higher economic growth as captured by growth in population density. Moreover, economies that become more isolated from the frontier got an additional boost to their economic growth. Columns (1)-(4) use the distance to the western technological frontier. Column (5) and (6) show the result is robust to using the local or the closest technological frontier. All columns account for region, time and region×time fixed effects. Additionally, columns (3)-(6) account for lagged values and changes in caloric suitability and colonial status. Heteroskedasticity robust standard error estimates clustered at the country level are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table 6 explores the first prediction that countries that are isolated from the pre-industrial technological frontier tend to grow faster, and that increases in their level of isolation boosts their economic performance. Column (1) establishes that the pre-industrial distance to the technological frontier in a period is positively associated with future increases in population density during the following period. Additionally, column (2) establishes that isolated countries that became even more isolated, benefited of a boost to population density growth. These results account for the potential confounding effects of region, period and region-period unobservable heterogeneity.

A potential concern with the results of columns (1) and (2) is that they reflect the confounding effects of other time-varying country characteristics. In order to mitigate this concern, columns (3) and (4) replicate the analysis but account additionally for the lag, difference and interaction of the set of a country's time-varying characteristics included in Table 4. Reassuringly, the results remain unchanged. Furthermore, the results are robust to the distance measure employed, since the distance to the local or to the closest frontier generate qualitatively similar results (columns 5 and 6).

Table 7: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Pre-industrial Population Density

	Log Population Density in Period						
	Full Sample		Distance From Frontier Always ≥				
			1 Std	2 Std			
					Distance to China Always ≥		
					1 Std	2 Std	3 Std
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time at MDD	0.03**	0.03**	0.03**	0.04**	0.03**	0.03**	0.03**
	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Colonial Status		0.06	0.20**	0.23*	0.24	0.16	0.16
		(0.12)	(0.09)	(0.12)	(0.16)	(0.13)	(0.13)
Pre-industrial distance local frontier		-0.09	0.28***	0.39***	0.39***	0.42***	0.42***
		(0.08)	(0.09)	(0.08)	(0.07)	(0.07)	(0.07)
Caloric Suitability		-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region × Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.85	0.85	0.90	0.91	0.94	0.95	0.95
Observations	467	463	298	178	161	110	106

Notes: This table establishes the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era. In particular, years at MDD measures the number of centuries a country had been located at more than 9 weeks of travel (more than one standard deviation further away than the average country) from pre-industrial technological frontiers. Columns (3)-(7) additionally impose that the country never moves too close to a western frontier, nor is located close to the eastern frontier (China). All columns account for country, time and region×time fixed effects. Heteroskedasticity robust standard error estimates clustered at the country level are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table 7 further explores the predicted benefits of being isolated from the frontier. In particular, it analyzes the association between the time (measured in centuries) that a country spent more than one standard deviation farther away than the average country from pre-industrial technological frontiers, i.e., at the More Desirable Distances (MDD). The theory predicts that the more time a country was located at the MDD the higher its economic development. Column (1) establishes that after accounting for country, period, and region-period fixed effects, the time spent at the MDD is positively associated with population density. The results suggest that for each century a country was located at the MDD, its population density increased by 3%. Additionally, accounting for a country's colonial status, its distance to a local technological frontier, its caloric suitability, and the time since the Neolithic Revolution does not affect the results (column 2).

A potential concern with these results is that countries located at the MDD in one period, may be located close to another frontier in a different period. Thus, the positive effect of being located at the MDD may be reflecting the confounding positive effect of being close to the frontier in different periods. In order to address this concern, columns (3)-(7) constrain the sample to countries that are always more than 1 or 2 standard deviations away from the technological frontier.[19] As established in

[19]Constraining the sample to include only countries that are always more than 3 standard deviations (i.e., 9 weeks)

Table 8: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Pre-industrial Population Density

	Log Population Density in Period						
	Full Sample		Distance From Frontier Always ≥				
			1 Std	2 Std			
					Distance to China Always ≥		
					1 Std	2 Std	3 Std
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
MDD Index	0.21***	0.22***	0.20***	0.22***	0.18**	0.18**	0.18**
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Colonial Status		0.06	0.19**	0.23*	0.24	0.09	0.09
		(0.12)	(0.09)	(0.12)	(0.16)	(0.12)	(0.12)
Pre-industrial distance local frontier		-0.10	0.26***	0.35***	0.35***	0.39***	0.39***
		(0.08)	(0.08)	(0.07)	(0.06)	(0.06)	(0.06)
Caloric suitability		-0.00	0.00	-0.00	-0.00	-0.00	-0.00
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region × Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.85	0.85	0.90	0.92	0.94	0.96	0.96
Observations	467	463	298	178	161	110	106

Notes: This table establishes the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era. In particular, MDD measures the number of technological frontiers for which a country had been located at more than 9 weeks of travel (more than one standard deviation further away than the average country). Columns (3)-(7) additionally impose that the country never moves too close to a western frontier, nor is located close to the eastern frontier (China). All columns account for country, time and region×time fixed effects. Heteroskedasticity robust standard error estimates clustered at the country level are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

columns (3) and (4), constraining the sample to countries located always more than 1 or 2 standard deviations away from the technological frontier does not affect the results. Moreover, focusing on countries that are additionally far away from China, thus accounting for the potential confounding effect of diffusion from the Eastern technological frontier does not alter the results either.

Finally, Table 8 establishes the robustness of the results to the measure of the time a country was located at the MDD. In particular, instead of using the time spent at the MDD, which might potentially be subject to measurement error, it employs the MDD Index that counts the number of pre-industrial technological frontiers for which the country was located at the MDD. Reassuringly, the results remain qualitatively similar and imply that for each pre-industrial technological frontier for which a country was at the MDD, its population density increased by 18%.

away from the technological frontier in every period results in a much smaller sample size. Reassuringly, the results remain qualitatively similar.

6 Distance to the Pre-industrial Technological Frontier and Contemporary Economic Development

This section explores the persistent effects of the distance to the pre-industrial technological frontier on contemporary economic development. In particular, it establishes the existence of a U-shaped relation between contemporary GDP per capita and the distance to the UK, which was the technological frontier around 1800. Moreover, the analysis demonstrates a cumulative positive effect of being isolated from the technological frontiers during the pre-industrial era on contemporary economic development. In particular, the analysis demonstrates the persistent effect of isolation from the frontier on contemporary GDP per capita, innovation and entrepreneurial activity. Thus, the results suggest that isolation from the frontier may have beneficial effects on innovation and entrepreneurship as proposed by the theory.

Table 9: Distance from the Pre-industrial Technological Frontier and Contemporary Development

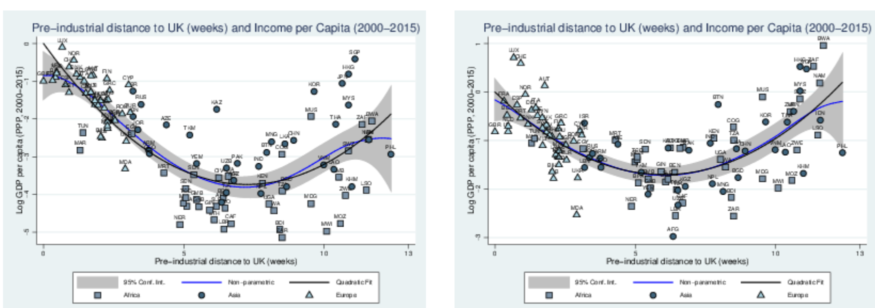
	Log[GDP per capita (2000-2015CE)]							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-industrial distance to frontier	-1.03***	-0.57***	-0.68***	-0.65***	-0.64***	-0.65***	-0.61***	-0.57***
	(0.09)	(0.12)	(0.12)	(0.14)	(0.16)	(0.17)	(0.18)	(0.19)
Sq. Pre-industrial distance to frontier	0.07***	0.04***	0.05***	0.05***	0.05***	0.05***	0.05***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Pre-industrial distance to China					0.01	-0.02	0.09	0.17
					(0.05)	(0.11)	(0.16)	(0.23)
Sq.Pre-industrial distance to China						0.00	-0.00	-0.01
						(0.01)	(0.01)	(0.01)
European Colony Dummy							-0.41	-0.52
							(0.35)	(0.42)
Pre-industrial distance to East Africa								0.18
								(0.18)
Sq. Pre-industrial distance to East Africa								-0.01
								(0.01)
LDD UK	7.25***	6.61***	6.17***	6.25***	6.21***	6.23***	6.08***	6.02***
	(0.27)	(0.39)	(0.29)	(0.40)	(0.50)	(0.51)	(0.56)	(0.63)
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Continental FE	No	No	No	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.57	0.72	0.77	0.77	0.77	0.77	0.77	0.77
Observations	112	112	112	112	112	112	112	112

Notes: This table establishes the U-shaped association between the distance to the pre-industrial technological frontier and contemporary income per capita (average 2000-2015CE). The analysis accounts for country's geographical characteristics, the time since the country experienced the Neolithic Revolution, continental fixed effects, colony fixed effects, and pre-industrial distances to China and East Africa (and their squares). Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table 9 explores the persistence of the non-monotonic effect of distance from the (last) pre-industrial technological frontier on economic development. In particular, it analyzes whether the pre-industrial distance to the UK has a U-shaped association with contemporary income per capita (average 2000-2015CE). Column (1) establishes that there exists an unconditional U-shaped association between these variables and estimates the Least Desirable Distance (LDD) to be at 7.3 weeks of travel from the UK. Figure 8(a) depicts this quadratic relation as well as the results of a non-parametric regression. The figure suggests that the quadratic specification is a good approximation to the underlying association.

Clearly, this U-shaped relation may be biased due to omitted variables. In order to mitigate this potential concern, columns (2)-(8) explore its robustness to accounting for the effect of various potential confounders. Reassuringly, the U-shaped relation and the existence of the LDD are robust to accounting for a country's geographical characteristics (column 2); the number of years since a country experienced the Neolithic Revolution (column 3); continental fixed effects (column 4); the pre-industrial distance to China (column 5) and its square (column 6); the effect of European colonization (column 7); and the pre-industrial distance to East Africa and its square (column 8). Figure 8(b) depicts the U-shaped relation and semi-parametric regression associated with the specification in column (8). The results suggest that the LDD is located at 6 weeks of travel from the pre-industrial technological frontier. Moreover, additionally accounting for geographical characteristics associated with the emergence of pre-modern states, risk attitudes, and cooperation; religious composition of the population; institutional quality; a country's share of population with European ancestry; legal origins; and the distance to the contemporary technological frontier does not alter the qualitative nature of the results.

Figure 8: Distance to Pre-Industrial Technological Frontier (UK) and Income per capita (2000-2015CE)



(a) Unconditional Relation

(b) Conditional Relation

Table 10 further explores the potential persistent effects of isolation from the pre-industrial technological frontier on contemporary economic development. It exploits variations in the location of the western pre-industrial frontier in the Old World to analyze the effect of the time a country spent isolated from the pre-industrial technological frontier. In particular, column (1) establishes the positive association between the time (measured in centuries) that a country spend more than one standard deviation farther away than the average country from pre-industrial technological frontiers, i.e., at the More Desirable Distances (MDD). The results suggest that after accounting for regional fixed effects, each additional century at the MDD is associated with a 7% increase in contemporary income per capita. Moreover, accounting for other geographical characteristics of a country, the number of years since it experienced the Neolithic revolution and its colonial experience does not qualitatively alter

Table 10: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Contemporary Development

	Log[GDP per capita (2000-2015CE)]								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Time at MDD	0.07***	0.07***	0.08***	0.07**	0.07**	0.08***	0.08***	0.05*	0.07**
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Colony FE	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Volatility Controls	No	No	No	Yes	No	No	No	No	No
Religious Shares	No	No	No	No	Yes	No	No	No	No
Constraints on Executive	No	No	No	No	No	Yes	No	No	No
Population Share with European Ancestry	No	No	No	No	No	No	Yes	No	No
Legal Origin FE	No	No	No	No	No	No	No	Yes	No
Distance to USA	No	No	No	No	No	No	No	No	Yes
Adjusted-R^2	0.70	0.76	0.76	0.77	0.76	0.76	0.76	0.79	0.76
Observations	105	105	105	105	105	105	105	105	105

Notes: This table establishes the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era on contemporary income per capita (average 2000-2015CE). The analysis accounts for regional fixed effects, country's geographical characteristics, the time since the country experienced the Neolithic Revolution, colony fixed effects, geographical determinants of statehood, cooperation and risk preferences, religious composition of the population, constraints on the executive, european ancestry, legal origins, and distance to the contemporary technological frontier. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

the results (columns 2-3).

A potential concern with these results is that they may be capturing the potential confounding effects of other sources of economic development. In particular, the time spent at the MDD may be correlated with geographical characteristics associated with risk attitudes, trust, cooperation and pre-modern states (Bentzen et al., 2016; Depetris-Chauvin and Özak, 2015; Durante, 2009), which may have independently affected development. Similarly, changes in the distance to the pre-industrial technological frontier may be correlated with the religious composition of a country, which in turn may independently affect development. Moreover, the results may be biased if a country's distance to the pre-industrial technological frontier is associated with the quality of its institutions, the share of its population that descends from Europeans, its legal origins, or its distance to the contemporary technological frontier. Reassuringly, as columns (4)-(9) establish, accounting for these characteristics does not alter the estimated positive association between the time spent at the MDD and contemporary economic development.

Additionally, the analysis explores the potential persistent effects of isolation from the pre-industrial technological frontier on contemporary innovation. In particular, the theory predicts that periods of isolation from the technological frontier during the pre-industrial era promoted culture and institutions that were conducive to innovation and entrepreneurship, and thus to economic development. Table 11 explores this prediction by analyzing the association between a country's time spent at the MDD and its contemporary propensity to innovative, as measured by its average patenting activity per capita in the 2000-2015CE period. Column (1) establishes that after accounting for unobserved regional heterogeneity, an additional century of isolation from the technological frontier during the pre-industrial era is associated with a 15% increase in the number of patents per capita. Additionally accounting for geographical characteristics, the time since the Neolithic Revolution, the effects of colonization, and the geographical characteristics associated with risk attitudes, trust, cooperation and pre-modern states increases the statistical and economic significance of the effect. Specifically, after accounting for all these confounders, the results suggest that an additional century of isolation from the technological frontier during the pre-industrial era is associated with an increase of 17% in contemporary patenting activity (columns 2-5).

Table 11: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Contemporary Patenting Activity

	Log[Patents per Capita (2000-2015CE)]					
	All					Residents
	(1)	(2)	(3)	(4)	(5)	(6)
Time at MDD	0.15**	0.14**	0.14**	0.17***	0.17***	0.20***
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	No	Yes	Yes	Yes
Colony FE	No	No	No	Yes	Yes	Yes
Volatility Controls	No	No	No	No	Yes	Yes
Adjusted-R^2	0.60	0.70	0.70	0.74	0.78	0.80
Observations	84	84	84	84	84	84

Notes: This table establishes the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era on domestic patenting activity (average patents per capita 2000-2015CE). The analysis accounts for regional fixed effects, country's geographical characteristics, the time since the country experienced the Neolithic Revolution, colony fixed effects, and geographical determinants of statehood, cooperation and risk preferences. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

A potential concern with these results is that they capture foreign patenting activity. In order to mitigate this concern, columns (6) replicates the analysis for the domestic patenting activity of residents only. In particular, it establishes that there is a statistically and economically significant positive association between the time spent at the MDD and domestic patenting activity by residents of a country. After accounting for the same set of controls as in column (5), the analysis suggests that an additional century of isolation from the technological frontier during the pre-industrial era is associated with an increase of 20% in contemporary domestic patenting activity by residents. This result supports the proposed theory that isolation from the frontier during the pre-industrial era was conducive to the emergence of a culture and institutions promote innovation and entrepreneurship.

A major potential concern with this result is that it may capture the confounding effect of omitted cultural or institutional characteristics of the country. In particular, the time spent at the MDD may be correlated with the religious composition of a country, and thus with a major cultural determinant of economic behavior (Andersen, Bentzen, Dalgaard and Sharp, 2016). Similarly, given the European expansion in the post-1500 era, the time spent at the MDD may be correlated with the culture or institutions brought by European migrants. Moreover, the results may be biased if the time spent at

Table 12: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Contemporary Domestic Patenting Activity (Robustness)

	Log[Patents per capita by Residents (2000-2015CE)]							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time at MDD	0.18***	0.17***	0.17***	0.17**	0.18***	0.12**	0.26***	0.18**
	(0.05)	(0.06)	(0.06)	(0.07)	(0.05)	(0.06)	(0.05)	(0.07)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Colony FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Volatility Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Religious Shares	No	Yes	No	No	No	No	No	Yes
Constraints on Executive	No	No	Yes	No	No	No	No	Yes
Main Colonizer FE	No	No	No	Yes	No	No	No	Yes
Population Share with European Ancestry	No	No	No	No	Yes	No	No	Yes
Legal Origin FE	No	No	No	No	No	Yes	No	Yes
Distance to USA	No	No	No	No	No	No	Yes	Yes
Adjusted-R^2	0.80	0.79	0.80	0.77	0.80	0.84	0.81	0.82
Observations	81	81	81	81	81	81	81	81

Notes: This table establishes the robustness of the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era on domestic patenting activity (average patents per capita 2000-2015CE) by residents. In particular, it establishes the robustness of the result to accounting for religious composition, institutional quality, colonizer's identity, european ancestry, legal origins, and distance to contemporary frontier. All columns account for the full set of controls in Table 11. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

the MDD is correlated with a country's distance to the contemporary technological frontier.

In order to mitigate these concerns, Table 12 explores the robustness of the positive association between the time spent at the MDD and domestic patenting activity by residents to accounting for the potential effects of these confounders. Column (1) replicates the analysis of column (6) in Table 11 for the sample of countries for which all additional controls are available. The result remains statistically and economically significant and suggests that an additional century of isolation from the technological frontier during the pre-industrial era is associated with an increase of 18% in contemporary domestic patenting activity by residents. Reassuringly, accounting for a country's religious composition, and thus for any cultural effects of religion (column 2); its level of constraints on the executive (column 3); fixed effects for the identity of its main colonizer, and thus for any unobserved cultural, institutional or ancestral characteristics associated with its main colonizer (column 4); the share of its population that descends from European ancestors, and thus for the extent of European influence in the country's culture, institutions and human capital (column 5); fixed effects for the origin of its legal system, and thus for any unobserved heterogeneity due to its legal tradition (column 6); or its distance to the contemporary technological frontier does not qualitatively affect the results. Moreover, accounting simultaneously for all these potential confounders has no effect on the estimated relation.

Another concern with these results is that not all innovative activity results in new patents. Thus, the results may underestimate the potential positive effect of the time spent at the MDD on innovation. On the other hand, patents may not translate directly into economic activity and thus development. In order to address this concern, Table 13 analyzes the effect of the time spent at

Table 13: Persistent Effect of Isolation from the Pre-industrial Technological Frontier on Contemporary Entrepreneurial Activity

	Log[New Firms per 1,000 people (2000-2015CE)]						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time at MDD	0.16***	0.19**	0.18**	0.19**	0.18**	0.17**	0.19**
	(0.06)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	Yes	Yes	Yes	Yes
Colony FE	No	No	No	Yes	Yes	Yes	Yes
Volatility Controls	No	No	No	No	Yes	Yes	Yes
Religious Shares	No	No	No	No	No	Yes	Yes
Constraints on Executive	No	No	No	No	No	Yes	Yes
Main Colonizer FE	No	No	No	No	No	No	Yes
Population Share with European Ancestry	No	No	No	No	No	No	Yes
Legal Origin FE	No	No	No	No	No	No	Yes
Distance to USA	No	No	No	No	No	No	Yes
Adjusted-R^2	0.41	0.56	0.55	0.55	0.54	0.54	0.65
Observations	85	85	85	85	85	85	85

Notes: This table establishes the positive cumulative effect of being isolated from the technological frontier during the pre-industrial era on the number of new firms registered per 1,000 people of ages 15-64 (average 2000-2015CE). In particular, it establishes the robustness of the result to accounting for regional fixed effects, all geographical controls in Table 11, time since the country experienced the Neolithic Revolution, colony fixed effects, geographical determinants of statehood, risk attitudes and cooperation, religious composition, institutional quality, colonizer's identity, european ancestry, legal origins, and distance to contemporary frontier. Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

the MDD on entrepreneurship. In particular, innovative activity that results in the creation of new business opportunities should potentially be accompanied by the arrival of new firms in the economy. Reassuringly, the results in Table 13 suggest that there exists an economically and statistically significant positive association between the time spent at the MDD and the density of new firms. Moreover, this association is robust to accounting for regional fixed effects, geographical characteristics, the time since the Neolithic Revolution, colonial fixed effects, religious composition, institutional quality, colonizer fixed effects, european ancestry, legal origin fixed effects, and the distance to the contemporary technological frontier. In particular, after accounting for the potential effect of all these confounders, the analysis suggests that an additional century of isolation from the technological frontier during the pre-industrial era is associated with an increase of 19% in the number of new firms per 1,000 people.

7 Conclusions

This research explores the effects of the geographical distance to the pre-industrial technological frontier on economic development. It proposes that during the pre-industrial era, while remoteness from the frontier diminished imitation, it fostered the emergence of a culture conducive to innovation, knowledge creation and entrepreneurship, which may have persisted into the modern era. In line with this prediction, the analysis establishes both theoretically and empirically that there exists a persistent non-monotonic effect of distance to the frontier on economic development. In particular, exploiting a novel measure of the travel time to the technological frontier and variations in its location during the pre-industrial era, it establishes a robust persistent U-shaped relation between the distance to the pre-industrial technological frontier and economic development. Moreover, it demonstrates that isolation from the pre-industrial technological frontier has had a positive cumulative effect on innovation and entrepreneurial activity levels, suggesting isolation may indeed have encouraged the emergence of a culture conducive to innovation and entrepreneurship.

Although technological progress may have diminished the role of geographical distance in the contemporary period, the theory suggests that cultural and institutional differences from the contemporary technological frontier may be similarly conducive to innovation and entrepreneurship in the modern era. Thus, these forces may be driving the innovative and entrepreneurial activities in locations where cultural and institutional differences may prevent technological diffusion from the contemporary technological frontier. In particular, health care innovations that could substantially lower costs and increase access are being generated in countries that are culturally and institutionally different from the West. For example, the development and simplification of cataract surgery with lens implantation at the community level, small incision cataract surgery, intraocular lenses, and sutureless surgical procedures has been pioneered by a group of doctors in the Tilganga Eye Center in Nepal. Similarly, General Electric's strategy of reverse innovation, in which products are developed in markets dissimilar to the frontier and then distributed globally, have generated innovations like the portable ultrasound and ECG (Immelt et al., 2009).

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APPENDIX NOT FOR PUBLICATION (available online only)

A Human Mobility Index and Seafaring

This section explains the construction of the Human Mobility Index with Seafaring (HMISea) and the distance measures based on it, and performs some validation tests for these measures. Unlike previous approaches, the analysis measures geographic distances during the pre-industrial era by the travel time between locations. This approach can be justified by fact that during the pre-industrial era, travel times were the most important determinants of transportation costs (O'Rourke and Williamson, 2001). The analysis constructs the HMISea in two steps: First, the analysis estimates the Human Mobility Index (HMI), which estimates the time required to travel on each square kilometer on land during the pre-industrial era. Second, it estimates the time required to cross each square kilometer of sea during the pre-industrial era.

The Human Mobility Index (HMI) is based on Hayes (1994) study of infantry movement. In particular, Hayes (1994) estimates the maximal sustainable speeds of dismounted infantry movement under different temperature, relative humidity, slope, and terrain conditions: he determined the maximum sustainable metabolic rates for soldiers of weight 70 kilograms, 23 years of age, and 1.7 meters height, each carrying a load of 20 kilograms, which he then used to estimate the maximum sustainable speed for each terrain characteristic. Hayes focused on the levels of metabolic rates and speeds that can be sustained for long periods of time without causing the soldier to become a victim of heat-exhaustion. The different meteorological, terrain, and risk conditions considered by him are:

- temperature: 5°-35°C in 5° increments
- relative humidity: 5, 25, 50, 75 and 95%
- cloud cover: night, cloudy, partially cloudy, clear sky
- slope: -50% to 50% in 10% steps, except in the range -20% to 20% where 5% steps were used
- terrain: black top, dirt road, and loose sand
- heat exhaustion risk: high, medium, and low

Using Hayes (1994) data, this paper estimates the relationship between the highest sustainable speed and the geographical variables considered by him. The estimated relationship can be applied to the geographical conditions in each cell of 1 square kilometer in the world to estimate the minimum travel time to cross it.

The analysis uses the estimated relationship under clear sky, high risk conditions, and loose sand to construct HMI, i.e., when estimating the time of travel on each square kilometer on land. Hayes' data suggest that the high risk of heat stress assumption generates *ceteris paribus* the highest sustainable speeds among any configuration of meteorological and terrain conditions. On the other hand, the clear sky assumption generates the slowest speeds sustainable under high risk of heat exhaustion. Additionally, among the types of terrains Hayes analyzes, loose sand seems closer to the types one would expect humans to have encountered earlier in history. Using this configuration of sky cover conditions, heat exhaustion risk levels, and terrain types, the analysis computes the maximum sustainable speed on each square kilometer in the world, which determines the (minimum) time required to cross it, given its slope, its temperature, and its relative humidity.[20]

[20] While it would be possible to use data for a particular day or month or year, the analysis uses the average yearly temperatures and relative humidities for each square kilometer, since the research is not in trying to capture the conditions of a specific voyage, but of the average conditions of travel.

In order to construct the Human Mobility Index (HMI), the analysis computes the average slope in each cell i of one square kilometer ($30'' \times 30''$) in the world using the GLOBE data set (GLOBE Task Team and others, 1999) as

$$slope_i = \frac{1}{\bar{l}} \left(\frac{1}{8} \sum_{k=1}^{8} (h_i - h_{j_k}) \right)$$

where the term in parenthesis is the average change in elevation when moving out of the cell i and $\bar{l}$ is the distance between the centers of the cells. Additionally, the analysis uses the average temperature in each cell i according to Hijmans et al. (2005) and the average relative humidity from New et al. (2002). Given that New et al. (2002) present their data in cells of size $10' \times 10'$, the analysis assigns to each cell i of size $30'' \times 30''$, the value of the $10' \times 10'$ cell in which it is contained without any transformation.

The HMI cost surface can be used to calculate distances between any two points on the same continental mass to estimate the minimum travel time between them, for periods before the advent of seafaring technology or for distances among places in which seafaring is either unfeasible or regarded as inferior to mobility by land. Although this might be useful for helping to answer certain types of questions, the lack of the possibility to cross major bodies of water might limit the usefulness of these analyses and the types of questions that can be answered. For this reason, the analysis extends the HMI cost surface in order to incorporate the possibility of travel across larger bodies of water.

The history of ancient seafaring can be characterized by three major events: (i) the introduction of boats with paddles (ca. 11000-5,000 BCE), (ii) the invention of the sail (ca. 3,500 BCE), and (iii) the invention of navigational devices (ca. 100 CE). Table A.1 shows some of the major developments in the history of seafaring from 11000 BCE to 1,200 CE. Although many improvements and innovations were accumulated during this period, the data suggests that the gains that these permitted in terms of speed and wider applicability were limited (Braudel, 1972). Özak (2010) constructs a data set that compiles estimations, made by historians and from primary sources, of the travel speed that ships attained in various voyages that took place between the years 500 BCE and 1500 CE. This data suggests that the average speed remained relatively stable during this period.[21] The main differences in speed stem, unsurprisingly, not from the period in which the voyage took place, but its purpose and location. In particular, the climatic conditions, currents, and winds characteristic of each sea are reflected on the speeds attained.

Based on this information, the analysis sets the speed required to cross a cell i in a sea by averaging the speeds of the voyages that passed through that sea. If no information is available, although the historical record indicates that sea travel was common in that sea before the Era of Exploration, the analysis assigns to it the value of the closest sea for which information is available. Table A.2 shows the assigned speeds and implied crossing times. Combining the HMI cost surface and the Seafaring travel times generates the HMISea cost surface, which can be used to determine minimal travel times among locations employing pre-industrial technologies.

In order to test the reliability of these estimates, the analysis constructs optimal travel times between various regions and compare these estimates or the paths they generate with a sample of historical data on trade, news diffusion, and cultural distances.

[21] Furthermore, if one takes the speed of the earliest steam ships as an upper bound, these estimates suggest that not much speed gain could be achieved in this era. Historians like Braudel (1972) and O'Rourke and Williamson (2001) argue that innovation in seafaring mostly increased dependability and lowered the risk of travel, but did not increase speed by much, before the advent of the steam engine and the internal combustion engine.

A.1 Historical Trade Routes

This section validates the new measure by comparing paths among capitals in the Old World with the location of historical trade, banking, pilgrimage and postal routes as compiled by Ciolek (2004). In particular, Ciolek (2004) compiles and georeferences around 4,500 stopping places of networks that allow for the movement of goods, people, and information from the year 500 BCE to 1,820 CE in the Old World (OWTRAD).[22] The analysis establishes that an artificial transportation network based on minimum travel paths among capitals in the Old World predicts the location of the historical OWTRAD network.

The analysis constructs the paths that minimize total travel time among pairs of capitals in the Old World (OPHMISea) and explores how well these paths explain the location of the historical locations identified by Ciolek (2004). In particular, it compares the transportation network among capitals generated using HMISea, OPHMISea, with the historical network compiled by Ciolek (2004). Importantly, with the exception of some capitals, the historical (OWTRAD) and artificial (OPHMISea) networks do not share any nodes in common. So, one should not expect the historical nodes to be geographically close to the paths on this artificial network, unless the OPHMISea network is capturing travel conditions during this era.

Figures 9-11 overlay the network (OPHMISea) on the OWTRAD nodes. The figures show that there is a non-depreciable set of nodes, which are not capitals, that are very close to the optimal paths. In order to have a better measure as to how these locations are geographically distributed with respect to the optimal paths, the analysis computes the minimum distance from each location to the artificial network OPHMISea. Table A.3 and A.4 present some statistics of the distribution of these distances.

Clearly, it is difficult to know if these distances are "close" in a meaningful sense. Furthermore, one could argue that the artificial network is located close to the historical nodes by pure chance. In order to address these concerns, the analysis compares the distances between OPHMISea and OWTRAD, with the distances to random linear networks (RLN). In particular, the analysis created 5,000 random linear networks (RLN) between the same capitals used to create the OPHMISea network and computed the minimum distance between each RLN and OWTRAD. These distributions of distances to RNL provide a measure of "closeness" between the OPHMISea and OWTRAD networks or whether it is all driven by chance. For each set of 5,000 RLN's the analysis imposed a different number of edges that each capital should have.

As can be seen in table A.3 the OPHMISea network performs rather well compared to the RLN's. In particular, all the statistics presented in table A.3 are lower for the OPHMISea network than for any of the RLN's, sometimes by two orders of magnitude. Additionally, table A.4 shows that less than 10% of OWTRAD nodes are over 90 kms from the OPHMISea network. On the other hand, over 50% of those nodes are at a distance higher than 360 kms for the RLN's, even when these are fully connected. These results suggest that the OPHMISea network and the OWTRAD nodes are close in a meaningful sense. Furthermore, they hint that distances measured by using HMISea and the paths they generate are closely related to travel and trade conditions in the pre-industrial.

[22] The data is available at `http://www.ciolek.com/owtrad.html`.

Table A.1: A timeline of seafaring.

Year	Event	Civilization	Note
11000 BCE	Evidence of trade		Obsidian imported into Greece from the island of Melos
6000 BCE	People settle the island of Crete		
5000 BCE	Dugout boats and wodden paddle in China		Neolithic dugout boats and wooden paddles have been excavated at Hemudu and Xiaoshan in China's Zhejiang province
4500 BCE	Oak canoes are used on the Seine		The oldest wooden boats ever found in Europe. The largest of the canoes is nearly 5 meters (16 ft)
4000 BCE	Boats in Egypt	Egyptian	"Egyptians build boats made from planks joined together; previuosly, boats were dogout canoes and possible rafts of reeds bound together or skins stretched over a framework"
3500 BCE	Invention of sails	Sumerians Egyptians	
3000 BCE	Evidence of sailing activities		"Boats built in Egypt or Mesopotamia are paddled or sailed with a simple square sail; rowing has not yet been discovered; egyptians boats are essentially papyrus rafts at this time, although shaped with upturned ends"
2900 BCE	Earliest contacts between Egypt and Crete	Egyptian	"Bowls found on crete appear to have been made in Egypt, suggesting seagoing trade between the two; it is likely that the Minoan ships were even more venturous, trading all over the mediterranean by this period"
2650 BCE	Import of timber from Lebanon	Egyptian	"A command from the Egyptian pharao Snefru to bring ""40 ships filled with cedar logs"" to Egypt from Lebannon is the first written record of the existence of boats and shipping"
2500 BCE	Wooden Boats and invention of oars	Egyptian	"Boats in Egypt are now made of wood, instead of being papyrus rafts with unturned ends; oars have probably been invented by this time"
2500 BCE	Shipping		"Clay tablets record imports of stone to southern Mesopotamia form either Magan or Makran (both ports on the Persian Gulf); Magan developed a reputation as a port, and the stone was probably transported by boat to the mouth of the Euphrates at the head of the gulf and then up the Tigris-Euphrates river system"
2400 BCE	Fleet of transports to ferry troops to some Asiatic coast	Egyptian	Pharaoh Sahure orders for his pyramid a representation of the levant coast; this is the earliest known depiction of seagoing ships that has been preserved and the earliest recorde use of ships for military purposes (they were undoubtely used in war earlier)
2000 BCE	Multi-planked boats in China	Xia Dynasty	
2000 BCE	Mentuhotep sends a ship to the Red Sea	Egyptian	
2000-1500 BCE	Heyday of Minoan maritime activity	Minoan	

Table A.1: A timeline of seafaring (continued).

Year	Event	Civilization	Note
1500 BCE	Expedition to Punt	Egyptian	
1400 BCE	Seagoing ships in the Mediterraean		Seagoing ships in the Mediterraean are built by first joining planks together to make a hull
1100 BCE	Wenamon's voyage	Egyptian	To bring wood from Lebanon
1100 BCE	Voyage of the Argo	Greek	To go to Colchis (Georgia today)
970 BCE	Trade with India	Phoenician	
1000-700 BCE	Phoenician colonize the west	Phoenician	From Tyre (where a port was built) to Utica to Cadiz
800 BCE	Invention of the Penteconter	Greek	"Penteconters are believed to have been between 28 and 33 meters long, approximately 4 meters wide and capable of reaching a top speed of 9 knots (18km/h)"
700 BCE	Invention of the two-banked galleys (Bireme)	Phoenician	
550 BCE	Invention of the trireme	Greek	"This type was employed by ancient Greece, Rome, and other Mediterranean maritime nations. The Athenian trireme had 54 oarsmen in the lowest or thalamite bank, 54 in the second or zygite bank, and 62 in the uppermost or thranite bank. Such a galley would have a length of about 39 m (about 128 ft) and a maximum width of perhaps 4.6 m (15 ft) at the waterline. The boat would sink about 1.2 m (about 4 ft) into the water."
500 BCE	Canal linking the Mediterranean with the Indian Ocean	Persian	This canal was 145km (90 miles) long and 45m (150ft) wide
425 BCE	Trade by sea with China	Chinesse Babylonian Greek	"Babylonians sailed to the South China Sea. Meanwhile, Chinese silk was sent to Greece by sea."
398 BCE	Invention of the quinquereme	Greek	
350 BCE	Peryplus of Niarchus	Greek	"The Periplus (pilot book) of Niarchus, an officer of Alexander the Great, describes the Persian coast. Niarchus commissioned thirty oared galleys to transport the troops of Alexander the Great from northwest India back to Mesopotamia, via the Persian Gulf and the Tigris, an established commercial route."
200 BCE	Construction of Magic Canal in China	Chinese	That enables a ship to sail from Canton (or anywhere else on the China Sea) to the latitude of present day Beijing
200 BCE	Construction of the largest naval vessel in the classical age	Egyptian	"Built by Ptolemy IV of Egypt. It had 4000 rowers in 40 banks, and carried as many as 3250 others as a crew and fighting marines (was a catamaran over 120 m-400 ft- long)"

Table A.1: A timeline of seafaring (continued).

Year	Event	Civilization	Note
200 BCE	Invention of the dry dock	Egyptian	“Ptolemy’s ship was built in a channel that was connected to the sea; when the ship was completed, the channel was filled with water and launched it ”
200 BCE	Introduction of three-masted vessels	Greek	“A foremast called an artemon, the main, and a mizzenmast at the rear”
120 BCE	Eudoxus sails to India	Greek	
12 BCE	Construction of Canal in Netherlands	Roman	Nero Claudius Drusus joins the Flevo Lacus (the largest lake in Netherlands) to the Rhine with a canal that also uses the Yssl River for part of the passage
0	Use of a small triangular topsail above the mainsail	Roman	
0	Earliest known despiction of a ship’s rudder	Chinesse	
45 CE	Construction of Canal in Germany	Roman	Gnaesus Domitius Corbulo digs a ship’s canal joining the Rhine with the Meuse River
62 CE	St. Paul’s voyage to Rome	Roman	
70 CE	The Grand Canal of China is started	Chinesse	965 Km (600 mi) long
100 CE	Use of grid for location	Chinesse	Zhang Heng develops the method of using a grid to locate points on a map
130 CE	Creation of device for orientation	Chinesse	Zhang Heng combines a water clock with an armallary to produce a device that keeps track of where stars are expected to be in the sky
270 CE	First form of compass	Chinesse	“The first form of compass is probably used for finding south, earlier applications of magnetic lodestones were more magical than practical”
520 CE	Paddle wheel boats	Roman	“The first paddle wheel boats are designed, to be powered by oxen walking in circles, as in a mill; it is unlikely that these were built”
1020 CE	Earliest known evidence that seagoing wooden ships are bieng built in the modern way		“A vessel wrecked off Serce Limani (Turkey), the construction started with a keel and framework to which planked is added”
1080 CE	First known reference to use of magnetic compass for navigation	Chinesse	Chinese scientist Shen Kua’s Dream pool essays contains the first reference
1170 CE	Regulations and navigation for navigation in China	Chinesse	“Were described by Zhu Yu, son of a former high port official and then governor of Guangzhou. Large ships carried several hundred men, the smaller ones more than a hundred. They navigated by the coasts, the stars, the compass, and seabed sampling.”

Table A.1: A timeline of seafaring (continued).

Year	Event	Civilization	Note
1180 CE	Sternpost rudder		"The sternpost rudder, possibly borrowed from the chinese, replaces the steering oars that have been used in Europe and the near East since antiquity"
1190 CE	First known western reference to the magnetic compass		in De naturis rerum by Alexander Neckam)

Table A.2: Speeds on sea.

Sea	Number of Voyages	Average Speed	Min. Speed	Max. Speed	Std. Deviation	Speed on Cell i	Time Required (hours)
Arabian Sea	9	6.99	4.82	9.45	1.46	7.56	0.13
Atlantic Ocean	8	11.6	3.47	28.94	7.35	12.55	0.08
Bay of Bengal	2	7.92	6.39	9.45	1.53	8.57	0.12
Black Sea	2	12.6	10.72	14.47	1.88	13.62	0.07
Gulf of Thailand	2	5.43	5.02	5.83	0.41	5.87	0.17
Indian Ocean	13	6.97	5.02	9.45	1.44	7.54	0.13
Malacca Strait	5	6.89	5.02	9.45	1.56	7.46	0.13
Mediterranean	87	9.62	2.14	17.23	4.06	10.4	0.1
North Sea	3	8.13	7.03	9.09	0.85	8.79	0.11
Persian Gulf	2	6.16	4.82	7.5	1.34	6.66	0.15
Red Sea	3	5.8	3.06	7.23	1.94	6.28	0.16
South China Sea	3	4.52	2.7	5.83	1.33	4.89	0.2
Bay of Bizcay	NA	NA	NA	NA	NA	12.55	0.08
Phillipine Sea	NA	NA	NA	NA	NA	4.89	0.2
Sea of Japan	NA	NA	NA	NA	NA	4.89	0.2
East China Sea	NA	NA	NA	NA	NA	4.89	0.2
Gulf of Tonkin	NA	NA	NA	NA	NA	4.89	0.2
Taiwan Strait	NA	NA	NA	NA	NA	4.89	0.2

Table A.2: Speeds on sea (continued).

Sea	Number of Voyages	Average Speed	Min. Speed	Max. Speed	Std. Deviation	Speed on Cell i	Time Required (hours)
Mozambique Channel	NA	NA	NA	NA	NA	7.54	0.13
English Channel	NA	NA	NA	NA	NA	12.55	0.08
Baltic Sea	NA	NA	NA	NA	NA	8.79	0.11
Caspian Sea	NA	NA	NA	NA	NA	13.62	0.07

Source: Özak (2010)

Table A.3: Distribution of distance from historical locations to Optimal Paths and Random Linear Networks.

Network	Distance from OWTRAD Nodes to Network.				
	Edges†	Average	Std	Median	Max (Max)§
OPHMISea		35	56	15	610
RLN4	4	2405	2824	480	9421(9431)
RLN6	6	2399	2827	454	9417(9431)
RLN8	8	2394	2828	437	9414(9431)
RLN16	16	2385	2830	406	9403(9431)
RLN32	32	2379	2829	384	9388(9431)
RLN64	64	2374	2829	370	9375(9429)
LN128‡	128	2371	2827	363	9366(9366)

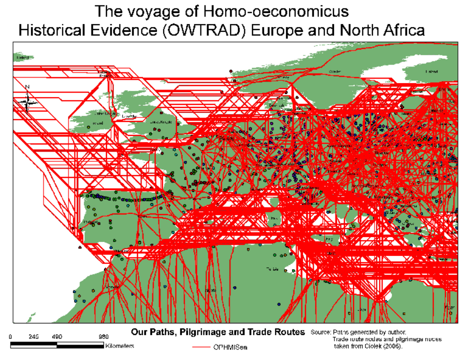
† Number of capitals to which each capital is randomly connected. ‡ All capitals are connected to each other.
§ Average maximum and in parenthesis maximum over all maxima.
Distance in Kilometers. Calculations by author.

Table A.4: Deciles of the distribution of distance from historical locations to Optimal Paths and Random Linear Networks.

Network	Distance from OWTRAD Nodes to Network (Deciles).								
	1	2	3	4	5	6	7	8	9
OPHMISea	1	3	6	10	15	24	35	52	90
RLN4	3	9	18	36	480	2755	3787	5747	7120
RLN6	2	6	12	24	454	2742	3779	5747	7120
RLN8	2	4	9	18	437	2733	3773	5746	7120
RLN16	1	2	4	9	406	2709	3756	5746	7119
RLN32	0	1	2	4	384	2692	3741	5745	7119
RLN64	0	0	1	2	370	2681	3729	5745	7118
LN128†	0	0	0	1	363	2675	3724	5745	7117

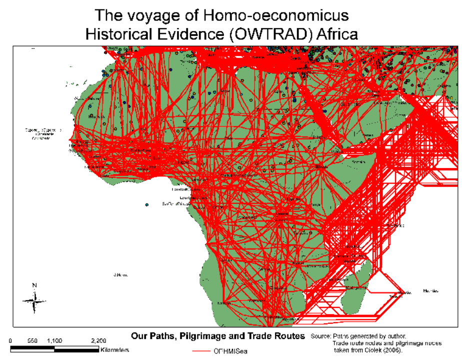
Distance in Kilometers. Calculations by author. † All capitals are connected to each other.

Figure 9: Optimal Paths for HMISea, trade and pilgrimage routes data for Europe and North Africa.



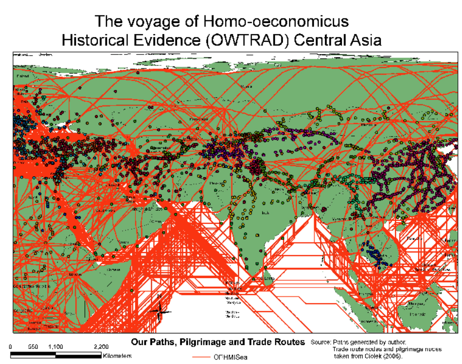
Source: Computations by author and data by Ciolek (2004).

Figure 10: Optimal Paths for HMISea, trade and pilgrimage routes for Africa and the Middle East.



Source: Computations by author and data by Ciolek (2004).

Figure 11: Optimal Paths for HMISea, trade and pilgrimage routes for Asia and the Middle East.



Source: Computations by author and data by Ciolek (2004).

A.2 Diffusion of News from Venice

This section validates the new measure by showing that HMISea estimated travel times are good predictors of actual recorded historical travel times. In particular, using historical data on the diffusion of news to Venice it shows that HMISea travel distances to Venice are highly positively correlated with recorded historical travel times.

In particular, in his *magnum opus*, Braudel (1972) analyzes the connections between history and geographical space using the Mediterranean as his example. One aspect analyzed by him is the effect of geography on communication and transportation costs. Using data by Sardella (1948) on the record of arrival of letters and news to the Signoria of Venice between 1497 and 1532 and on evidence of the Venetian *avvisi* available at the Public Record Office in London, he constructs some measures of the speed with which news travelled to and from Venice. Table A.6 reproduces Braudel's data.[23] He summarized this information about the speed of the transmission of news in 1500, 1686-1700 and 1733-1765 by means of iso-chronic lines in three graphs that are reproduced in Figure 12. As can be seen there, and as Braudel (1972) himself argues, the maps are roughly identical, showing the persistence of the effect of technological limitations on the speed of communication.[24] These maps are not perfect, in the sense that they are only approximations since, as Braudel argues, the speed with which news traveled in the period was very volatile and depended both on climatic conditions and on the price paid to the courier. Furthermore, the iso-chronic lines can only be imperfectly asserted at places with which there is communication. Still, they serve as a another source for comparison of the proposed cost surfaces and the travel times generated by them.

The analysis compares Braudel's iso-chronic lines with the travel times generated by HMI and HMISea. In particualr, using both HMI and HMISea the analysis computes the optimal paths to get from any cell i in the Old World to Venice. Using georeferencing methods, figures 13(a)-13(c) overlay the graphs generated by Braudel on the surface of optimal accumulated times of travel to Venice and the iso-chronic lines generated by HMI. Each red iso-chronic line represents half a week time of travel, which, under the assumption that news was transported in twelve-hour working days, can be interpreted as representing a one week accumulated travel time. Figures 14(a)-14(c) repeat this same analysis using the HMISea data.

Although the iso-chronic lines look similar in certain regions, it is difficult to ascertain the adequacy of the measures compared to the estimates visually. For this reason, table A.6 reproduces the data on the number of days required to travel from Venice to various cities as presented by Braudel (1972) and on the computations using HMI and HMISea. For example, Braudel found that news from Antwerp to Venice took a minimum of 8 days, normally 16 days and on average 20 days, while both HMI and HMISea measures require 7 days of continuous travel, or 15 twelve-hour working days or 22 eight-hour working days. Looking at the average travel times over all the cases presented by Braudel, one can infer that on average, the HMI is similar to the "normal" time estimate of Braudel, while the transformation of HMI into 8 hour days makes it similar to Braudel's maximum time estimate and the 12 hour days makes it similar to the average time measured by him. On the other hand, HMISea is similar to the minimum times reported by Braudel, while the 12 and 8 hour conversions of HMISea are similar to the normal and average times found by him. Table A.7 compares again the different measures with Braudel's estimates confirming the similarity between HMI and the "normal" time estimates, and between HMISea and the minimum travel time of news under the 24-hour continuous travel interpretation. If a 12 or 8-hour interpretation is taken, then HMISea is similar to Braudel's "normal" and average time estimates. These results suggest that historical minimal travel distances are similar to the estimates generated by the use of HMISea.

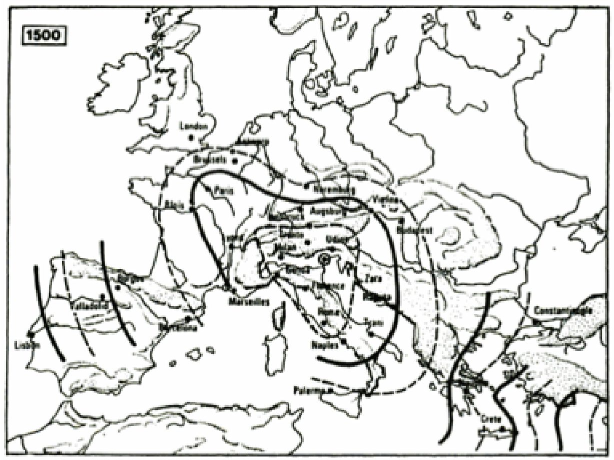
[23] The data is also aggregated in Braudel's presentation and analysis. There does not seem to exist a disaggregated version of the data, which would allow for a much better and interesting comparison, since one could control for the effect of price or urgency on travel speeds.

[24] In particular, Braudel (1972) argues that "[t]he differences from one map to another may seem very marked in certain directions. They are the result of the varying frequency of communications, depending on the urgency of the circumstances. Generally speaking, communication seems to be as slow on the third map as on the first, while the second shows noticeable shorter delays. But it cannot be regarded as definite proof." (p.367)

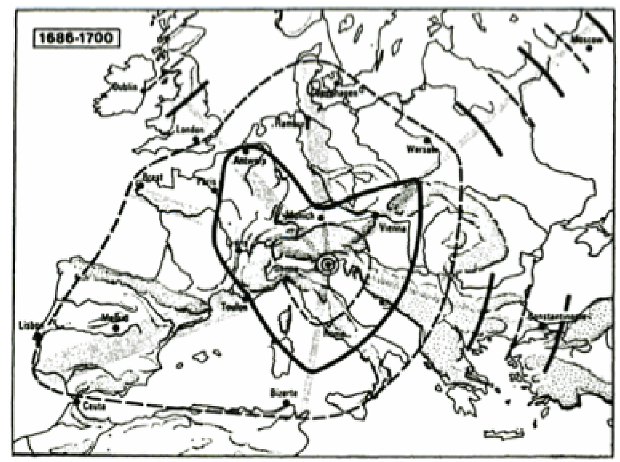
Table A.5: Correlation between Braudel's estimates, HMI and HMISea.

	Maximum	Average	Normal	Minimum	HMI
HMI	0.61	0.72	0.71	0.60	1
HMISea	0.65	0.68	0.65	0.71	0.77

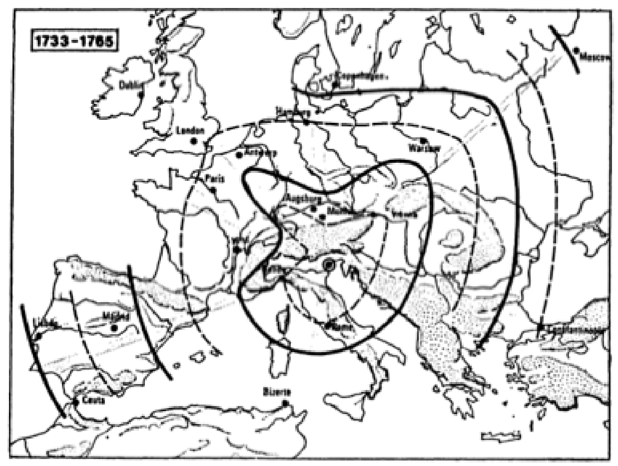
Figure 12: Diffusion of news from Venice.



(a) 1500 CE



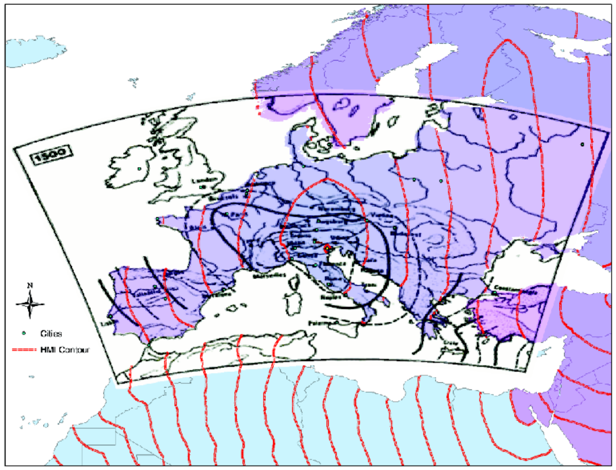
(b) 1686-1700CE



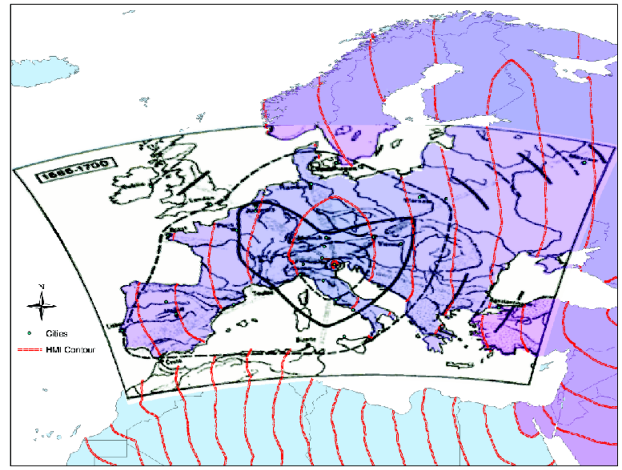
(c) 1733-1765CE

Source: Braudel (1972) Iso-chronic lines, representing intervals of one week, show all the locations that lie at the same travel time from Venice.

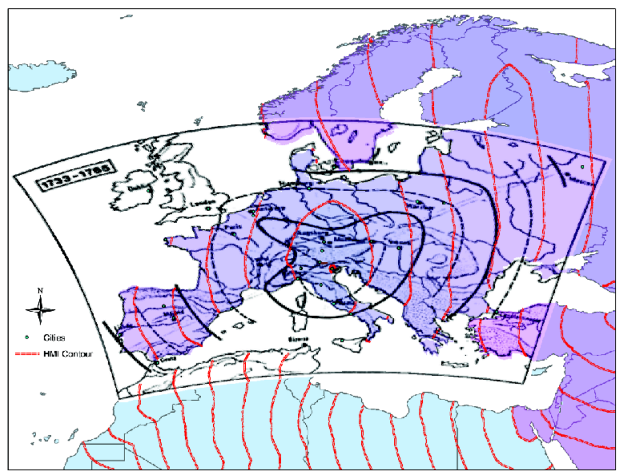
Figure 13: Distance from Venice (HMI).



(a) 1500 CE



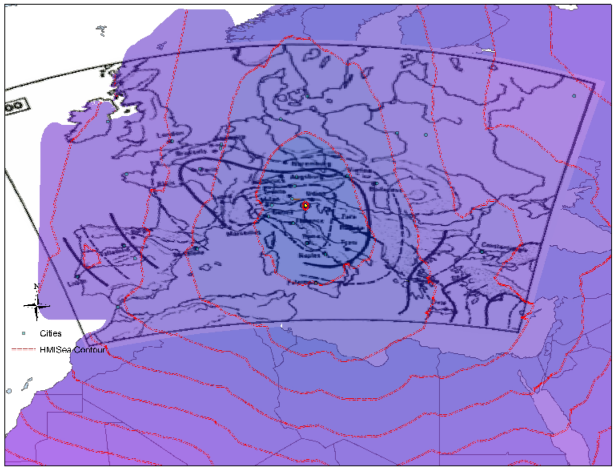
(b) 1686-1700CE



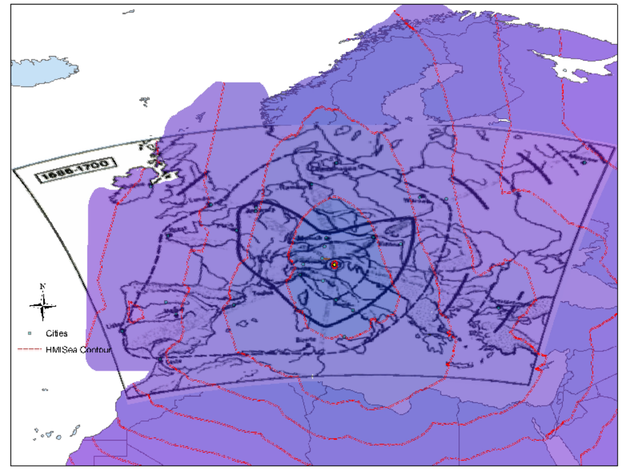
(c) 1733-1765CE

Georeferencing done by author. Original data by Braudel (1972). Red Iso-chronic lines, representing intervals of half week in HMI accumulated costs of travel to Venice. Under the assumption of a 12 hour travel per day, these iso-chronic lines can be interpreted as representing one week travel times.

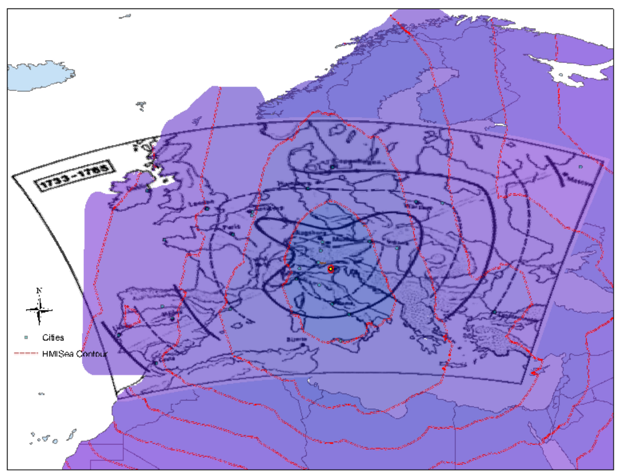
Figure 14: Distance from Venice (HMISea).



(a) 1500 CE



(b) 1686-1700CE



(c) 1733-1765CE

Georeferencing done by author. Original data by Braudel (1972). Red Iso-chronic lines, representing intervals of half week in HMISea accumulated costs of travel to Venice. Under the assumption of a 12 hour travel per day, these iso-chronic lines can be interpreted as representing one week travel times.

Table A.6: Distance to Venice from various cities as measured by the number of days travelled.

City	Braudel (1972)						HMI			HMISea		
	Total Cases	Normal Cases	Maximum	Average	Normal	Minimum	HMI	HMI days of 12 hours	HMI days of 8 hours	HMISea	HMISea days of 12 hours	HMISea days of 8 hours
Alexandria	266	19	89	65	55	17	43	86	129	10	20	30
Antwerp	83	13	36	20	16	8	7	15	22	7	15	22
Augsburg	110	19	21	11	12	5	2	4	6	2	4	6
Barcelona	171	16	77	22	19	8	10	19	29	6	13	19
Blois	345	53	27	14	10	5	9	18	27	9	18	26
Brussels	138	24	35	16	10	9	7	15	22	7	15	22
Budapest	317	39	35	18	19	7	6	12	18	5	11	16
Burgos	79	13	42	27	27	11	14	28	42	11	23	34
Calais	62	15	32	18	14	12	9	19	28	9	18	27
Candia	56	16	81	38	33	20	NA	NA	NA	8	15	23
Cairo	41	13	10	7	8	3	41	83	124	12	24	36
Constantinople	365	46	81	37	34	15	15	30	45	9	18	27
Corfu	316	39	45	19	15	7	NA	NA	NA	4	9	13
Damascus	56	17	102	80	76	28	34	69	103	12	24	37
Florence	387	103	13	4	3	1	1	3	4	1	3	4
Genoa	215	58	15	6	6	2	3	6	10	3	6	9
Innsbruck	163	41	16	7	6	4	1	2	3	1	2	3
Lisbon	35	9	69	46	43	27	20	40	59	13	26	39
London	672	78	52	27	24	9	NA	NA	NA	10	20	30
Lyons	812	225	25	12	13	4	6	12	18	6	12	18
Marseilles	26	7	21	14	12	8	6	12	18	5	9	14
Milan	871	329	8	3	3	1	3	5	8	3	5	8
Naples	682	180	20	9	8	4	NA	NA	NA	2	5	7
Nauplia	295	56	60	36	34	18	12	24	36	7	13	20
Nuremberg	39	11	32	20	21	8	2	5	7	2	5	7
Palermo	118	23	48	22	25	8	NA	NA	NA	4	7	11
Paris	473	62	34	12	12	7	8	17	25	8	17	25
Ragusa	95	18	26	13	14	5	NA	NA	NA	5	9	14
Rome	1053	406	9	4	4	2	2	5	7	2	4	6
Trani	94	14	30	12	12	4	NA	NA	NA	2	5	7
Trento	205	82	7	3	3	1	1	2	3	1	2	3
Udine	552	214	6	2	2	2	1	1	2	1	1	2
Valladolid	124	15	63	29	23	12	15	30	45	12	24	36
Vienna	145	32	32	14	13	8	4	7	11	3	7	10
Zara	153	28	25	8	6	1	3	7	10	1	3	4
Average	275	146	31	15	10	6	10	20	31	6	12	18
STD	265	132	23	14	11	5	12	23	35	4	8	11

Table A.7: Distance to Venice from various cities (Comparison).

	Braudel (1972)		HMI			HMISea			
City	Average/Minimum	Normal/Minimum	Average/HMI	Normal/HMI	HMI/Minimum	Average/HMISea	Normal/HMISea	HMISea/Minimum	HMISea/HMI
Alexandria	382	323	152	128	252	643	544	59	24
Antwerp	250	200	274	219	91	274	219	91	100
Augsburg	220	240	589	642	37	589	642	37	100
Barcelona	274	237	229	197	120	343	297	80	67
Blois	311	222	154	110	202	160	114	194	96
Brussels	178	111	220	137	81	220	137	81	100
Budapest	257	271	308	325	83	335	353	77	92
Burgos	245	245	194	194	126	239	239	102	81
Calais	149	116	192	149	78	201	156	74	95
Candia	188	163	NA	NA	NA	500	434	38	NA
Cairo	233	266	17	19	1376	59	67	395	29
Constantinople	246	226	248	227	99	412	378	60	60
Corfu	271	214	NA	NA	NA	445	351	61	NA
Damascus	285	271	233	222	122	655	622	44	36
Florence	400	300	302	227	132	302	227	132	100
Genoa	300	300	188	188	159	211	211	142	89
Innsbruck	175	150	627	538	28	627	538	28	100
Lisbon	170	159	233	217	73	352	329	48	66
London	299	266	NA	NA	NA	266	236	113	NA
Lyons	300	325	204	221	147	204	221	147	100
Marseilles	175	150	234	200	75	298	256	59	78
Milan	300	300	110	110	272	110	110	272	100
Naples	225	200	NA	NA	NA	364	324	62	NA
Nauplia	199	188	298	281	67	547	516	36	54
Nuremberg	250	262	859	902	29	859	902	29	100
Palermo	275	312	NA	NA	NA	628	713	44	NA
Paris	171	171	141	141	121	141	141	121	100
Ragusa	260	280	NA	NA	NA	286	308	91	NA
Rome	266	266	169	169	157	200	200	133	85
Trani	300	300	NA	NA	NA	487	487	62	NA
Trento	300	300	310	310	97	310	310	97	100
Udine	133	133	288	288	46	390	390	34	74
Valladolid	241	191	195	155	123	242	192	99	81
Vienna	174	162	382	355	46	425	394	41	90
Zara	800	600	235	176	341	557	418	144	42
Average	270	252	179	178	118	306	269	113	80
STD	92	73	108	103	107	151	136	68	24

A.3 Cultural Distances

This section validates the new measure by showing that they predict well cultural distances determined during the pre-industrial era. Cultural differences among societies are determined historically by their level of interaction, which depend, at least partially, on the initial differences in culture among those societies and their technological possibilities of interaction. Three measures that have been frequently used in order to measure cultural differences are genetic, religious, and linguistic distances between populations (Giuliano et al., 2006; Alesina et al., 2003; Cavalli-Sforza, 1973; Cavalli-Sforza and Bodmer, 1971; Cavalli-Sforza et al., 1994; Fearon, 2003; Liu et al., 2006; Prugnolle et al., 2005; Ramachandran et al., 2005). Özak (2010) analyzes how well various measures of geographical distance explain the cultural differences between populations as measured by genetic (Spolaore and Wacziarg, 2009), religious (Mecham et al., 2006), and linguistic (Fearon, 2003) distances. It shows that HMISea has a high explanatory power, is always statistically significant, and is positively correlated with these measures of cultural distance. I do not replicate all the analyses here, but show some representative results.

In particular, tables A.8 and A.9 analyze the relationship between genetic distance as measured by the FST and Nei distances to various geographic distances considered in Özak (2010). As established in those tables, the coefficient on HMISea always has the correct sign and is statistically significant. Additionally, it has a high explanatory power as measured by the adjusted R-squared. Notice that compared to the other measures it performs rather well, especially if compared to geodesic distances.

Similar results are obtained when using different measures of culture (Özak, 2010). These results further support the applicability of HMISea for measuring distances during the pre-industrial era. Furthermore, given its high positive correlation with various measures of cultural distance, one could use it as a proxy of cultural distance for regions in which only very coarse measures exist.

Table A.8: F_{ST} genetic distance in 1500 and Mobility Measures.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	Dependent variable: F_{ST} genetic distance in 1500											
HMI Cost (weeks)	0.560***				0.557***				0.880***			
	(0.032)				(0.059)				(0.081)			
HMISea Cost (weeks)		0.469***				0.508***				0.797***		
		(0.027)				(0.063)				(0.076)		
RIX distance (1000's km)			0.235***				0.341***				0.405***	
			(0.013)				(0.048)				(0.042)	
Geodesic Distance				1.038***				0.692***				1.279***
				(0.085)				(0.115)				(0.124)
Standardized β	0.619	0.505	0.487	0.503	0.615	0.547	0.706	0.335	0.972	0.858	0.839	0.620
Continental FE	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO	NO	NO
Country FE	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES
Adjusted R-squared	0.383	0.255	0.237	0.254	0.613	0.594	0.595	0.572	0.651	0.502	0.517	0.435
Observations	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454

Two-way clustered robust standard errors in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table A.9: *Nei* genetic distance in 1500 and Mobility Measures.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	Dependent variable: *Nei* genetic distance in 1500											
HMI Cost (weeks)	0.096***				0.112***				0.142***			
	(0.005)				(0.010)				(0.013)			
HMISea Cost (weeks)		0.081***				0.101***				0.130***		
		(0.004)				(0.011)				(0.012)		
RIX distance (1000's km)			0.040***				0.064***				0.065***	
			(0.002)				(0.008)				(0.007)	
Geodesic Distance				0.161***				0.091***				0.195***
				(0.015)				(0.022)				(0.021)
Standardized β	0.626	0.517	0.487	0.464	0.733	0.647	0.785	0.262	0.932	0.830	0.804	0.562
Continental FE	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO	NO	NO
Country FE	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES
Adjusted R-squared	0.393	0.267	0.238	0.215	0.587	0.558	0.550	0.495	0.640	0.507	0.516	0.421
Observations	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454	9454

Two-way clustered robust standard errors in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

B Summary Statistics

This section presents the summary statistics for the variables used in the different tables in the main body of the paper. Since I have tried to use the largest sample possible for each analysis, there are multiple samples. I present the summary statistics for each set of variables used in each table in the main body in a different table.

Table B.10: Summary statistics for variables used in regressions for table 1-3.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Pre-industrial distance to Netherlands (weeks)	5.393	3.595	0	12.067	82
Squared Pre-industrial distance to Netherlands	41.854	41.96	0	145.602	82
Pre-industrial distance to China	8.24	3.48	0	14.306	82
Sq. Pre-industrial distance to China	79.861	57.093	0	204.669	82
average technology adoption in agriculture in period	0.768	0.317	0	1	82
average technology adoption in communications in period	0.558	0.381	0	1	82
average technology adoption in transportation in period	0.348	0.267	0	1	82
average technology adoption in military in period	0.485	0.372	0	1	82
average technology adoption in industry in period	0.787	0.273	0	1	82
average of the sectoral technology adoption in period	0.589	0.286	0.1	1	82
average of the sectoral technology adoption in period (migration corrected)	0.6	0.272	0.157	0.995	82
Lagged Average Technology	0.845	0.179	0.6	1	82
European Colony (includes Turkey)	0.159	0.367	0	1	82
Pre-industrial distance to local technological frontier in 1500CE	3.155	2.492	0	9.731	82
Pre-industrial distance to closest trade route	0.58	0.949	0	3.824	82
Latitude in degrees	24.183	23.572	-29.317	60.133	82
Squared Latitude	1133.7	1081.724	0.111	3616.018	82
Island dummy	0.073	0.262	0	1	82
1 if landlocked	0.244	0.432	0	1	82
Arable land (% of land area)	17.259	15.485	0.32	65.346	82
% land area tropics+subtropics (Af+Am+Aw+Cw)	0.325	0.416	0	1	82
mean m above sea level (in 1000m)	0.61	0.497	0.03	2.565	82
Area in millions of km2	0.909	2.1	0.028	16.573	82

Table B.11: Summary statistics for variables used in regressions for table **??**.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Populationdensity from McEvedy and Jones	1.055	1.553	-3.172	5.757	497
Pre-industrial (HMISea) distance to frontier in period	4.936	3.061	0	12.378	497
Squared Pre-industrial (HMISea) distance to frontier in period	33.717	34.493	0	153.227	497
Pre-industrial distance to China	7.928	3.263	0	14.306	497
Sq. Pre-industrial distance to China	73.483	53.72	0	204.669	497
Years (BP) since transition to agriculture	4.528	2.474	-0.749	10.3	478
European Colony (includes Turkey)	0.209	0.407	0	1	497

Table B.12: Summary statistics for variables used in regressions for table **??**.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Log GDP per capita (PPP, year 2000)	8.1	1.37	5.42	10.49	102
Pre-industrial distance to UK (weeks)	5.4	3.47	0	12.38	102
Fst genetic distance relative to United Kingdom, dominant group	0.09	0.08	0	0.23	102
Diference latitude relative to United Kingdom	26.85	22.75	0	80.82	102
Diference absolute latitude relative to United Kingdom	22.34	16.5	0	51.17	102
Diference longitude relative to United Kingdom	36.74	33.7	0	139.92	102
Geodesic distance relative to United States (1000's km)	9.18	2.69	5.12	16.18	102
Geodesic distance relative to Japan (1000's km)	9.47	3.35	0	14.75	102
Geodesic distance relative to United Kingdom (1000's km)	4.69	3.03	0	11.72	102
Common official language with United Kingdom	0.23	0.42	0	1	102
Religious distance to United Kingdom (weighted)	0.81	0.14	0	1	102
Linguistic distance to United Kingdom (weighted)	0.97	0.2	0	2.02	102
Absolute latitude	30.21	17.84	0.33	60.13	102
Years (BP) since transition to agriculture	5.26	2.34	1	10.5	102
Arable land (% of land area)	18.32	14.52	0.47	61.95	102
Island dummy	0.08	0.27	0	1	102
1 if landlocked	0.3	0.46	0	1	102
% land area tropics+subtropics (Af+Am+Aw+Cw)	0.31	0.42	0	1	102
mean m above sea level (in 1000m)	0.65	0.62	0.01	3.19	102
Area in millions of km2	0.67	1.91	0.01	16.57	102
mean distance to coast or river	394.52	513.86	11.04	2385.58	102
%area 100km from icefree coast or sea-nav. river	0.43	0.38	0	1	102
Ethnic fractionalization	0.46	0.27	0	0.93	102
legal origin - british	0.26	0.44	0	1	102
legal origin - french	0.35	0.48	0	1	102
legal origin - socialist	0.29	0.46	0	1	102
legal origin - german	0.05	0.22	0	1	102
legal origin - scandinavian	0.04	0.2	0	1	102
Executive Constraints (Decision Rules): 1 (low) - 7 (high)	1.63	16.16	-88	7	102
Protestants as %pop 1980	11.83	21.41	0	97.8	102
Catholics as %pop 1980	20.82	28.73	0	96.90	102
muslims as % pop 1980	24.7	33.83	0	99.40	102

Table B.13: Summary statistics for variables used in regressions for table **??**.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Log GDP per capita (PPP, year 2000)	8.13	1.38	5.42	10.89	106
LDD Index	0.51	0.83	0	3	106
MDD Index	1.25	1.1	0	4	106
MDD Index	0.35	0.86	0	4	106
Absolute latitude	30.62	17.87	0.33	60.13	106
Years (BP) since transition to agriculture	5.28	2.32	1	10.5	106
Arable land (% of land area)	18.5	14.58	0.47	61.95	106
Island dummy	0.08	0.27	0	1	106
1 if landlocked	0.3	0.46	0	1	106
% land area tropics+subtropics (Af+Am+Aw+Cw)	0.3	0.42	0	1	106
mean m above sea level (in 1000m)	0.64	0.61	0.01	3.19	106
Area in millions of km2	0.65	1.88	0	16.57	106
mean distance to coast or river	382.38	507.8	11.04	2385.58	106
%area 100km from icefree coast or sea-nav. river	0.44	0.38	0	1	106

C A model of technology imitation and creation in a world with many frontiers

This section complements the presentation of the model presented in the main body of the text. The world consists of a set of economies $\mathcal{E} \subseteq \mathbb{R}^n$ and n technological leaders. Assume that all economies in $\mathcal{E}$ are identical except for their geographical distance $\mathbf{d} = (d_1, \ldots, d_n)$ from these leaders, and thus identify each economy with this distance vector $\mathbf{d}$. Each economy $\mathbf{d} \in \mathcal{E}$, is populated by overlapping generations of two-period lived agents. Population is constant and is normalized so that its size is 1. Each agent is endowed with one unit of time when young and one unit of time when old. For simplicity, assume that young agents can only engage in activities of imitation or creation of technology, and do not engage in consumption. On the other hand, old agents can only engage in production and consumption activities, where their production possibilities are determined by their own technology, which is generated by their decisions when young and the technology left by their parents.[25]

Individuals born in period $t-1$ inherit a level of technology A_{t-1} from their parents. They increase their stock of technology, which will be available for production in period t, using two types of intermediate inputs. The first intermediate input, $\tilde{I}$, is produced by imitation from the technological frontiers, while the second, $\tilde{R}$, is produced through independent creation. Productivity in each activity depends not only on the amount of labor the individual inputs, but also on the amount of labor their parents allocated when they were young. This captures the idea of intertemporal spillovers in imitation and creation of technologies, where the productivity of the current generation depends on the allocations of previous generations.

In particular, let l_t denote the amount of labor an individual born in period $t-1$ devotes to independent creation. She produces a quantity $\tilde{R}_t = a l_{t-1}^{\alpha'} l_t^{\alpha} A_{t-1}$ of independent knowledge, where $a > 0$, $\alpha', \alpha \in (0,1)$. She devotes the rest of her time, $(1 - l_t)$, to creating intermediate knowledge through imitation from the frontiers. Let i_{jt} denote the amount of time she devotes to imitating from frontier j, so that, $\sum_j i_{jt} = 1 - l_t$. Additionally, assume that the intermediate knowledge from each frontier is generated using similar technologies, namely

$$\tilde{I}_{jt} = b(d_j) i_{jt-1}^{\beta'} i_{jt}^{\beta} A_{t-1}, \qquad j = 1, \ldots, n \tag{8}$$

where $\beta', \beta \in (0,1)$, $b : \mathbb{R}_+ \to \mathbb{R}_{++}$ is continuous, decreasing, and twice differentiable. The function $b(d)$ captures the negative effect of distance on the productivity of imitation. So, from the point of view of the young individual, the only difference between frontiers is their distance. She combines the intermediate knowledge she gained from the frontiers through a constant elasticity of substitution production function to produce her aggregate knowledge from imitation

$$\tilde{I}_t = \left(\sum_{j=1}^{n} \lambda_{2j} \tilde{I}_{jt}^{\rho_2} \right)^{\frac{1}{\rho_2}} \tag{9}$$

where $\sum_{j=1}^{n} \lambda_{2j} = 1$, $\lambda_{2j} \in [0,1]$, $0 \leq \rho_2 \equiv \frac{\eta_2 - 1}{\eta_2} \leq 1$, and $\eta_2 \geq 1$ is the constant elasticity of substitution of knowledge between any two frontiers. The new knowledge she gains from imitation and independent creation are aggregated through another constant elasticity of substitution production function to produce total new knowledge. This new knowledge is added to the existing stock of

[25] These assumptions are made for convenience and in order to simplify the analysis. Changing them would not alter the main qualitative results since the underlying mechanism does not depend on them. For example, one could allow young agents to produce and consume or old agents to engage in additional research activities, without affecting the main results.

technology, so that

$$A_t - A_{t-1} = \Big[\lambda_1 \tilde{R}_t^{\rho_1} + (1-\lambda_1)\tilde{I}_t^{\rho_1}\Big]^{\frac{1}{\rho_1}} \tag{10}$$

where $\lambda_1 \in (0,1)$, $0 \leq \rho_1 \equiv \frac{\eta_1 - 1}{\eta_1} \leq 1$, and $\eta_1 \geq 1$ is the constant elasticity of substitution between imitation and creation. Letting $R_t = \tilde{R}_t / A_{t-1}$ and $I_t = \tilde{I}_t / A_{t-1}$, the growth rate of technology can be written as

$$g_t = \frac{A_t - A_{t-1}}{A_{t-1}} = \Big[\lambda_1 R_t^{\rho_1} + (1-\lambda_1) I_t^{\rho_1}\Big]^{\frac{1}{\rho_1}}. \tag{11}$$

Let $u(c_t)$, be the utility an agent born in period $t-1$ derives from consumption, where $u'(c) > 0$, $u''(c) < 0$. She chooses $l_t \in [0,1]$ and $i_{jt} \in [0,1]$ for $j = 1, \ldots, n$, in order to maximize her lifetime expected utility, i.e. she solves the following problem

$$\max_{(l_t,(i_{jt})_{j=1}^n)\in[0,1]^{n+1}} \quad u(c_t) \qquad \text{subject to} \qquad c_t = (1+g_t)A_{t-1},\ l_t + \sum_{j=1}^n i_{jt} = 1. \tag{12}$$

I assume the following two conditions are satisfied by the parameters of the production functions:

$$(\alpha' + \alpha)\rho_1 < 1, \qquad (\beta' + \beta)\rho_1 < 1, \tag{ES}$$

$$\frac{\rho_1 \beta \left[\frac{\alpha'}{\alpha} - \frac{\beta'}{\beta}\right] x}{\big(1 - (\alpha' + \alpha)\rho_1\big)(1-x) + \big(1 - (\beta' + \beta)\rho_1\big)x} = 1 \text{ for some } x \in (0,1). \tag{U}$$

Condition (ES) ensures that the marginal productivity of labor of young and old agents is "jointly" decreasing in the production of intermediate products. Condition (U) gives a measure of the strength of intertemporal spillovers across sectors, and imposes limits on the differences in labor productivities across them. Clearly, $\alpha'/\alpha > \beta'/\beta$ is a necessary condition for (U) to hold, which implies intertemporal spillovers are more important in creation than imitation Additionally, it implies that if in the production of each intermediate input the same quantities of current and past labor are used, then the marginal rate of technical substitution between current and past labor is larger in I than in R. So, as the distance d increases, the lower productivity of labor in imitation generates a substitution out of imitation and into research.

Clearly, the individual will allocate her time in all activities until the marginal product of labor is equal in all of them. The marginal productivities are given by

$$\frac{\partial g_t}{\partial R_t}\frac{\partial R_t}{\partial l_t} = \lambda_1 \alpha \left(\frac{g_t}{R_t}\right)^{1-\rho_1} \frac{R_t}{l_t} \tag{13}$$

$$\frac{\partial g_t}{\partial I_t}\frac{\partial I_t}{\partial I_{jt}}\frac{\partial I_{jt}}{\partial i_{jt}} = (1-\lambda_1)\lambda_{2j}\beta \left(\frac{g_t}{I_t}\right)^{1-\rho_1} \left(\frac{I_t}{I_{jt}}\right)^{1-\rho_2} \frac{I_{jt}}{i_{jt}} \tag{14}$$

Thus, it must be that for all $j, j' = 1, \ldots, n$

$$\frac{\partial g_t}{\partial R_t}\frac{\partial R_t}{\partial l_t} = \frac{\partial g_t}{\partial I_t}\frac{\partial I_t}{\partial I_{jt}}\frac{\partial I_{jt}}{\partial i_{jt}}, \qquad \text{and} \qquad \frac{\partial g_t}{\partial I_t}\frac{\partial I_t}{\partial I_{jt}}\frac{\partial I_{jt}}{\partial i_{jt}} = \frac{\partial g_t}{\partial I_t}\frac{\partial I_t}{\partial I_{j't}}\frac{\partial I_{j't}}{\partial i_{j't}}.$$

In particular, from (14) the last condition is

$$\frac{\partial I_t}{\partial I_{jt}}\frac{\partial I_{jt}}{\partial i_{jt}} = \lambda_{2j}\beta\left(\frac{I_t}{I_{jt}}\right)^{1-\rho_2}\frac{I_{jt}}{i_{jt}} = \lambda_{2j'}\beta\left(\frac{I_t}{I_{j't}}\right)^{1-\rho_2}\frac{I_{j't}}{i_{j't}} = \frac{\partial I_t}{\partial I_{j't}}\frac{\partial I_{j't}}{\partial i_{j't}},$$

which can be rewritten as the ratio of labor used in imitation in j to j', namely

$$i_t^{j,j'} \equiv \frac{i_{jt}}{i_{j't}} = \frac{\lambda_{2j}}{\lambda_{2j'}}\left(\frac{I_{jt}}{I_{j't}}\right)^{\rho_2} = \frac{\lambda_{2j}}{\lambda_{2j'}}\left(\frac{b(d_j)}{b(d_{j'})}(i_{t-1}^{j,j'})^{\beta'}(i_t^{j,j'})^{\beta}\right)^{\rho_2}.$$

This implies that in a steady state the ratio of labor used in imitation from j and j' is

$$i^{j,j'} \equiv \frac{i_j}{i_{j'}} = \left(\frac{\lambda_{2j}}{\lambda_{2j'}}\right)^{\frac{1}{1-\rho_2(\beta'+\beta)}}\left(\frac{b(d_j)}{b(d_{j'})}\right)^{\frac{\rho_2}{1-\rho_2(\beta'+\beta)}} \tag{15}$$

Clearly, $i^{j,j'}$ is decreasing in d_j and increasing in $d_{j'}$, so that increases in the distance to frontier j causes an increase in the relative amount of labor allocated to all other frontiers. This implies that in a steady state the ratio of knowledge imitated from frontiers j and j' is

$$\frac{I_j}{I_{j'}} = \left(\frac{\lambda_{2j}}{\lambda_{2j'}}\right)^{\frac{(\beta'+\beta)}{1-\rho_2(\beta'+\beta)}}\left(\frac{b(d_j)}{b(d_{j'})}\right)^{\frac{1}{1-\rho_2(\beta'+\beta)}}, \tag{16}$$

which is also decreasing in d_j and increasing in $d_{j'}$. This implies that

$$\frac{I}{I_j} = \left[\lambda_{2j} + \sum_{j'\neq j}\lambda_{2j}\left(\frac{I_j}{I_{j'}}\right)^{-\rho_2}\right]^{\frac{1}{\rho_2}}.$$

The ratio of marginal productivities of labor in a steady state imply that for each $j = 1,\ldots,n$, the ratio of labor allocated to imitating from j to labor used for independent creation satisfies

$$\frac{i_j}{l} = \underbrace{\frac{(1-\lambda_1)}{\lambda_1}\frac{\beta}{\alpha}}_{\Lambda}\lambda_{2j}\left(\frac{I}{R}\right)^{\rho_1}\left(\frac{I}{I_j}\right)^{-\rho_2}. \tag{17}$$

Replacing in the time endowment condition, this implies that the steady state allocation of labor to creation satisfies

$$l^* = \frac{1}{1+\Lambda\left[\sum_{j=1}^n \lambda_{2j}\left(\frac{I_j}{I}\right)^{\rho_2}\right]\left(\frac{I}{R}\right)^{\rho_1}} = \frac{1}{1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}}. \tag{18}$$

From equation (17) and the production functions for technology, it follows that for $j = 1,\ldots,n$

$$i_j = \frac{\Lambda\lambda_{2j}\left(\frac{I}{R}\right)^{\rho_1}\left(\frac{I_j}{I}\right)^{\rho_2}}{1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}}, \qquad I_j = b(d_j)^{\frac{1}{1-\rho_2(\beta'+\beta)}}\left(\frac{\Lambda\left(\frac{I}{R}\right)^{\rho_1}\frac{\lambda_{2j}}{I^{\rho_2}}}{1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}}\right)^{\frac{\beta'+\beta}{1-\rho_2(\beta'+\beta)}}, \tag{19}$$

and

$$I^{\rho_2} = \left(\sum_{j=1}^{n} \lambda_{2j} b(d_j)^{\frac{\rho_2}{1-\rho_2(\beta'+\beta)}}\right) \left(\frac{\Lambda \left(\frac{I}{R}\right)^{\rho_1} \frac{\lambda_2}{I^{\rho_2}}}{1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}}\right)^{\frac{\rho_2(\beta'+\beta)}{1-\rho_2(\beta'+\beta)}},$$

which is equivalent to

$$I = \left(\frac{\Lambda \left(\frac{I}{R}\right)^{\rho_1}}{1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}}\right)^{(\beta'+\beta)} \left(\sum_{j=1}^{n} \lambda_{2j}^{\frac{1}{1-\rho_2(\beta'+\beta)}} b(d_j)^{\frac{\rho_2}{1-\rho_2(\beta'+\beta)}}\right)^{\frac{1-\rho_2(\beta'+\beta)}{\rho_2}}. \tag{20}$$

All these are functions of $\mathbf{d}$ and the ratio of imitation to creation I/R, which is itself determined by following condition,

$$\frac{I}{R} = \frac{\left(\Lambda \left(\frac{I}{R}\right)^{\rho_1}\right)^{\beta'+\beta}}{\left(1+\Lambda\left(\frac{I}{R}\right)^{\rho_1}\right)^{(\beta'+\beta)-(\alpha'+\alpha)}} \frac{\left(\sum_{j=1}^{n} \lambda_{2j}^{\frac{1}{1-\rho_2(\beta'+\beta)}} b(d_j)^{\frac{\rho_2}{1-\rho_2(\beta'+\beta)}}\right)^{\frac{1-\rho_2(\beta'+\beta)}{\rho_2}}}{a}. \tag{21}$$

The right hand side is a strictly concave function of I/R with a slope that is infinite at $I/R = 0$ and goes to zero as $I/R \to \infty$. Thus, there exists a unique $(I/R)^*(\mathbf{d}) > 0$ that satisfies this equation, which is decreasing in each d_j $j = 1, \ldots, n$. This implies that l^* and R^* are increasing in d_j. So, the steady state growth rate of economy $\mathbf{d}$ is

$$g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = R^*(d) \left[\lambda_1 + (1-\lambda_1)\left(\frac{I}{R}(\mathbf{d}, \lambda_{\mathbf{2}})\right)^{\rho_1}\right]^{\frac{1}{\rho_1}}, \tag{22}$$

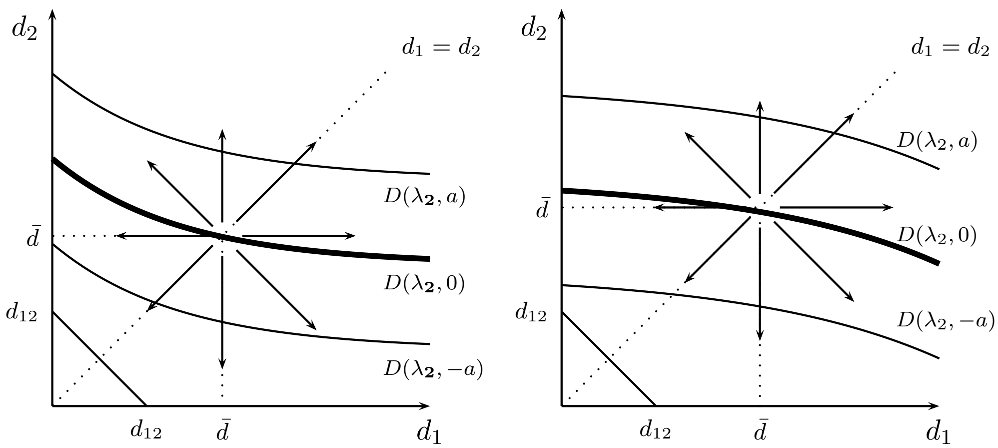
where $\lambda_{\mathbf{2}} = (\lambda_{2j})_{j=1}^{n}$. From the previous results, the first factor is increasing and the second one is decreasing in all the components of $\mathbf{d}$. This implies

$$\begin{aligned}\frac{\partial g^*}{\partial d_j} =& \frac{\partial R^*}{\partial d_j}\frac{g^*}{R^*} + (1-\lambda_1)\frac{\partial (I/R)^*}{\partial d_j} R^* \left(\frac{g^*}{R^*}\right)^{1-\rho_1} \\ =& \frac{g^*}{R^*}\left[\frac{\partial R^*}{\partial d_j} + (1-\lambda_1)\frac{\partial (I/R)^*}{\partial d_j}\frac{(R^*)}{\lambda_1 + (1-\lambda_1)\left((I/R)^*\right)^{\rho_1}}\right],\end{aligned}$$

where that variations in the distance to frontier j, d_j, generate a trade-off between imitation and creation that affect the growth rate of the economy.

Clearly, economies that are equidistant from all frontiers, effectively have only one frontier, and thus behave as if they existed in a world with a unique frontier. For these economies, $\mathbf{d} = d \cdot \mathbf{e}$ and $g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = G(d)$, where $\mathbf{e}$ is the n dimensional vector of ones, $d \in \mathbb{R}_+$, and $G(d)$ is the steady state growth rate in a world with a unique frontier for an economy at distance d from it. In appendix D I prove that assumptions (ES) and (U) imply that in a world with a unique frontier, $G(d)$ is U-shaped with the lowest growth rate attained at a distance $\bar{d} > 0$. Since any $d \in \mathbb{R}_+$ can be written as $d = \bar{d} + z$, $z \in \mathbb{R}$, this implies that equidistant economies' growth rates are given by $g^*\left((\bar{d}+z)\cdot\mathbf{e}, \lambda_{\mathbf{2}}\right) = G(\bar{d}+z)$, so that the growth rate for these economies is also U-shaped.

Figure 15: Isogrowth maps in a world with two frontiers.



(a) Convex $b(d)$ (b) Concave $b(d)$

$D(\lambda_2, 0)$ is the set of economies that have the lowest growth rate. The arrows show the direction of increase in the growth rate. d_{12} is the distance between frontier 1 and 2.

This implies that a similar non-monotonicity holds for all other economies as well. To see this, let a z-isogrowth curve be the set of economies that grow at rate $G(\bar{d}+z)$, i.e.

$$D(\lambda_{\mathbf{2}}, z) = \left\{ \mathbf{d} \in \mathcal{E} \mid g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = G(\bar{d}+z) \right\}. \tag{23}$$

Clearly, $[D(\lambda_{\mathbf{2}}, z)]_{z\in\mathbb{R}}$ defines a partition of $\mathcal{E}$.[26] Thus, $D(\lambda_{\mathbf{2}}, 0)$ is the $(n-1)$-manifold that splits $\mathcal{E}$ in two regions, such that for any $z_1 < z_2 < 0 < z_3 < z_4$, if $\mathbf{d}_i \in D(\lambda_{\mathbf{2}}, i)$, $i = 0, 1, 2, 3, 4$, it follows that $g^*(\mathbf{d}_1, \lambda_{\mathbf{2}}) > g^*(\mathbf{d}_2, \lambda_{\mathbf{2}}) > g^*(\mathbf{d}_0, \lambda_{\mathbf{2}})$ and $g^*(\mathbf{d}_0, \lambda_{\mathbf{2}}) < g^*(\mathbf{d}_3, \lambda_{\mathbf{2}}) < g^*(\mathbf{d}_4, \lambda_{\mathbf{2}})$. But, this implies that for any economy $\mathbf{d} \in D(\lambda_{\mathbf{2}}, z)$ where $z \geq 0$, $\partial g^*(\mathbf{d}, \lambda_{\mathbf{2}})/\partial d_j > 0$ for all $j = 1, \ldots, n$. Furthermore, for each frontier j, given the distances to the other $n-1$ frontiers, $\mathbf{d}_{-j}$, the steady state growth rate $g^*(\mathbf{d}, \lambda_{\mathbf{2}}) = G_j(d_j)$ is also U-shaped and has a minimum at some $\bar{d}_j(\mathbf{d}_{-j}) > 0$.

These results imply that the steady state profile of growth rates looks like a valley with the economies belonging to $D(\lambda_{\mathbf{2}}, 0)$ at its bottom. Figure 2 shows the isogrowth maps in a world with two frontiers. Panel (a) assumes $b(d)$ is convex, while panel (b) assumes $b(d)$ is concave. The distance $\bar{d}$ is the least desirable distance from the technological frontier and is located where the 45-degree line intersects $D(\lambda_{\mathbf{2}}, 0)$.

Notice that conventional wisdom is a special case of this theory in which either (i) $\bar{d} = \infty$, so that $D(\lambda_{\mathbf{2}}, z) = \emptyset$ for all $z \geq 0$, or (ii) the observable world is too small, so that $D(\lambda_{\mathbf{2}}, 0)$ is not observable. In either case, there would not exist a valley and a non-monotonicity cannot exist (see also appendix E).

[26] Since economies for which I/R is equal have the same growth rate, it follows that

$$D(\lambda_{\mathbf{2}}, z) = \left\{ \mathbf{d} \in \mathcal{E} \;\middle|\; \left(\sum_{j=1}^{n} \lambda_{2j}^{\frac{1}{1-\rho_2(\beta'+\beta)}} b(d_j)^{\frac{\rho_2}{1-\rho_2(\beta'+\beta)}} \right)^{\frac{1-\rho_2(\beta'+\beta)}{\rho_2}} = b(\bar{d}+z) \right\}.$$

D A model with a unique frontier

This section presents a version of the model presented in section 3 for the case of a unique frontier, $n = 1$. The proofs are collected in appendix G

The world consists of a set of economies $\mathcal{E} = [0, \tilde{d}]$, where $\tilde{d}$ is large enough,[27] and a technological leader economy. Assume that all economies in $\mathcal{E}$ are identical except for their geographical distance, d, to the technological leader and thus identify each economy with this distance d. Each economy $d \in \mathcal{E}$, is populated by overlapping generations of two-period lived agents. Population is constant and is normalized so that its size is 1. Each agent is endowed with one unit of time when young and one unit of time when old. For simplicity, assume that young agents can only engage in activities of imitation or creation of technology, and do not engage in consumption. On the other hand, old agents can only engage in production and consumption activities, where their production possibilities are determined by their own technology, which is generated by their decisions when young and the technology left by their parents.

Individuals born in period $t-1$ inherit a level of technology A_{t-1} from their parents. They increase their stock of technology, which will be available for production in period t, using two types of intermediate inputs. The first intermediate input, I, is produced by imitation from the technological frontier, while the second, R, is produced through independent creation. Let l_t denote the amount of labor an individual born in period $t-1$ devotes to independent creation. She produces a quantity $\tilde{R}_t = a l_{t-1}^{\alpha'} l_t^{\alpha} A_{t-1}$ of independent knowledge, where $a, \alpha', \alpha > 0$. She devotes the rest of her time, $(1-l_t)$, to imitation and generates $\tilde{I}_t = b(d)(1-l_{t-1})^{\beta'}(1-l_t)^{\beta} A_{t-1}$, where $\beta', \beta > 0$, $b(d)$ is continuous, decreasing, convex, and twice differentiable. The function $b(d)$ captures the negative effect of distance on the productivity of imitation. In order to capture the idea of intertemporal spillovers, I assume the productivity of each individual in the production of these intermediate goods depends on her parents' decisions in the past.

These intermediate products are aggregated through a constant elasticity of substitution production function to produce new knowledge, which is added to the existing stock of technology, so that

$$A_t - A_{t-1} = \left[\lambda \tilde{R}_t^{\rho} + (1-\lambda)\tilde{I}_t^{\rho}\right]^{\frac{1}{\rho}} \tag{24}$$

where $\lambda \in (0,1)$, $0 \leq \rho \equiv \frac{\eta-1}{\eta} \leq 1$, and $\eta \geq 1$ is the constant elasticity of substitution between imitation and creation. Letting $R_t = \tilde{R}_t / A_{t-1}$ and $I_t = \tilde{I}_t / A_{t-1}$, the growth rate of technology can be written as

$$g_t = \frac{A_t - A_{t-1}}{A_{t-1}} = \left[\lambda R_t^{\rho} + (1-\lambda) I_t^{\rho}\right]^{\frac{1}{\rho}}. \tag{25}$$

Let $u(c_t)$, be the utility an agent born in period $t-1$ derives from consumption, where $u'(c) > 0$, $u''(c) < 0$. She chooses $l_t \in [0,1]$ in order to maximize her lifetime expected utility, i.e. she solves the following problem

$$\max_{l_t \in [0,1]} \quad u(c_t) \qquad \text{subject to} \qquad c_t = (1+g_t)A_{t-1} \tag{26}$$

I assume the following two conditions are satisfied by the parameters of the production functions:

(ES) $(\alpha' + \alpha)\rho < 1$, $(\beta' + \beta)\rho < 1$.

[27] For the theoretical analysis the total number of economies and their spatial distribution is unimportant, as long as the set $\mathcal{E}$ is big (long) enough. In particular, I assume that $\tilde{d} = \inf\{d > 0 \mid G(d) \geq G(0)\}$, where $G(\cdot)$ is defined in equation (27). On the other hand, the number of economies and their distribution across space is very important for the empirical analysis, since it can affect the statistical significance and the sign of the parameters.

(U) $\frac{\rho\beta\left[\frac{\alpha'}{\alpha}-\frac{\beta'}{\beta}\right]x}{\left(1-(\alpha'+\alpha)\rho\right)(1-x)+\left(1-(\beta'+\beta)\rho\right)x} = 1$ for some $x \in (0,1)$.

The interpretation of these conditions was given in the text.

D.1 Equilibrium

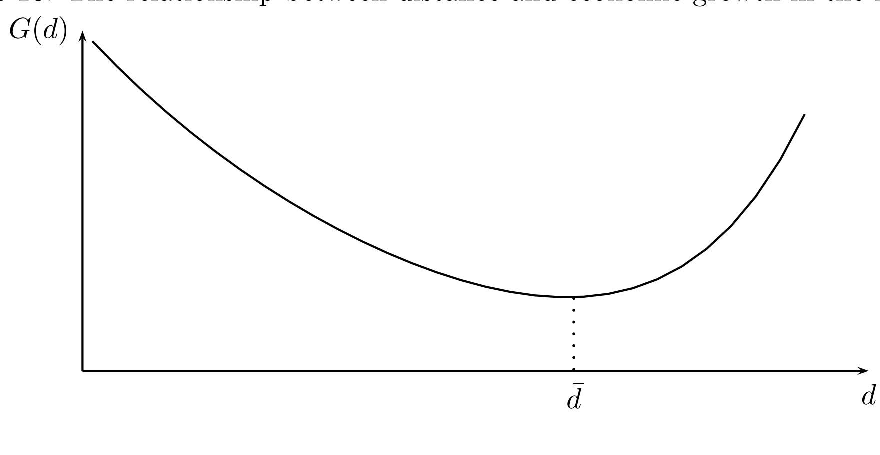
Given $A_0(d) > 0$ and $l_0(d) \geq 0$, an *equilibrium* for economy d is a sequence $\{l_t^*(d)\}_{t=0}^{\infty}$ such that for each $t \geq 1$, l_t^* solves the optimization problem (26). A *stationary equilibrium* for economy d is an equilibrium such that $l_t^* = l^*$ for all $t \geq 0$. An *equilibrium profile* is a sequence of functions, $\{\{l_t^*(d)\}_{t=0}^{\infty}\}_{d\in\mathcal{E}}$, such that for each $d \in \mathcal{E}$ the sequence $\{l_t^*(d)\}_{t=0}^{\infty}$ is an equilibrium for economy d. Similarly, a *stationary equilibrium profile* is an equilibrium profile such that each economy $d \in \mathcal{E}$ is in a stationary equilibrium. Given the stationary equilibrium profile $\{\{l^*(d)\}_{t=0}^{\infty}\}_{d\in\mathcal{E}}$, the *profile of stationary growth rates* is the function $G : \mathcal{E} \to \mathbb{R}$ that assigns to each economy d its growth rate in a stationary equilibrium, i.e.

$$G(d) = \left[\gamma l^*(d)^{(\alpha'+\alpha)\rho} + \delta(1-l^*(d))^{(\beta'+\beta)\rho}\right]^{\frac{1}{\rho}}. \tag{27}$$

It is not difficult to see that for any $d \in \mathcal{E}$, if $l_0 = 0$, then $l_t = 0$ for all $t \geq 1$ is the unique (stationary) equilibrium. Similarly, if $l_0 = 1$, then $l_t = 1$ for all $t \geq 1$ is the unique (stationary) equilibrium. Since these two cases are not very interesting, as they are not stable to errors made by the agents, and seem rather artificially generated by the choice of production functions, I shall assume in what follows that $l_0(d) \in (0,1)$ for all $d \in \mathcal{E}$. In the appendix I prove that:

Theorem D.1. *Given $A_0(d) > 0$ and $l_0(d) \in (0,1)$, each economy d has a* unique *equilibrium. Additionally, each economy has a* unique, asymptotically stable, and sub-optimal *stationary equilibrium. Finally, there exists an economy $\bar{d}$, such that the profile of stationary growth rates is a decreasing function of d for all economies $d \leq \bar{d}$ and is an increasing function of d for all economies $d > \bar{d}$.*

Figure 16: The relationship between distance and economic growth in the model.



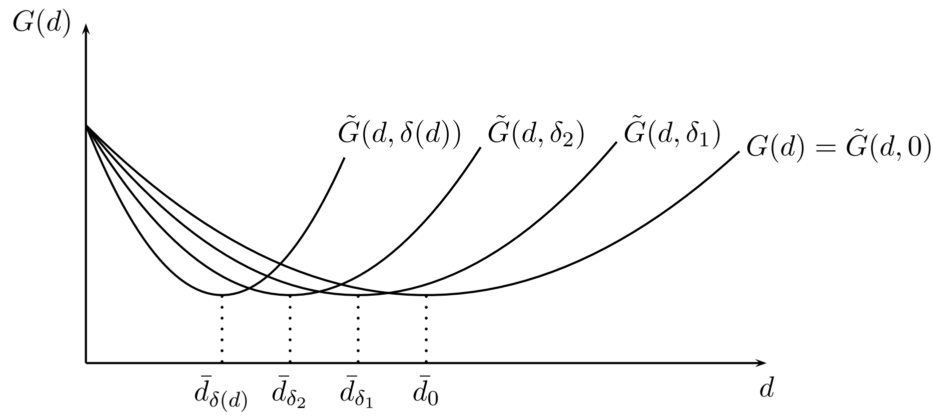
This shows the non-monotonic effect of distance on growth rates in the stationary equilibrium: Initially, for $d \in [0, \bar{d}]$ the growth rates fall as the distance from the technological frontier increases, but once $d > \bar{d}$ growth rates increase. Thus, there is a U-shaped relation between the distance from the frontier and the rate of growth of an economy, as shown in Figure 16. Notice that if $\tilde{d} \leq \bar{d}$, i.e. the world is too "small", then conventional wisdom holds true.

It is not difficult to prove that this U-shaped relation between distance from the frontier and economic growth translates into a U-shaped relation between distance and income levels *irrespective* of the shape of the initial profile of technology levels (see appendix). This implies that in this model there is no tendency towards convergence among economies. Furthermore, the economy at $\bar{d}$ will be the least developed economy in the long-run, making the distance $\bar{d}$ the *least desirable distance (LDD)* from the technological frontier.

D.2 The Effect of Cultural Barriers to Diffusion

The analysis conducted so far has focused on the effects of geographical distance on the substitution of imitation and creation of new technologies.[28] But as mentioned in the introduction, cultural differences, among others, act as barriers to the adoption and imitation of technologies. A simple extension of the previous model can introduce this additional complexity by considering an additional measure of distance between economies $\delta \in \mathbb{R}_+$, so that every economy $d \in \mathcal{E}$ is identified by a pair (d, δ) and the productivity of imitation is determined by $\tilde{b}(d, \delta)$. Assume that $\tilde{b}(\cdot, \cdot)$ is continuous, decreasing in both parameters, twice differentiable and such that for any $d \in \mathcal{E}$, $\tilde{b}(d, 0) = b(d)$. It is easy to prove that for any $\delta > 0$ and for any economy $d \in \mathcal{E}$ there exists a unique economy $d_\delta \geq d$ such that $\tilde{b}(d, \delta) = b(d_\delta)$. This implies that for any fixed $\delta > 0$ the profile of stationary growth rates $\left\{\tilde{G}(d, \delta)\right\}_{d \in \mathcal{E}}$ is a contraction of the profile $\{G(d)\}_{d \in \mathcal{E}}$ in the sense that $\tilde{g}(d, \delta) = g(d_\delta)$ for each $d \in \mathcal{E}$. Additionally, if $\delta_1 < \delta_2$, then $d_{\delta_1} < d_{\delta_2}$, which implies that $\left\{\tilde{G}(d, \delta_2)\right\}_{d \in \mathcal{E}}$ is a stronger contraction of $\{G(d)\}_{d \in \mathcal{E}}$ than $\left\{\tilde{G}(d, \delta_1)\right\}_{d \in \mathcal{E}}$, so that $\bar{d}_{\delta_1} > \bar{d}_{\delta_2}$.

Figure 17: The effect of cultural distance on the relationship between growth and geographical distance.



Since cultural distances in general increase with geographical distances, one should expect δ to be an increasing function of d. Assuming that $\delta = \delta(d)$ is a continuous and increasing function of d it is not difficult to prove, using an analysis similar to the previous one, that this causes an additional contraction of the stationary equilibrium. Figure 17 shows these effects graphically.

Clearly, these results imply that the estimates of the distance d from the frontier will be affected if one controls for other distances that affect the productivity of imitation.

[28] This is not completely accurate, since the meaning of the distance d is open to interpretation. A priori any measure of distance that satisfies the conditions assumed above must generate the same results. So, this same model can explain why large institutional or cultural distances increase innovative efforts during the modern era, as exemplified by the case studies in Immelt et al. (2009).

E Monte Carlo Simulations

This section uses Monte Carlo simulations in order to assess how conventional theory and the theory presented in this paper can be differentiated econometrically. To do so, it follows two avenues: First, using the theory presented in section 3 it creates artificial worlds in which either conventional theory or the proposed theory hold. It adds random shocks to the implied steady state growth rates and use samples of economies, located in similar patterns as the actual Old World economies, or at the actual location of Old World economies, to run regressions similar to equation 6. Second, it creates artificial development data and studies how differences in the relation between distance to one or two frontiers affect the regression analysis. Of particular interest is the effect of the inclusion of the distance to one or two possible frontiers on the value and statistical significance of the various estimates, especially of the LDD. The objective of this analysis is to determine whether the quadratic coefficients, which capture the non-monotonicity, and the LDD's generated by them, have the right signs and statistical significance as predicted by the theory.

E.1 Model-based artificial economies

This section presents the results of generating artificial economies based on the model presented in section 3 when there are two technological frontiers (n=2). The main objective of these simulations is to serve as a guide on how to test econometrically the difference between a world in which conventional wisdom holds, i.e. $\bar{d} = \infty$ or $\sup_{\mathbf{d}\in\mathcal{E}} \|\mathbf{d}\| < \bar{d}$, from one when the theory put forward in this paper holds and is observable. In order to do so, for each world $\mathcal{E}$ I choose a set of parameters and a function $b(d)$ such that given the actual locations of countries in the Old World, there exists at least one set of parameters $a, \alpha, \alpha', \beta, \beta', \rho_1, \rho_2, \lambda_1, \lambda_2 \in [0, 1]$ that satisfy assumptions (ES) and (U), and the theoretical value of $\bar{d}$ is less than the maximum of the distances from China and the Netherlands to the countries in the Old World. This implies that $\mathcal{E} = \left\{(d_1, d_2) \in \mathbb{R}^2_+ \mid d_1 \leq \max d_{CHN} \leq 15, d_2 \leq \max d_{NLD} \leq 15\right\}$. Additionally, it ensures that for at least one parametrization the U-shape holds in theory and could in principle be observable/estimable.[29]

Notice that if λ_2 is too small or too big, so that one frontier has a much larger importance, then the world will behave almost like a world with one frontier, where the non-monotonicity is easy to determine.[30] Simulations showed that λ_2 does not have to deviate a lot from 0.5 for the world to behave basically like a one-frontier economy. For this reason, and since a priori there is no reason to assume frontiers might differ in their importance, I assume that $\lambda_2 = 0.5$. Similarly, I assume $\lambda_1 = 0.5$ so as to not assign a major relative importance to creation vis-à-vis adoption. Clearly, neither parameter is essential for assumptions (ES) and (U) for any set of the other parameters.

In addition, it is necessary to choose a functional form for $b(d)$. I follow of the literature on technological diffusion (see e.g. Keller, 2004) and assume that $b(d) = b_0 \exp(-b_1 d)$. Since b_0's size only matters relative to a, I set $a = 0.55$ and $b_0 = 1$. Additionally, I choose $b_1 = 0.05$, which implies that for given levels of inputs, the elasticity of the output from imitation with respect to the distance to the frontier is -0.05.

The remaining set of parameters are related to the CES and Cobb-Douglas production functions. The set of all possible parameter values is $[0, 1]^6$, which I discretize. In particular, I let $\rho_1, \rho_2, \alpha, \alpha', \beta, \beta' \in \{0.1, 0.3, 0.5, 0.7, 0.9\}$. This generates a set of 15,625 worlds $\mathcal{E}$. Of these, I discard all economies such that $\alpha + \alpha' > 1$ and $\beta + \beta' > 1$. This leaves me with a set of 5624 worlds. Each

[29]Simulations with other parameter values generated similar results to the ones presented here. The main difficulty is generating observability, since condition (U) can be satisfied by many parameter values generating a theoretically true U-shape, which cannot be identified.

[30]In that case, only one of the distances will have a non-monotonicity, while the other will always be not statistically significant.

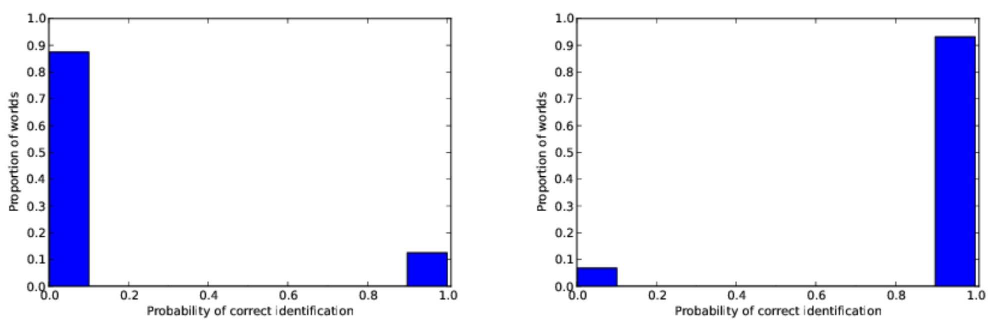
world has a set of economies located on a lattice that belongs to $[0,15]^2$ where every point on the lattice is at a distance of 0.25 from its neighbors to the north, south, east and west.

For every world $\mathcal{E}$ I compute the steady state growth rate for all economies. The perfect sample to identify the non-monotonicity and estimate the LDD is the set of countries equidistant from the frontiers, i.e. those located on the 45-degree line in figure 2. Figure 3 shows the growth surface of one such world and the profile of growth rates along the equidistant economies. Additionally, since for each world I know if condition (U) is satisfied or not, I need to establish if the U-shape would be identifiable. For this, I consider only the set of equidistant economies. I estimate a quadratic relation between the growth rate in these economies and their distance to the frontier. The regression correctly identifies the model if it rejects the U-shape when the world does not have a U-shape (or it is not observable), or, when it fails to reject the U-shape when the world has one.

Figure 18 presents the distribution of worlds' probability of correctly identifying the U-shape. In figure 18(a) I present the frequency distribution of worlds' probability of correctly identifying the non-monotonicity, when they satisfied assumption (U). As can be seen there, in most worlds that have a U-shape, the econometric test with the sample of equidistant economies fails to identify this non-monotonicity. In particular, only in 12.5% of the worlds is the non-monotonicity correctly identified when the U-shape is actually present.

On the other hand, figure 18(b) presents the frequency distribution of worlds' probability of correctly identifying the lack of non-monotonicity, when they did not satisfy condition (U). In this case, for most worlds, the econometric test does reject the U-shape, when it is not present. In particular, in 93.7% of the worlds the U-shape is correctly rejected. These results suggest that not rejecting a non-monotonicity, when one uses the sample of equidistant countries would be a strong indicator of the existence of the U-shape.

Figure 18: Identification of U-shape on sample to equidistant economies.



(a) Worlds with theoretical U-shape. Test incorrectly rejects U-shape.

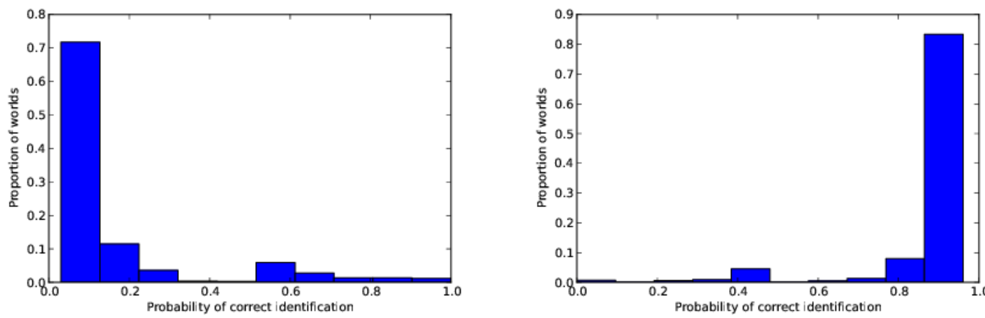
(b) Worlds without theoretical U-shape. Test correctly rejects U-shape.

Unfortunately, in the empirical analysis I do not have observations for the sample of equidistant economies. In order to overcome this problem, I use Monte Carlo simulations based on the sample of economies in the artificial world that are located where the countries in the Old World would be.[31] For this sample I generate 1000 artificial copies of each possible world, and add a normally distributed random shock to the steady state growth rate of each economy in the sample. The random shock has mean zero and a standard deviation equal to the standard deviation of steady state growth rates across all economies in the artificial world.

[31]This is one of the main constraints in the choice of values for a and b_1 above.

Using these samples of artificial worlds, I estimate a quadratic relation between the steady state growth rate in an economy and the distances to both frontiers. For each simulation I test if one or both LDD's are statistically significant and smaller than the maximum distance to their frontier. Since I know if the world has a U-shape I can determine the probability of correctly identifying the U-shape for each artificial world.

Figure 19: Identification of U-shape on sample of Old World economies.



(a) Worlds with theoretical U-shape. Test incorrectly rejects U-shape.

(b) Worlds without theoretical U-shape. Test correctly rejects U-shape.

Figure 19 summarizes the result of these experiments. In figure 19(a) I show the frequency distribution of worlds' probability of correctly identifying the U-shape, when the world has a U-shape. As can be seen there, in most worlds that have a U-shape, the econometric test incorrectly rejects the null hypothesis that the LDD of *at least one* frontier is finite and less than the maximum distance to it. In particular, the average probability of not rejecting the U-shape with respect to at least one frontier is 16.2%, while the median is 7.0%. Furthermore, for worlds in which the sample of equidistant countries correctly identifies the U-shape when it exists, the median probability of correctly identifying the U-shape with the sample of Old World countries is 26.0%.

On the other hand, figure 19(b) shows that in most worlds that do not have a U-shape, the test correctly rejects the hypothesis that the LDD of *both* economies is statistically significant and less than the maximum distance to it. The average probability of correctly identifying the model in these worlds is 88.6% and the median probability is 94.0%. Additionally, for the worlds in which the sample of equidistant countries correctly rejects the U-shape when it does not exist, the median probability of correctly rejecting the U-shape with the sample of Old World countries is 95.0%.

The results of these Monte Carlo simulations suggest that the probability of incorrectly finding a U-shape when the world does not have one is pretty slim. Furthermore, in general, the test tends to reject the null hypothesis of existence of a U-shape in both samples, even when the U-shape exists. Thus, when the world does not have a U-shape, the probability of making an error of type II by not rejecting the U-shape, is less than 5%. On the other hand, for a world where the U-shape exists, the probability of making an error of type I is quite large (over 80%). Thus, these results suggest that the test has a high power for the question being asked. Furthermore, and as the next section will further show, not rejecting the null hypothesis of a U-shaped relation seems a strong indicator that there *does exist* a U-shape.

E.2 General artificial economies

In this subsection I take a less parametric approach by looking at the more general implications of both theories, without considering the specific CES functional forms used in this paper. In particular, using the distances to the Netherlands and China I construct for each country various artificial income processes based on different assumptions about the relation between income and distance:

$$\begin{aligned}
y_i^1 =& a + b_1 \mathbb{I}_{i1} d_{i1} + b_2 \mathbb{I}_{i2} d_{i2} + \epsilon_i \\
y_i^2 =& a + b_1 d_{i1} + b_2 d_{i2} + \epsilon_i \\
y_i^3 =& a + b_1 d_{i1} + b_{12} d_{i1}^2 + \epsilon_i \\
y_i^4 =& a + b_1 d_{i1} + b_{12} d_{i1}^2 + b_2 d_{i2} + \epsilon_i
\end{aligned}$$

where y_i^s is country i's income under the data generating process s, $\mathbb{I}_{ij}$ is an indicator function with value 1 if the country i's income is affected by frontier $j = 1, 2$; $a \in \mathbb{R}$, $b_1, b_2 < 0$, $b_{12} > 0$, and $\epsilon_i \sim \mathcal{N}(\mu, \sigma^2)$. I assume that $\mathbb{I}_{i1} = 1 - \mathbb{I}_{i2}$, frontier 1 is the Netherlands and frontier 2 is China, and that the $\mathbb{I}_{i1} = 1$ if the country does not lie in Asia and zero otherwise. Processes y^1 and y^2 represent the conventional wisdom, where income is a monotonically decreasing function of the distance to the technological frontier. Processes y^3 and y^4 capture the idea of a U-shaped relation between economic development and distance.

Having generated a cross country sample for each income process, I run various econometric specifications in order to estimate the effect of distance on income. The specifications I consider are:

$$\begin{aligned}
R_1: \ y_i =& \alpha + \beta_1 d_{i1} + \beta_{12} d_{i1}^2 \\
R_2: \ y_i =& \alpha + \beta_1 d_{i1} + \beta_{12} d_{i1}^2 + \beta_2 d_{i2} \\
R_3: \ y_i =& \alpha + \beta_1 d_{i1} + \beta_{12} d_{i1}^2 + \beta_2 d_{i2} + \beta_{22} d_{i2}^2 \\
R_4: \ y_i =& \alpha + \beta_1 d_{i1} + \beta_{12} d_{i1}^2 + \beta_{13} \mathbb{I}_{i2} d_{i1} \\
R_5: \ y_i =& \alpha + \beta_1 d_{i1} + \beta_{12} d_{i1}^2 + \beta_{13} \mathbb{I}_{i2} d_{i1} + \beta_{14} \mathbb{I}_{i2} d_{i1}^2
\end{aligned}$$

Repeating this process T times gives a distribution of the parameters of the different econometric specifications for each income process. I use these results in order to compare the sign pattern and statistical significance generated by these econometric specifications between a world where the conventional wisdom holds, with one where the theory proposed in this paper does.

Tables E.14-E.16 present the results under the following parametric assumptions: $a = 1$, $b_1 = b_2 = -0.5$, $b_{12} = 0.05$, $T = 5000$, $\mu = 0$, and $\sigma^2 = 0.5$.[32] As can be seen from the tables, if income is generated according to conventional wisdom (y^1 or y^2), the inclusion of the distance to the second frontier renders the inflection point at the LDD_1 statistically insignificant, with the wrong sign or outside the sample, capturing perfectly the fact that there does not exist a U-shaped relation between distance and income per capita. On the other hand, if income is generated according to the models presented in this paper (y^3 or y^4), then the inclusion of the distance to a second frontier *does not* affect the sign or statistical significance of the estimate of the LDD, which remains within the sample range. Thus, inclusion of the distance to the second technological frontier should allow one to differentiate between both worlds.

Furthermore, comparison of the sign patterns and statistical significances from the estimated parameters in the different specifications R_1-R_5 for the artificial processes $y^1 - y^4$ with the ones from the technological sophistication in 1500CE data, shows that the technology data resembles (more closely) the pattern from y^3-y^4, i.e. the data generated by the models in this paper.

[32]Varying the parameters generated in similar results.

Table E.14: Results of Monte Simulations.

	Econometric Specification R_1				
	y^1	y^2	y^3	y^4	Tech. Soph.
β_1	—	—	—	—	—
	-0.56***	-0.77***	-0.50***	-0.77***	-0.12***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.03)
β_{12}	+++	+++	+++	+++	+++
	0.02***	0.03***	0.05***	0.08***	0.01***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
LDD_1	+++	+++	+++	+++	+++
	12.88***	15.31***	4.99***	5.09***	5.46***
	(2.06)	(2.18)	(0.17)	(0.11)	(0.37)

Notes: (i) Column y^s denotes that the dependent variable is income process s. In column Tech. Soph. the level of technological sophistication in 1500CE from Comin et al. (2010). (ii) LDD_1 is least desirable distance (LDD) to frontier 1. It is equal to $-\beta_1/(2 * \beta_{12})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests. Sign patterns denoted by + and -. The number of pluses or minuses denotes the statistical significance of each estimate.

Table E.15: Results of Monte Simulations (continued).

	Econometric Specification R_2					Econometric Specification R_3				
	y^1	y^2	y^3	y^4	Tech. Soph.	y^1	y^2	y^3	y^4	Tech. Soph.
β_1	—	—	—	—	—	—	—	—	—	—
	-0.43***	-0.50***	-0.50***	-0.50***	-0.14***	-0.72***	-0.50***	-0.50***	-0.50***	-0.14***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.02)	(0.07)	(0.07)	(0.07)	(0.07)	(0.03)
β_{12}	+		+++	+++	+++	+++		+++	+++	+++
	0.01*	0.00	0.05***	0.05***	0.01***	0.03***	-0.00	0.05***	0.05***	0.01***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
β_2	—	—		—	—	—	—		—	
	-0.24***	-0.50***	-0.00	-0.50***	-0.04***	-0.88***	-0.50***	0.00	-0.50***	-0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.09)	(0.09)	(0.09)	(0.09)	(0.04)
β_{22}						+++				
						0.04***	-0.00	-0.00	-0.00	-0.00
						(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
LDD_1			+++	+++	+++	+++		+++	+++	+++
	7.74	-98.30	4.99***	4.99***	7.62***	12.97***	-19.05	4.98***	4.98***	7.36***
	(1167.05)	(5207.55)	(0.17)	(0.17)	(0.82)	(1.61)	(3368.26)	(0.23)	(0.23)	(1.13)
LDD_2						+++				
						10.93***	27.95	6.74	28.02	-19.02
						(0.46)	(3000.25)	(102.25)	(3002.76)	(87.50)

Notes: (i) Column y^s denotes that the dependent variable is income process s. In column Tech. Soph. the level of technological sophistication in 1500CE from Comin et al. (2010). (ii) LDD_i is least desirable distance (LDD) to frontier $i = 1, 2$. It is equal to $-\beta_1/(2*\beta_{12})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests. Sign patterns denoted by + and -. The number of pluses or minuses denotes the statistical significance of each estimate.

Table E.16: Results of Monte Simulations (continued).

	Econometric Specification R_4					Econometric Specification R_5				
	y^1	y^2	y^3	y^4	Tech. Soph.	y^1	y^2	y^3	y^4	Tech. Soph.
β_1	—	—	—	—	—	—	—	—	—	—
	-0.59***	-0.82***	-0.50***	-0.82***	-0.14***	-0.44***	-1.02***	-0.50***	-1.02***	-0.12***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.02)	(0.07)	(0.07)	(0.07)	(0.07)	(0.03)
β_{12}	+		+++	+++	++		+++	+++	+++	
	0.01*	0.01	0.05***	0.06***	0.01**	-0.00	0.03***	0.05***	0.08***	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
β_{13}	+++	+++		+++	++		+++		+++	
	0.28***	0.47***	0.00	0.47***	0.04**	-0.06	0.93***	0.00	0.93***	0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.08)	(0.08)	(0.08)	(0.08)	(0.03)
β_{14}					+++	—		—		
						0.04***	-0.05***	-0.00	-0.05***	0.00
						(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
LDD_1			+++	+++	+++		+++	+++	+++	+
	33.47	116.87	5.00***	7.36***	9.38***	-25.36	20.00***	5.00***	6.67***	12.11*
	(188.45)	(4477.99)	(0.20)	(0.24)	(2.46)	(2079.03)	(4.34)	(0.20)	(0.17)	(5.24)
$LDD_1\mathbb{I}_2$							+++		+++	
						0.52	9.36***	4.12	9.36***	-3.17
						(1.42)	(0.90)	(24.49)	(0.90)	(6.98)

Notes: (i) Column y^s denotes that the dependent variable is income process s. In column Tech. Soph. the level of technological sophistication in 1500CE from Comin et al. (2010). (ii) LDD_i is least desirable distance (LDD) to frontier $i = 1, 2$. It is equal to $-\beta_1/(2{*}\beta_{12})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests. Sign patterns denoted by + and -. The number of pluses or minuses denotes the statistical significance of each estimate.

F Additional Results and Tables

This section reproduces some of the tables in the text, presenting the estimated coefficients for all controls, and presents some additional results that were not included in the paper in order to save space.

F.1 Historical Evidence I: Technological Sophistication

Table F.17 reproduces table 1 and is presented mostly for completeness. Since the results from this table suggest a monotonic relation with the distance to China, in table F.18 I repeat the analysis, allowing each sectorial technology index to be linearly and quadratically dependent on the distance to China. As can be seen there the results are unchanged and the estimates of the LDD remain basically unchanged.

As explained above, the analysis in the main body of the paper focuses on the Old World. I exclude the New World and Oceania from the analysis, since their development experiences were mainly affected by other forces both pre-1500 and post-1500, which prevent a clean analysis of the effect of geographical distance from the frontier. In particular, pre-1500 Diamond (1997) suggested the extinction of megafauna, continental size, lack of domesticable plants, among others had a major impact on the differential development of these three regions. Additionally, post-1500 population replacement with its cultural, technological, and political effects, played a major role in these two continents. Furthermore, the lack of interaction among the three regions raises major difficulties for the analysis based on geographical distances. In particular, geodesic distances clearly underestimate the distance between the New and Old World, while there is no straight forward way to generalize my measures to include them for the pre-contact period. I tackle the problem in two ways in order to assess if the results presented before are driven by the exclusion of the New World.

First, I use the HMISea measure to find the distance between New World countries and the Netherlands and China using the Bering strait as crossing point that allowed both continents to be in contact. With this assumption I do not mean that both continents were in contact through this path, especially post 15000BCE. Still, it creates measures of distance between the technological frontiers in the Old World and countries in the New World, which maintain the ordering one should expect in terms of distance. In particular, we should consider countries in the New World to be farther away from the frontiers in the Old World than any country in the Old World. Additionally, countries in the New World also maintain a distance ordering that seems reasonable.[33] Using these distance measures, columns (1)-(4) in table F.19 analyze the relation between technological sophistication in 1500 CE and distance from the frontiers in the Old World. In particular, I analyze the individual and joint relations of the distances, with and without continental fixed effects. Here again I cannot reject the existence of a U-shape with a finite (in-sample) LDD.

Although these first results do not reject the existence of a non-monotonicity, they might just be capturing measurement errors, or even worse a completely different source of comparative development. Although the distance to the frontiers in the Old World from countries in the New World is mismeasured, as long as the measurement error does not change the ordering of countries in terms of their distance, it seems this type of measurement error could change the curvature of the U-shape, but should not generate the observed non-monotonicity.

On the other hand, by construction the distances from the frontiers in the Old World to countries in the New World will be correlated among themselves and with the distance from Addis-Ababa. Thus, we might be just capturing the effect of genetic diversity on development as suggested by Ashraf and

[33]This is the case unless we consider all countries in the New World to be equally distant from the frontiers in the Old World. But this would imply that we should not include them in our analysis, since there is no variation that could be exploited. This would take us back to the analysis in the main body of the paper.

Galor (2013). Columns (5)-(7) analyze this possibility. According to Ashraf and Galor (2013) the further away a population is from Addis-Ababa, the more homogeneous genetically it will be. Since genetic distance ought to have an inverse U-shaped effect on development, one should expect to find a U-shaped relation from the distance to Addis-Ababa. While this was not a problem in the Old World sample, since the distance to the frontiers and to Addis-Ababa were uncorrelated, in the New World sample these three measures are almost perfectly correlated by construction. As can be seen in column (5) the distance to Addis-Ababa has a U-shaped relation with the level of technological sophistication. But when controlling for the distance from the frontiers in the Old World, the distance to Addis-Ababa has either an inverse U-shaped (without continental fixed effects) or only a positive effect (with continental fixed effects), while the distance to the Netherlands still has a U-shaped relation and to China a negative one.

Thus, the first approach to including the New World into the analysis does not reject the existence of a U-shaped relation to the distance from the technological frontiers in the Old Word. Still, the caveats raised suggest that this approach is not without problems. A second approach one can take is to assume that the New and Old Worlds have their own frontiers from which the countries within it interact (i.e. $\lambda_{2j} = 0$ for frontiers outside the landmass or $\lim_{d_j \to \infty} b(d_j) = 0$), e.g. Mexico or Peru in the New World. This is equivalent to running additional independent regressions for the New World. Clearly, this implies that the results for the Old World presented in the main body of the paper do not change, since this amounts to a seemingly unrelated regression analysis.

Columns (8)-(10) in table F.19 analyze the relation between the distance from Mexico and Peru on technological sophistication in the New World. The results of column (8) show that there exists a U-shaped relation with the distance to Mexico, while column (9) shows an inverse U-shaped relation with the distance to Peru. In column (10) when I control for the distance to both Mexico and Peru, I find that there exists a U-shaped relation with the distance to Mexico, but only a negative one from Peru. These results do not reject the theory proposed in this paper, but are based on a very small sample, which excludes the caribbean islands, and on two negatively correlated distance measures.

As a final check I joined both subsamples and assigned to each country the frontiers on its continental mass. In order to do so, for each country I assigned a distance of zero for each frontier not on the same landmass. The results are shown in columns (10)-(12) of table F.19. The results are basically the same, with a U-shaped relation to at least one frontier in both the Old and New Worlds.

The results of table F.19 suggest that the results presented in the main body of the paper are not driven by the exclusion of the New World from the analysis. But it also shows that its inclusion is not straightforward and subject to many caveats and problems. Furthermore, this analysis cannot be extended to the panel data framework used in the main body of the paper, which exploits changes in the locations of the Western frontier.

In table 3 I had shown that controlling for the effects of local technological frontiers, trade, European colonization, and the advantages of backwardness could not explain the existence of the U-shape in average technology. Tables F.20-F.23 show the results at the sectorial level for each of these channels. As can be seen the results do not depend on the level of sectorial aggregation and confirm the analysis presented in section 5.

The Monte Carlo simulations of appendix E had shown that in a world with two frontiers, if conventional wisdom holds and economies' development depend only on the closest frontier, the inclusion of both distances would not generate a U-shape. In table F.24 I further analyze the effect of including the minimum distance to either frontier as one of the regressors. The results show that the U-shape is not generated by misspecification of the relevant distance. Inclusion of the distance to the closest frontier does not change the results in the text. The U-shaped relation remains statistically and economically significant. This result and the theoretical model suggest that technology from both frontiers are not perfect substitutes. Thus, the existence of the U-shape supports the theory presented in the paper.

Table F.17: Technology in 1500 CE and pre-industrial distance from the technological frontiers.

	Dependent Variable is Technological Index in 1500CE								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.)	(Av.)	(Av.M.)
Pre-industrial	-0.12***	-0.09*	-0.14***	-0.20***	-0.12***	-0.13***	-0.14***	-0.14***	-0.14***
distance NLD	(0.04)	(0.05)	(0.03)	(0.05)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)
Sq. Pre-ind.	0.01**	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
distance NLD	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial	-0.03	-0.00	-0.05	-0.03	-0.01	-0.06**	-0.03	-0.04***	-0.03
distance CHN	(0.06)	(0.10)	(0.04)	(0.07)	(0.04)	(0.03)	(0.04)	(0.01)	(0.04)
Sq. Pre-ind.	-0.00	-0.00	0.00	-0.00	-0.00	0.00	-0.00		-0.00
distance CHN	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)
Latitude in degrees	0.01	0.01	0.00	0.00	0.00		0.01	0.00	0.01
	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)		(0.00)	(0.00)	(0.00)
Squared Latitude	-0.00**	-0.00	-0.00**	-0.00	-0.00		-0.00**	-0.00**	-0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
Island dummy	0.15**	0.18*	-0.04	-0.21*	-0.06		0.01	0.01	-0.02
	(0.06)	(0.10)	(0.11)	(0.11)	(0.04)		(0.05)	(0.05)	(0.05)
1 if landlocked	0.11	0.03	-0.11***	0.03	-0.11		-0.01	-0.01	-0.02
	(0.07)	(0.05)	(0.04)	(0.06)	(0.07)		(0.04)	(0.03)	(0.03)
Arable land (% of land area)	0.00*	0.00*	0.00	-0.00	0.00		0.00*	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
% land area tropics+subtropics	0.12	-0.08	-0.08	-0.05	-0.02		-0.02	-0.02	-0.04
	(0.09)	(0.08)	(0.05)	(0.07)	(0.07)		(0.05)	(0.05)	(0.05)
mean m above sea level (in 1000m)	-0.02	-0.06	-0.02	-0.16**	-0.07		-0.07	-0.08	-0.07
	(0.07)	(0.06)	(0.07)	(0.08)	(0.12)		(0.05)	(0.05)	(0.05)
Area in millions of km2	0.02*	0.00	0.01*	0.02	0.01		0.01*	0.01*	0.01*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
LDD NLD	8.29***	6.04**	9.17***	7.45***	6.10***	9.04***	7.36***	7.62***	7.10***
	(1.86)	(2.66)	(1.86)	(1.52)	(0.61)	(0.71)	(1.13)	(0.82)	(1.04)
LDD CHN	-19.05	-1.71	100.84	-13.80	-5.13	62.24	-19.02		-24.40
	(124.55)	(121.83)	(589.86)	(68.82)	(22.95)	(189.19)	(87.50)		(126.45)
Observations	84	84	84	84	84	87	84	84	84
Adjusted R-squared	0.59	0.75	0.74	0.69	0.66	0.79	0.84	0.84	0.84

Notes: (i) Technology index obtained from Comin et al. (2010). The labels of the columns reflect the various indices constructed by them. Agr is agriculture, Comm is communications, Trans is transport, Mil is military, Ind is industry, Average is the average index, and Average Mig is the average index corrected for migration. (ii) Pre-industrial distance to Netherlands is the minimum total travel time (in weeks) along the optimal path between a country's capital and the Netherlands (see text for construction). (iii) Additional controls in all columns: (iii.1) Latitude and latitude squared of the country's capital taken from CEPII. (iii.2) The average percentage of land that was arable in all years reported by the World Development Indicators. (iii.3) Percentage of land area in tropics and subtropics, (iii.4) mean elevation above sea level, (iii.5) land area, (iii.6) island dummy is equal to one if country is an island. Landlocked dummy is one if country is landlocked. (iv) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (v) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.18: Technology in 1500 CE and pre-industrial distance from the technological frontiers.

	Dependent Variable is Technological Index in 1500CE											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	(Agr)	(Agr)	(Comm)	(Comm)	(Trans)	(Trans)	(Mil)	(Mil)	(Ind)	(Ind)	(Av.)	(Av.)
Pre-Industrial distance	-0.13***	-0.12***	-0.10**	-0.09*	-0.14***	-0.14***	-0.21***	-0.20***	-0.13***	-0.12***	-0.14***	-0.14***
to Netherlands (weeks)	(0.04)	(0.04)	(0.05)	(0.05)	(0.03)	(0.03)	(0.04)	(0.05)	(0.04)	(0.04)	(0.02)	(0.03)
Sq. Pre-Industrial distance	0.01**	0.01**	0.01**	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
to Netherlands	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-Industrial distance	-0.04***	-0.03	-0.01	-0.00	-0.05***	-0.05	-0.05***	-0.03	-0.04***	-0.01	-0.04***	-0.03
to China (weeks)	(0.02)	(0.06)	(0.02)	(0.10)	(0.01)	(0.04)	(0.01)	(0.07)	(0.01)	(0.04)	(0.01)	(0.04)
Sq. Pre-Industrial distance		-0.00		-0.00		0.00		-0.00		-0.00		-0.00
to China		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)		(0.00)
Additional controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Least Desirable Distance	8.64***	8.29***	6.30***	6.04**	9.06***	9.17***	7.75***	7.45***	6.57***	6.10***	7.62***	7.36***
	(1.72)	(1.86)	(1.67)	(2.66)	(1.53)	(1.86)	(1.10)	(1.52)	(0.44)	(0.61)	(0.82)	(1.13)
Observations	84	84	84	84	84	84	84	84	84	84	84	84
Adjusted R-squared	0.60	0.59	0.75	0.75	0.74	0.74	0.70	0.69	0.66	0.66	0.84	0.84

Notes: (i) Technology index obtained from Comin et al. (2010). The labels of the columns reflect the various indices constructed by them. Agr is agriculture, Comm is communications, Trans is transport, Mil is military, Ind is industry, Average is the average index, and Average Mig is the average index corrected for migration. (ii) Pre-industrial distance to Netherlands is the minimum total travel time (in weeks) along the optimal path between a country's capital and the Netherlands (see text for construction). (iii) Additional controls in all columns: (iii.1) Latitude and latitude squared of the country's capital taken from CEPII. (iii.2) The average percentage of land that was arable in all years reported by the World Development Indicators. (iii.3) Percentage of land area in tropics and subtropics, (iii.4) mean elevation above sea level, (iii.5) land area, (iii.6) island dummy is equal to one if country is an island. Landlocked dummy is one if country is landlocked. (iv) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (v) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.19: Technology in 1500CE and pre-industrial distance from technological frontiers (including the New World).

	Dependent Variable is Average Technological Sophistication in 1500CE											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	(World)	(World)	(World)	(World)	(World)	(World)	(World)	(New World)	(New World)	(New World)	(World)	(World)
Pre-ind. dist. to Netherlands	-0.03***		-0.09***	-0.07***		-0.13***	-0.09***				-0.03***	-0.11***
	(0.01)		(0.01)	(0.01)		(0.02)	(0.02)				(0.01)	(0.02)
Sq. Pre-ind. dist. to Netherlands	0.00**		0.00***	0.00***		0.01***	0.00***				0.00***	0.01***
	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)				(0.00)	(0.00)
Pre-ind. dist. to China		-0.04***	-0.03**	-0.02		-0.04***	-0.00				0.05**	-0.06*
		(0.02)	(0.01)	(0.03)		(0.01)	(0.03)				(0.03)	(0.03)
Sq. Pre-ind. distance to China		0.00	-0.00	-0.00		-0.00*	-0.00**				-0.00***	0.00
		(0.00)	(0.00)	(0.00)		(0.00)	(0.00)				(0.00)	(0.00)
Pre-ind. dist. to Ethiopia					-0.04***	0.05***	0.04**					
					(0.01)	(0.02)	(0.02)					
Sq. Pre-ind. distance to Ethiopia					0.00**	-0.00*	-0.00					
					(0.00)	(0.00)	(0.00)					
Pre-ind. dist. to Mexico								-0.03***		-0.03	-0.10***	-0.16***
								(0.01)		(0.02)	(0.03)	(0.04)
Sq. Pre-ind. dist. to Mexico								0.00***		0.00	0.01***	-0.01**
								(0.00)		(0.00)	(0.00)	(0.00)
Pre-ind. dist. to Peru									0.03***	0.00	-0.09***	-0.10***
									(0.01)	(0.02)	(0.03)	(0.03)
Sq. Pre-ind. dist. to Peru									-0.00	-0.00	0.00	0.02***
									(0.00)	(0.00)	(0.00)	(0.00)
LDD NLD	23.10***		13.79***	12.64***		11.87***	12.95***				5.35***	10.37***
	(3.55)		(0.54)	(2.24)		(1.50)	(2.53)				(1.47)	(1.54)
LDD CHN		25.65***	-14.03	-8.04		-14.47	-0.21				5.60***	31.82
		(9.10)	(14.76)	(18.91)		(12.52)	(4.49)				(1.26)	(39.10)
LDD ETH					20.92***	10.48***	57.70					
					(2.19)	(2.71)	(233.71)					
LDD MEX								6.66***		6.15**	5.16***	-7.60**
								(1.29)		(2.03)	(1.49)	(3.27)
LDD PER									7.60*	0.53	14.47**	3.28***
									(3.67)	(11.36)	(7.05)	(0.64)
Additional Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Continental FE	NO	NO	NO	YES	NO	NO	YES	NO	NO	NO	NO	YES
Adjusted R-squared	0.73	0.75	0.86	0.88	0.74	0.87	0.90	0.73	0.66	0.68	0.86	0.89
Observations	105	105	105	105	105	105	105	21	21	21	105	105

Notes: (i) Technology index obtained from Comin et al. (2010). (ii) Pre-industrial distances to Netherlands, China, Mexico, and Peru are the minimum total travel time (in weeks) along the optimal path between a country's capital and these countries (see text for construction and additional notes). (iii) Additional controls in all columns: (iii.1) Latitude and latitude squared of the country's capital taken from CEPII. (iii.2) The average percentage of land that was arable in all years reported by the World Development Indicators. (iii.3) Percentage of land area in tropics and subtropics, (iii.4) mean elevation above sea level, (iii.5) land area, (iii.6) island dummy is equal to one if country is an island. Landlocked dummy is one if country is landlocked. (iv) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (v) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.20: Technological sophistication and distance to the technological frontier in 1500CE. Is the U-shape generated by local technological frontiers?

	Dependent Variable is Technological sophistication in 1500CE						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.Mig.)
Pre-industrial distance to Netherlands (weeks)	-0.15***	-0.07	-0.12***	-0.22***	-0.10***	-0.13***	-0.14***
	(0.05)	(0.06)	(0.03)	(0.07)	(0.03)	(0.03)	(0.03)
Sq. Pre-industrial distance to Netherlands	0.01***	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to China	-0.05	0.01	-0.03	-0.05	0.00	-0.02	-0.03
	(0.06)	(0.09)	(0.05)	(0.09)	(0.06)	(0.05)	(0.04)
Sq. Pre-industrial distance to China	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-ind. dist. to local technological frontier	0.03	-0.02	-0.03	0.02	-0.02	-0.00	0.00
	(0.04)	(0.04)	(0.03)	(0.04)	(0.05)	(0.02)	(0.02)
LDD NLD	9.34***	5.19*	8.22***	7.90***	5.54***	7.30***	7.12***
	(2.10)	(3.04)	(2.33)	(1.95)	(1.77)	(1.42)	(1.31)
LDD CHN	280.54	6.53	-33.44	-45.22	0.18	-16.83	-26.14
	(9,049.43)	(19.32)	(191.86)	(395.98)	(19.00)	(79.47)	(145.27)
Additional Controls	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.59	0.75	0.74	0.69	0.65	0.83	0.84
Observations	84	84	84	84	84	84	84

Notes: Estimation by OLS. See table 1 for list of additional controls. (i) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (ii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.21: Technological sophistication and distance to the technological frontier in 1500CE. Is the U-shape generated by trade?

	Dependent Variable is Technological sophistication in 1500CE						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.Mig.)
Pre-industrial distance to Netherlands (weeks)	-0.13***	-0.09*	-0.14***	-0.20***	-0.12***	-0.14***	-0.14***
	(0.04)	(0.05)	(0.03)	(0.05)	(0.04)	(0.03)	(0.03)
Sq. Pre-industrial (HMISea) distance to Netherlands	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to China	-0.03	0.00	-0.05	-0.03	-0.01	-0.02	-0.03
	(0.06)	(0.10)	(0.04)	(0.07)	(0.04)	(0.04)	(0.04)
Sq. Pre-industrial distance to China	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to closest trade route	0.03	-0.04	-0.04	-0.02	0.02	-0.01	-0.00
	(0.07)	(0.05)	(0.04)	(0.05)	(0.04)	(0.03)	(0.03)
LDD NLD	8.82***	5.49**	8.45***	7.26***	6.30***	7.21***	7.05***
	(2.56)	(2.51)	(1.71)	(1.48)	(0.88)	(1.20)	(1.13)
LDD CHN	-21.31	4.56	86.66	-12.63	-6.19	-17.92	-23.99
	(133.14)	(61.83)	(465.05)	(65.65)	(25.62)	(84.45)	(125.73)
Additional Controls	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.59	0.75	0.74	0.69	0.65	0.83	0.84
Observations	84	84	84	84	84	84	84

Notes: Estimation by OLS. See table 1 for list of additional controls. (i) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (ii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.22: Technological sophistication and distance to the technological frontier in 1500CE. Is the U-shape generated by European colonization?

	Dependent Variable is Technological sophistication in 1500CE						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.Mig.)
Pre-industrial (HMISea) distance to Netherlands (weeks)	-0.13***	-0.11**	-0.15***	-0.21***	-0.13***	-0.14***	-0.14***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.02)
Squared Pre-industrial (HMISea) distance to Netherlands	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to China	-0.03	-0.04	-0.06	-0.05	-0.03	-0.04	-0.04
	(0.07)	(0.09)	(0.04)	(0.06)	(0.04)	(0.04)	(0.04)
Sq. Pre-industrial distance to China	-0.00	0.00	0.00	-0.00	-0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
European Colony (inludes Turkey)	-0.03	-0.25***	-0.05	-0.13	-0.11	-0.11**	-0.11**
	(0.10)	(0.06)	(0.06)	(0.09)	(0.09)	(0.05)	(0.05)
LDD NLD	8.48***	7.50***	9.46***	7.89***	6.57***	7.91***	7.62***
	(2.10)	(2.57)	(1.95)	(1.57)	(0.72)	(1.12)	(1.02)
LDD CHN	-29.84	19.60	53.60	-90.63	-26.98	524.79	124.90
	(232.75)	(41.62)	(134.44)	(1,026.07)	(118.99)	(23,227.24)	(1,183.13)
Additional Controls	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.59	0.78	0.74	0.70	0.66	0.85	0.85
Observations	84	84	84	84	84	84	84

Notes: Estimation by OLS. See table 1 for list of additional controls. (i) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (ii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.23: Technological sophistication and distance to the technological frontier in 1500CE. Is the U-shape generated by technological backwardness?

	Dependent Variable is Technological sophistication in 1500CE						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.Mig.)
Pre-industrial distance to Netherlands (weeks)	-0.13***	-0.11**	-0.14***	-0.21***	-0.13***	-0.14***	-0.14***
	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.03)	(0.03)
Sq. Pre-ind. dist. to Netherlands	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to China	-0.03	-0.02	-0.05	-0.04	-0.02	-0.03	-0.03
	(0.07)	(0.10)	(0.04)	(0.07)	(0.04)	(0.04)	(0.04)
Sq. Pre-industrial distance to China	-0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lagged technological sophistication	-0.06	0.06	0.06	0.02	-0.12	-0.01	-0.02
	(0.20)	(0.23)	(0.09)	(0.23)	(0.12)	(0.11)	(0.10)
LDD NLD	8.72***	6.60**	8.84***	7.57***	6.60***	7.59***	7.36***
	(2.51)	(2.73)	(1.96)	(1.64)	(0.85)	(1.27)	(1.20)
LDD CHN	-11.71	141.92	89.94	-28.42	-7.88	-27.86	-52.60
	(57.89)	(9,289.32)	(500.22)	(174.53)	(26.59)	(135.43)	(392.53)
Additional Controls	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.63	0.77	0.72	0.68	0.65	0.84	0.83
Observations	82	82	82	82	82	82	82

Notes: Estimation by OLS. See table 1 for list of additional controls. (i) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (ii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.24: Technological sophistication and distance to the technological frontier in 1500CE. Robustness to minimal distance to frontiers.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.)	(Av.)	(Av.M.)
Pre-industrial (HMISea) distance to Netherlands (weeks)	-0.15**	-0.07	-0.15***	-0.18***	-0.16***	-0.10***	-0.14***	-0.14***	-0.14***
	(0.07)	(0.09)	(0.03)	(0.06)	(0.04)	(0.02)	(0.04)	(0.04)	(0.04)
Squared Pre-industrial (HMISea) distance to Netherlands	0.01*	0.01	0.01***	0.01**	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pre-industrial distance to China	-0.05**	-0.01	-0.05***	-0.05***	-0.04***	-0.03***	-0.04***	-0.04***	-0.04***
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Distance Closest Frontier	0.01	-0.03	0.01	-0.03	0.03	-0.04***	-0.00	-0.00	-0.00
	(0.04)	(0.06)	(0.03)	(0.04)	(0.03)	(0.01)	(0.03)	(0.03)	(0.03)
LDD	8.49***	6.04**	8.93***	7.84***	6.66***	7.73***	7.62***	7.62***	7.30***
	(1.52)	(2.48)	(1.44)	(1.35)	(0.44)	(0.83)	(0.83)	(0.83)	(0.74)
Additional Variables	YES	YES	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.59	0.75	0.74	0.70	0.66	0.82	0.84	0.84	0.84
Observations	84	84	84	84	84	84	84	84	84

Notes: This table establishes that the statistically and economically significant U-shaped relation between distance to the western frontier and technological sophistication is robust to the inclusion of the minimal distance to either frontier. Estimation by OLS. See table 1 for list of additional controls. (i) Least desirable distance (LDD) is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (ii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

F.2 Non- and Semi-Parametric Specification Tests

This section presents results on various non- and semi-parametric specification tests. Table F.25 establishes that the relation between technological sophistication and the distance from the Netherlands is quadratic. It shows the T-statistic suggested by Härdle and Mammen (1993) for comparing non-parametric and parametric regression fits. Following Yatchew (2003) it also presents the statistic for comparing semi-parametric and parametric regression fits. In all cases, the T-statistic is smaller than the (wild-bootstrap) critical value. Thus, one cannot reject the hypothesis that the quadratic parametric regression and the non- and semi-parametric regressions are the same.

Additionally, based on the strictly monotone estimator of Mammen (1991) and a specification test proposed by Yatchew (2003), tables F.26 and F.27 show the results of the test of the null-hypothesis that the relation between the distance to the Netherlands and the level of technological sophistication in 1500CE is strictly monotone. The null-hypothesis is rejected whenever the V-statistic is always larger than the (wild-bootstrap) critical value. As can be seen, the hypothesis that a semi-parametric regression between the distance to the Netherlands and the level of technological sophistication in 1500CE is strictly increasing or strictly decreasing is always rejected. Thus, one can reject the hypothesis that the relation between the distance to the Netherlands and the level of technological sophistication in 1500CE is strictly monotone.

Table F.25: Non- and Semi-Parametric Specification Test for Quadratic Relation

	Non-Parametric							Semi-Parametric						
	(1) (Agr)	(2) (Comm)	(3) (Trans)	(4) (Mil)	(5) (Ind)	(6) (Av.)	(7) (Av.M.)	(8) (Agr)	(9) (Comm)	(10) (Trans)	(11) (Mil)	(12) (Ind)	(13) (Av.)	(14) (Av.M.)
T^*-stat	0.037	0.038	0.059*	0.071	0.053	0.042	0.037	0.017	0.038	0.020	0.045	0.022	0.018	0.018
	(0.029)	(0.026)	(0.014)	(0.024)	(0.017)	(0.014)	(0.013)	(0.023)	(0.016)	(0.011)	(0.021)	(0.020)	(0.006)	(0.005)
Critical Value	0.097	0.089	0.047	0.087	0.060	0.049	0.043	0.071	0.053	0.034	0.060	0.060	0.020	0.018
Observations	84	84	84	84	84	84	84	84	84	84	84	84	84	84

Table F.26: Non- and Semi-Parametric Specification Test for Strict Monotonicity (Increasing)

	Non-Parametric							Semi-Parametric						
	(1) (Agr)	(2) (Comm)	(3) (Trans)	(4) (Mil)	(5) (Ind)	(6) (Av.)	(7) (Av.M.)	(8) (Agr)	(9) (Comm)	(10) (Trans)	(11) (Mil)	(12) (Ind)	(13) (Av.)	(14) (Av.M.)
V-stat	29.83	55.49	75.27	57.32	52.51	69.51	67.54	44.71	85.21	119.28	105.00	46.13	161.74	156.00
	(4.32)	(5.72)	(5.15)	(5.50)	(7.57)	(4.96)	(5.08)	(5.19)	(4.30)	(6.05)	(5.91)	(6.14)	(4.63)	(4.70)
Critical Value	22.29	24.77	21.84	24.25	30.34	22.46	22.83	14.67	12.58	14.19	15.74	17.54	14.60	14.56
Observations	84	84	84	84	84	84	84	84	84	84	84	84	84	84

Table F.27: Non- and Semi-Parametric Specification Test for Strict Monotonicity (Decreasing)

	Non-Parametric							Semi-Parametric						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.M.)	(Agr)	(Comm)	(Trans)	(Mil)	(Ind)	(Av.)	(Av.M.)
V-stat	6.00	3.92	12.65	6.37	16.05	8.65	8.90	17.21	26.57	29.06	21.20	23.63	50.01	52.29
	(4.25)	(6.64)	(5.41)	(4.98)	(6.45)	(4.95)	(5.07)	(5.42)	(5.85)	(5.09)	(5.11)	(6.27)	(5.58)	(5.80)
Critical Value	21.58	27.61	22.74	22.83	27.36	22.18	22.40	14.78	14.74	14.59	16.04	15.83	14.67	14.34
Observations	84	84	84	84	84	84	84	84	84	84	84	84	84	84

F.3 Historical Evidence II: Population Density

In table 4 I used panel data methods to analyze the relation between distance to the frontier and economic development. I exploited changes in the location of the western frontier in the Old World in order to identify this relation even under the presence of country and time fixed effects. In tables F.28-F.31 I repeat the analysis, but in each column I restrict the sample to the countries located on the same continent. As before I use both the fixed effects (FE) estimator with country and year fixed effects, as well as the first-difference (FD) estimator. Additionally, as in the previous section, I test the other possible explanations for the U-shape. Given the lack of data I can control only for the effects of the Neolithic Revolution and European colonization. Although the results are based on smaller samples, they are consistent with the analysis in the main body of the text and suggest the existence of a U-shaped relation with the distance to the technological frontier. Thus, the non-monotonicity does not seem to be generated by some intercontinental differences. In part, this was to be expected since country fixed effects should capture these possible sources of differences.

Table F.28: Population density and distance to the western technological frontier in the Old World (by continent).

	Dependent Variable is Population density in 1CE, 1000CE, 1500CE, 1800CE					
	FE Estimator			FD Estimator		
	(1)	(2)	(3)	(4)	(5)	(6)
	(Asia)	(Africa)	(Europe)	(Asia)	(Africa)	(Europe)
Pre-industrial distance to frontier in period	-0.53***	-0.21	-0.57***	-0.12**	-0.03	-0.43**
	(0.11)	(0.19)	(0.16)	(0.06)	(0.06)	(0.17)
Sq. Pre-ind. distance to frontier in period	0.03***	0.02*	0.09***	0.01***	0.02***	0.07**
	(0.01)	(0.01)	(0.03)	(0.01)	(0.00)	(0.03)
LDD	9.94***	4.86***	3.06***	4.25***	1.10	2.95***
	(2.31)	(1.80)	(0.39)	(0.81)	(1.59)	(0.25)
Year FE	YES	YES	YES	NO	NO	NO
Country FE	YES	YES	YES	NO	NO	NO
Adjusted R-squared	0.65	0.83	0.83	0.04	0.11	0.03
Number of countries	38	45	38			
Observations	148	171	148	115	126	112

Notes: (i) Estimators used are (FE) fixed effects estimator, (FD) first-difference estimator. (ii) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.29: Population density and distance to the western technological frontier in the Old World (by continent).
Is the U-shape generated by the Neolithic Revolution?

	Dependent Variable is Population density in 1CE, 1000CE, 1500CE, 1800CE					
	FE Estimator			FD Estimator		
	(1)	(2)	(3)	(4)	(5)	(6)
	(Asia)	(Africa)	(Europe)	(Asia)	(Africa)	(Europe)
Pre-industrial distance to frontier in period	-0.53***	-0.21	-0.57***	-0.12**	-0.15*	-0.22
	(0.11)	(0.19)	(0.16)	(0.06)	(0.08)	(0.17)
Sq. Pre-ind. dist. to frontier in period	0.03***	0.02*	0.09***	0.01**	0.01**	0.01
	(0.01)	(0.01)	(0.03)	(0.00)	(0.01)	(0.04)
Years (BP) since transition to agriculture	0.99***	1.02***	1.06***	0.67***	1.03***	0.82***
	(0.16)	(0.07)	(0.07)	(0.10)	(0.08)	(0.06)
LDD	9.94***	4.86***	3.06***	4.92***	6.20***	7.95
	(2.31)	(1.80)	(0.39)	(0.80)	(1.00)	(13.88)
Year FE	YES	YES	YES	NO	NO	NO
Country FE	YES	YES	YES	NO	NO	NO
Adjusted R-squared	0.65	0.83	0.83	0.44	0.77	0.47
Number of countries	38	45	38			
Observations	148	171	148	115	126	112

Notes: (i) Estimators used are (FE) fixed effects estimator, (FD) first-difference estimator. (ii) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.30: Population density and distance to the western technological frontier in the Old World (by continent). Is the U-shape generated by European colonization?

	Dependent Variable is Population density in 1CE, 1000CE, 1500CE, 1800CE					
	FE Estimator			FD Estimator		
	(1)	(2)	(3)	(4)	(5)	(6)
	(Asia)	(Africa)	(Europe)	(Asia)	(Africa)	(Europe)
Pre-industrial distance to frontier in period	-0.53***	-0.21	-0.57***	-0.26***	-0.00	-0.43**
	(0.09)	(0.20)	(0.16)	(0.06)	(0.05)	(0.17)
Sq. Pre-ind. distance to frontier in period	0.03***	0.02*	0.09***	0.01***	0.01***	0.07**
	(0.01)	(0.01)	(0.03)	(0.00)	(0.00)	(0.03)
European Colony (includes Turkey)	-0.02	-0.03		0.70***	0.44***	
	(0.21)	(0.16)		(0.11)	(0.05)	
LDD	9.90***	4.88**	3.06***	9.02***	0.12	2.95***
	(2.22)	(1.86)	(0.39)	(1.66)	(1.92)	(0.25)
Year FE	YES	YES	YES	NO	NO	NO
Country FE	YES	YES	YES	NO	NO	NO
Adjusted R-squared	0.65	0.83	0.83	0.14	0.21	0.03
Number of countries	38	45	38			
Observations	148	171	148	115	126	112

Notes: (i) Estimators used are (FE) fixed effects estimator, (FD) first-difference estimator. (ii) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table F.31: Population density and distance to the western technological frontier in the Old World (by continent). Is the U-shape jointly generated by European colonization and the Neolithic Transition?

	Dependent Variable is Population density in 1CE, 1000CE, 1500CE, 1800CE					
	FE Estimator			FD Estimator		
	(1) (Asia)	(2) (Africa)	(3) (Europe)	(4) (Asia)	(5) (Africa)	(6) (Europe)
Pre-industrial distance to frontier	-0.53***	-0.21	-0.57***	-0.13**	-0.13	-0.22
	(0.09)	(0.20)	(0.16)	(0.06)	(0.09)	(0.17)
Squared Pre-industrial distance to frontier	0.03***	0.02*	0.09***	0.01**	0.01**	0.01
	(0.01)	(0.01)	(0.03)	(0.00)	(0.01)	(0.04)
Years (BP) since transition to agriculture	1.00***	1.03***	1.06***	0.67***	0.99***	0.82***
	(0.20)	(0.09)	(0.07)	(0.12)	(0.08)	(0.06)
European Colony (includes Turkey)	-0.02	-0.03		0.02	0.15***	
	(0.21)	(0.16)		(0.10)	(0.05)	
LDD	9.90***	4.88**	3.06***	5.11***	5.94***	7.95
	(2.22)	(1.86)	(0.39)	(0.90)	(1.16)	(13.88)
Year FE	YES	YES	YES	NO	NO	NO
Country FE	YES	YES	YES	NO	NO	NO
Adjusted R-squared	0.65	0.83	0.83	0.43	0.78	0.47
Number of countries	38	45	38			
Observations	148	171	148	115	126	112

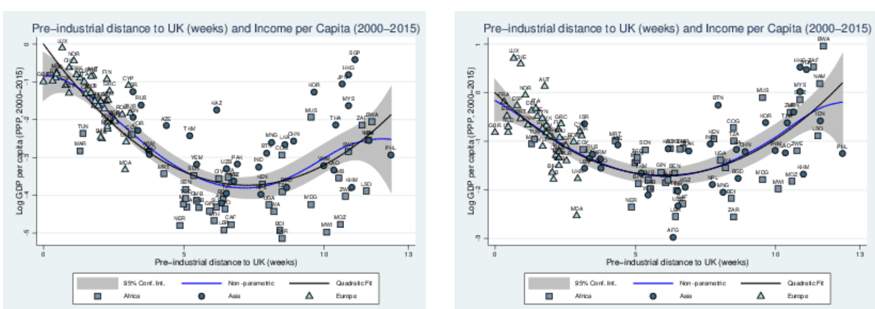
Notes: (i) Estimators used are (FE) fixed effects estimator, (FD) first-difference estimator. (ii) Least desirable distance is the number of weeks that minimizes the quadratic relation with respect to the pre-industrial distance to the Netherlands. It is equal to $-\beta_{Distance}/(2 \cdot \beta_{Sq.Distance})$. (iii) Heteroskedasticity robust standard error estimates are reported in parentheses; *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

F.4 Persistence

Table F.32: Distance from the Pre-industrial Technological Frontier and Contemporary Development

	Log[GDP per capita in 2000CE]							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-industrial distance to frontier	-1.10***	-0.60***	-0.60***	-0.63***	-0.55***	-0.56***	-0.50***	-0.49***
	(0.08)	(0.14)	(0.14)	(0.14)	(0.16)	(0.16)	(0.15)	(0.18)
Sq. Pre-industrial distance to frontier	0.07***	0.05***	0.05***	0.05***	0.05***	0.05***	0.04***	0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Pre-industrial distance to China					0.07	0.04	0.25	0.25
					(0.07)	(0.19)	(0.20)	(0.25)
Sq.Pre-industrial distance to China						0.00	-0.01	-0.01
						(0.01)	(0.01)	(0.02)
European Colony Dummy							-0.92**	-0.97***
							(0.38)	(0.35)
Pre-industrial distance to East Africa								0.06
								(0.20)
Sq. Pre-industrial distance to East Africa								-0.01
								(0.02)
LDD UK	7.46***	6.15***	6.15***	6.34***	5.81***	5.93***	5.64***	5.48***
	(0.27)	(0.50)	(0.51)	(0.70)	(0.94)	(1.20)	(1.14)	(1.29)
Geographical Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Continental FE	No	No	No	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.67	0.78	0.78	0.78	0.78	0.77	0.79	0.78
Observations	107	107	107	107	107	107	107	107

Figure 20: Distance to Pre-Industrial Technological Frontier (UK) and Income per capita (2000CE)



(a) Unconditional Relation

(b) Conditional Relation

Table F.33: Persistent Effect of Isolation from the Pre-industrial Technological Frontier and Contemporary Patenting Activity

	Log[Patents per capita in 2000CE]								
	All			Residents			Non-Residents		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Time at MDD	0.42***	0.54***	0.62***	0.42***	0.63***	0.71***	0.36***	0.33*	0.40**
	(0.06)	(0.13)	(0.11)	(0.09)	(0.12)	(0.14)	(0.03)	(0.18)	(0.15)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	No	No	Yes	No	No	Yes
Colony FE	No	No	Yes	No	No	Yes	No	No	Yes
Adjusted-R^2	0.63	0.79	0.83	0.70	0.82	0.84	0.42	0.53	0.55
Observations	63	63	63	63	63	63	63	63	63

Table F.34: Persistent Effect of Isolation from the Pre-industrial Technological Frontier and Contemporary Patenting Activity

	Log[Patents per capita in 2000CE]								
	All			Residents			Non-Residents		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MDD Index	1.11***	0.95**	1.18**	1.12***	1.24***	1.48**	0.83***	0.34	0.53
	(0.28)	(0.38)	(0.51)	(0.35)	(0.41)	(0.56)	(0.27)	(0.46)	(0.55)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographical Controls	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Time Since Neolithic Revolution	No	No	Yes	No	No	Yes	No	No	Yes
Colony FE	No	No	Yes	No	No	Yes	No	No	Yes
Adjusted-R^2	0.61	0.75	0.79	0.69	0.79	0.81	0.40	0.51	0.53
Observations	63	63	63	63	63	63	63	63	63

Table F.35: Persistent Effect of Isolation from the Pre-industrial Technological Frontier and Contemporary Domestic Patenting Activity:
Robustness to Legal Origins, Institutions and Religious Composition

	Log[Patents per capita by Residents in 2000CE]				
	(1)	(2)	(3)	(4)	(5)
Time at MDD	0.67***	0.43**	0.65***	0.68***	0.39***
	(0.15)	(0.16)	(0.15)	(0.12)	(0.13)
Regional FE	Yes	Yes	Yes	Yes	Yes
Geographical Controls	Yes	Yes	Yes	Yes	Yes
Time Since Neolithic Revolution	Yes	Yes	Yes	Yes	Yes
Colony FE	Yes	Yes	Yes	Yes	Yes
Legal Origin FE	No	Yes	No	No	Yes
Constraints on Executive	No	No	Yes	No	Yes
Religious Shares	No	No	No	Yes	Yes
Adjusted-R^2	0.84	0.87	0.84	0.88	0.91
Observations	63	63	63	63	63

G Proofs

The following intermediate results prove Theorem D.1.

Proposition G.1. *For each economy d and each $l_0 > 0$ there exists a unique equilibrium in which $l_t^* \in (0,1)$ for all $t \geq 1$.*

Proof. The first order condition of the problem in equation (26) is

$$u'(c_t) g_t^{\frac{1-\rho}{\rho}} \Big[\alpha \gamma_t l_t^{\alpha\rho - 1} - \beta \delta_t (1 - l_t)^{\beta\rho - 1} \Big] A_{t-1} = 0,$$

where

$$g_t = \gamma_t l_t^{\alpha\rho} + \delta_t (1 - l_t)^{\beta\rho}, \qquad \gamma_t = \lambda a^\rho l_{t-1}^{\alpha'\rho}, \qquad \delta_t = (1 - \lambda) \Big(b(d) \Big)^\rho (1 - l_{t-1})^{\beta'\rho}.$$

Thus, the solution to the agent's problem must satisfy the equation

$$F_1(l_t) \equiv \alpha \gamma_t l_t^{\alpha\rho - 1} - \beta \delta_t (1 - l_t)^{\beta\rho - 1} = 0. \tag{28}$$

Notice that this equation is continuous for $l_t \in (0,1)$, and

$$\lim_{l_t \to 0} F_1(l_t) = +\infty \qquad \text{and} \qquad \lim_{l_t \to 1} F_1(l_t) = -\infty.$$

Since

$$F_1'(l_t) = \alpha(\alpha\rho - 1)\gamma_t l_t^{\alpha\rho - 2} + (\beta\rho - 1)\beta\delta_t(1 - l_t)^{\beta\rho - 2} < 0$$

the intermediate value theorem implies that there exists a unique value $l_t^* \in (0,1)$ that solves the agent's problem. To see that the solution is interior, i.e. $l_t^* \in (0,1)$, it suffices to notice that the first order condition converges to $+\infty$ as $l_t \to 0$ and to $-\infty$ as $l_t \to 1$.

Additionally,

$$\begin{aligned}
\frac{\partial^2 c_{st}}{\partial l_t^2} =& g_t^{\frac{1-2\rho}{\rho}} \Big\{ (1-\rho) \Big[\alpha\gamma_t l_t^{\alpha\rho-1} - \beta\delta_t (1-l_t)^{\beta\rho-1} \Big]^2 \\
& - g_t \Big[\alpha(1-\alpha\rho)\gamma_t l_t^{\alpha\rho-2} + \beta(1-\beta\rho)\delta_t(1-l_t)^{\beta\rho-2} \Big] \Big\} A_{t-1} \\
=& g_t^{\frac{1-2\rho}{\rho}} \Big\{ (1-\rho)\alpha^2\gamma_t^2 l_t^{2\alpha\rho-2} + (1-\rho)\beta^2\delta_t^2(1-l_t)^{2\beta\rho-2} - 2(1-\rho)\alpha\beta\gamma_t\delta_t l_t^{\alpha\rho-1}(1-l_t)^{\beta\rho-1} \\
& - \alpha(1-\alpha\rho)\gamma_t^2 l_t^{2\alpha\rho-2} - \beta(1-\beta\rho)\delta_t^2(1-l_t)^{2\beta\rho-2} \\
& - \alpha(1-\alpha\rho)\gamma_t\delta_t l_t^{\alpha\rho-2}(1-l_t)^{\beta\rho} - \beta(1-\beta\rho)\gamma_t\delta_t l_t^{\alpha\rho}(1-l_t)^{\beta\rho-2} \Big\} A_{t-1} \\
=& g_t^{\frac{1-2\rho}{\rho}} \Big\{ \Big[(1-\rho)\alpha - (1-\alpha\rho) \Big] \alpha\gamma_t^2 l_t^{2\alpha\rho-2} + \Big[(1-\rho)\beta - (1-\beta\rho) \Big] \beta\delta_t^2 (1-l_t)^{2\beta\rho-2} \\
& - 2(1-\rho)\alpha\beta\gamma_t\delta_t l_t^{\alpha\rho-1}(1-l_t)^{\beta\rho-1} \\
& - \alpha(1-\alpha\rho)\gamma_t\delta_t l_t^{\alpha\rho-2}(1-l_t)^{\beta\rho} - \beta(1-\beta\rho)\gamma_t\delta_t l_t^{\alpha\rho}(1-l_t)^{\beta\rho-2} \Big\} A_{t-1} \\
=& - g_t^{\frac{1-2\rho}{\rho}} \Big\{ (1-\alpha)\alpha\gamma_t^2 l_t^{2\alpha\rho-2} + (1-\beta)\beta\delta_t^2(1-l_t)^{2\beta\rho-2} \\
& + 2(1-\rho)\alpha\beta\gamma_t\delta_t l_t^{\alpha\rho-1}(1-l_t)^{\beta\rho-1} \\
& + \alpha(1-\alpha\rho)\gamma_t\delta_t l_t^{\alpha\rho-2}(1-l_t)^{\beta\rho} + \beta(1-\beta\rho)\gamma_t\delta_t l_t^{\alpha\rho}(1-l_t)^{\beta\rho-2} \Big\} A_{t-1} < 0.
\end{aligned}$$

So, the second order condition of the problem in equation (26) is satisfied since

$$u''(c_{st})\left(\frac{\partial c_{st}}{\partial l_t}A_{t-1}\right)^2 + u'(c_{st})\frac{\partial^2 c_{st}}{\partial l_t^2} < 0. \qquad \blacksquare$$

Additionally,

Proposition G.2. *For each economy d there exists a unique stationary equilibrium such that $l_t^* = l^* \in (0,1)$ for all $t \geq 0$.*

Proof. In what follows, any variable without a time subscript t denotes its steady state value. In particular, redefine

$$\gamma = \lambda a^\rho, \qquad \delta = (1-\lambda)\Big(b(d)\Big)^\rho, \qquad g = \gamma l^{(\alpha'+\alpha)\rho} + \delta(1-l)^{(\beta'+\beta)\rho}.$$

The proof is similar to the previous one. In a stationary equilibrium the first order condition implies

$$u'(c)g^{\frac{1-\rho}{\rho}}\Big[\alpha\gamma l^{(\alpha'+\alpha)\rho-1} - \beta\delta(1-l)^{(\beta'+\beta)\rho-1}\Big]A_{t-1} = 0. \tag{29}$$

which is satisfied if, and only if,

$$F(l,d) \equiv \alpha\gamma l^{(\alpha'+\alpha)\rho-1} - \beta\delta(1-l)^{(\beta'+\beta)\rho-1} = 0 \tag{30}$$

Again notice that

$$\lim_{l\to 0} F(l,d) = +\infty \qquad \text{and} \qquad \lim_{l\to 1} F(l,d) = -\infty,$$

and

$$\frac{\partial F(l,d)}{\partial l} = \alpha\Big((\alpha'+\alpha)\rho - 1\Big)\gamma l^{(\alpha'+\alpha)\rho-2} + \beta\Big((\beta'+\beta)\rho-1\Big)\delta(1-l)^{(\beta'+\beta)\rho-2} < 0. \tag{31}$$

Thus, by the intermediate value theorem, there exists a unique value $l^* \in (0,1)$ that satisfies the first order condition in a stationary state. $\blacksquare$

Proposition G.3. *The unique stationary equilibrium of economy d is not Pareto efficient.*

Proof. To see this consider the problem faced by a central planner

$$\max_{l\in[0,1]} \quad u(c^o) \tag{32a}$$

$$c^o = \left\{\left[\lambda\left(al^{\alpha'+\alpha}\right)^\rho + (1-\lambda)\Big(b(d)(1-l)^{\beta'+\beta}\Big)^\rho\right]^{\frac{1}{\rho}} + 1\right\}A_{t-1} \tag{32b}$$

The first order condition of the problem is given by

$$u'(c^o)g^{\frac{1-\rho}{\rho}}\Big[(\alpha'+\alpha)\gamma l^{(\alpha'+\alpha)\rho-1} - (\beta'+\beta)\delta(1-l)^{(\beta'+\beta)\rho-1}\Big] = 0,$$

so that the unique solution is determined by the condition

$$(\alpha'+\alpha)\gamma l^{(\alpha'+\alpha)\rho-1} - (\beta'+\beta)\delta(1-l)^{(\beta'+\beta)\rho-1} = 0. \tag{33}$$

Clearly, equations (30) and (33) have different solutions, so that the solution to the planner's problem $l^o \neq l^*$. Using a similar argument as in the previous proof one can show that the left-hand side of equation (33) is strictly decreasing in l, converges to $+\infty$ as $l \to 0$ and to $-\infty$ as $l \to 1$, so that there exists a unique solution l^o to equation (33). Similarly, one can show that the second order condition is satisfied, and that $l^o \in (0,1)$. $\blacksquare$

Proposition G.4. *The unique stationary equilibrium is asymptotically stable.*

Proof. The dynamics of the economy are determined by the condition given in equation (28). The stationary equilibrium is asymptotically stable if

$$\left|\frac{\partial l_t}{\partial l_{t-1}}\right|_{l_t=l_{t-1}=l^*} < 1.$$

From previous results

$$F_1'(l_t) = \alpha(\alpha\rho - 1)\gamma_t l_t^{\alpha\rho-2} + (\beta\rho - 1)\beta\delta_t(1 - l_t)^{\beta\rho-2} < 0.$$

Thus, the Implicit Function Theorem implies that $l_t \equiv l_t(l_{t-1})$ is a continuous function of l_{t-1}. Letting $F_2(l_{t-1})$ denote the same condition as a function of l_{t-1}, so that

$$F_2(l_{t-1}) = \alpha\gamma l_{t-1}^{\alpha'\rho} l_t^{\alpha\rho-1} - \beta\delta(1 - l_{t-1})^{\beta'\rho}(1 - l_t)^{\beta\rho-1}$$

and

$$F_2'(l_{t-1}) = \alpha\alpha'\rho\gamma l_{t-1}^{\alpha'\rho-1} l_t^{\alpha\rho-1} + \beta\beta'\rho\delta(1 - l_{t-1})^{\beta'\rho-1}(1 - l_t)^{\beta\rho-1} > 0.$$

Clearly,

$$\frac{\partial l_t}{\partial l_{t-1}} = -\frac{F_2'(l_{t-1})}{F_1'(l_t)} > 0.$$

In a stationary state

$$\begin{aligned} F_1'(l^*) =& \alpha(\alpha\rho - 1)\gamma l^{*\,(\alpha'+\alpha)\rho-2} + (\beta\rho - 1)\beta\delta_t(1 - l_t)^{\beta\rho-2}, \\ F_2'(l^*) =& \alpha\alpha'\rho\gamma l^{*\,(\alpha'+\alpha)\rho-2} + \beta\beta'\rho\delta(1 - l^*)^{\beta\rho-2}, \end{aligned}$$

so that

$$-F_1'(l^*) - F_2'(l^*) = \alpha(1 - (\alpha' + \alpha)\rho)\gamma l^{*\,(\alpha'+\alpha)\rho-2} + (1 - (\beta' + \beta)\rho)\beta\delta_t(1 - l_t)^{\beta\rho-2} > 0.$$

This implies that

$$\left|\frac{\partial l_t}{\partial l_{t-1}}\right|_{l_t=l_{t-1}=l^*} = \left|-\frac{F_2'(l_{t-1})}{F_1'(l_t)}\right|_{l_t=l_{t-1}=l^*} < 1$$

and the stationary equilibrium is asymptotically stable. ∎

From the previous results and using the Implicit Function Theorem, one has that

Proposition G.5. *The stationary equilibrium allocation l^* is a continuous, increasing and differentiable function of d, i.e. $l^* = l^*(d)$, such that $\frac{\partial l^*(d)}{\partial d} > 0$. Additionally, it is a convex function of d ($\frac{\partial^2 l^*(d)}{\partial d^2} > 0$) if any of the following holds:*

(i) $[1 + (\beta' + \beta)]\rho \leq 1$,

(ii) $\Big(1 - (\alpha' + \alpha) + (\beta' + \beta)\Big) \leq 0$,

(iii) $\Big((\beta' + \beta) - (\alpha' + \alpha)\Big) \geq 0$, *and* $[1 - (\alpha' + \alpha) + 2(\beta' + \beta)]\rho \leq 1$.

Proof. Equation (31) and the Implicit Function Theorem imply that l^* is a continuous and differentiable function of d, such that

$$\frac{\partial l^*}{\partial d} = -\frac{\frac{\partial F(l^*,d)}{\partial d}}{\frac{\partial F(l^*,d)}{\partial l^*}}.$$

On the other hand,

$$\frac{\partial F(l^*,d)}{\partial d} = -\rho\beta\delta\frac{b'(d)}{b(d)}(1-l^*)^{(\beta'+\beta)\rho-1} > 0,$$

so that

$$\frac{\partial l^*}{\partial d} = -\frac{\frac{\partial F(l^*,d)}{\partial d}}{\frac{\partial F(l^*,d)}{\partial l^*}} = -\frac{\rho\frac{b'(d)}{b(d)}l^*(1-l^*)}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*} > 0. \tag{34}$$

Furthermore, the optimal allocation is a convex function of d under the additional assumptions. To see this, notice that

$$\begin{aligned}
\frac{\partial^2 F(l^*,d)}{\partial l^2} =&\alpha\Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)\gamma l^{*\,(\alpha'+\alpha)\rho-3}\\
&-\beta\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)\delta(1-l^*)^{(\beta'+\beta)\rho-3},\\
\frac{\partial^2 F(l^*,d)}{\partial d^2} =&-\beta\delta\left(\rho\frac{b'(d)}{b(d)}\right)^2(1-l^*)^{(\beta'+\beta)\rho-1}-\beta\delta\rho\frac{b''(d)b(d)-b'(d)^2}{b(d)^2}(1-l^*)^{(\beta'+\beta)\rho-1}\\
=&\beta\delta\rho\left\{(1-\rho)\left(\frac{b'(d)}{b(d)}\right)^2-\frac{b''(d)}{b(d)}\right\}(1-l^*)^{(\beta'+\beta)\rho-1} > 0,\\
\frac{\partial^2 F(l^*,d)}{\partial l\partial d} =&\rho\beta\Big((\beta'+\beta)\rho-1\Big)\delta\frac{b'(d)}{b(d)}(1-l^*)^{(\beta'+\beta)\rho-2} > 0,
\end{aligned}$$

and

$$\begin{aligned}
\frac{\partial^2 l^*}{\partial d^2} =& -\frac{\left(\frac{\partial^2 F(l^*,d)}{\partial d\partial l}\frac{\partial l^*}{\partial d}+\frac{\partial^2 F(l^*,d)}{\partial d^2}\right)\frac{\partial F(l^*,d)}{\partial l^*}-\frac{\partial F(l^*,d)}{\partial d}\left(\frac{\partial^2 F(l^*,d)}{\partial l^{*\,2}}\frac{\partial l^*}{\partial d}+\frac{\partial^2 F(l^*,d)}{\partial l^*\partial d}\right)}{\left(\frac{\partial F(l^*,d)}{\partial l^*}\right)^2}\\
&>0 \iff\\
&-\left(\frac{\partial^2 F(l^*,d)}{\partial d\partial l}\frac{\partial l^*}{\partial d}+\frac{\partial^2 F(l^*,d)}{\partial d^2}\right)\frac{\partial F(l^*,d)}{\partial l^*}+\frac{\partial F(l^*,d)}{\partial d}\left(\frac{\partial^2 F(l^*,d)}{\partial l^{*\,2}}\frac{\partial l^*}{\partial d}+\frac{\partial^2 F(l^*,d)}{\partial l^*\partial d}\right)\\
&=2\frac{\partial^2 F(l^*,d)}{\partial d\partial l}\frac{\partial F(l^*,d)}{\partial d}-\frac{\partial^2 F(l^*,d)}{\partial d^2}\frac{\partial F(l^*,d)}{\partial l^*}+\frac{\partial F(l^*,d)}{\partial d}\frac{\partial^2 F(l^*,d)}{\partial l^{*\,2}}\frac{\partial l^*}{\partial d}\\
&=2\Big(1-(\beta'+\beta)\rho\Big)\left(\rho\beta\delta\frac{b'(d)}{b(d)}\right)^2(1-l^*)^{2(\beta'+\beta)\rho-3}\\
&\quad+\alpha\Big(1-(\alpha'+\alpha)\rho\Big)\beta\gamma\delta\rho\left\{(1-\rho)\left(\frac{b'(d)}{b(d)}\right)^2-\frac{b''(d)}{b(d)}\right\}l^{*\,(\alpha'+\alpha)\rho-2}(1-l^*)^{(\beta'+\beta)\rho-1}\\
&\quad+(\beta\delta)^2\rho\Big(1-(\beta'+\beta)\rho\Big)\left\{(1-\rho)\left(\frac{b'(d)}{b(d)}\right)^2-\frac{b''(d)}{b(d)}\right\}(1-l^*)^{2(\beta'+\beta)\rho-3}
\end{aligned}$$

$$
\begin{aligned}
&- \alpha\beta\Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)\gamma\delta\rho\frac{b'(d)}{b(d)}l^{*\,(\alpha'+\alpha)\rho-3}(1-l^*)^{(\beta'+\beta)\rho-1}\frac{\partial l^*}{\partial d}\\
&+ \rho(\beta\delta)^2\frac{b'(d)}{b(d)}\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)(1-l^*)^{2(\beta'+\beta)\rho-4}\frac{\partial l^*}{\partial d}\\
=&2\Big(1-(\beta'+\beta)\rho\Big)\left(\rho\beta\delta\frac{b'(d)}{b(d)}\right)^2(1-l^*)^{2(\beta'+\beta)\rho-3}\\
&+ \Big(1-(\alpha'+\alpha)\rho\Big)(\beta\delta)^2\rho\left\{(1-\rho)\left(\frac{b'(d)}{b(d)}\right)^2-\frac{b''(d)}{b(d)}\right\}l^{*\,-1}(1-l^*)^{2(\beta'+\beta)\rho-2}\\
&+ (\beta\delta)^2\rho\Big(1-(\beta'+\beta)\rho\Big)\left\{(1-\rho)\left(\frac{b'(d)}{b(d)}\right)^2-\frac{b''(d)}{b(d)}\right\}(1-l^*)^{2(\beta'+\beta)\rho-3}\\
&- \Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)(\beta\delta)^2\rho\frac{b'(d)}{b(d)}l^{*\,-2}(1-l^*)^{2(\beta'+\beta)\rho-2}\frac{\partial l^*}{\partial d}\\
&+ \rho(\beta\delta)^2\frac{b'(d)}{b(d)}\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)(1-l^*)^{2(\beta'+\beta)\rho-4}\frac{\partial l^*}{\partial d}>0
\end{aligned}
$$

because

$$
\begin{aligned}
&2\Big(1-(\beta'+\beta)\rho\Big)\rho(1-l^*)\\
&+\Big(1-(\alpha'+\alpha)\rho\Big)(1-\rho)l^{*\,-1}(1-l^*)^2\\
&+\Big(1-(\beta'+\beta)\rho\Big)(1-\rho)(1-l^*)\\
&-\Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)\frac{b(d)}{b'(d)}l^{*\,-2}(1-l^*)^2\frac{\partial l^*}{\partial d}\\
&+\frac{b(d)}{b'(d)}\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)\frac{\partial l^*}{\partial d}\\
=&\Big(1-(\alpha'+\alpha)\rho\Big)(1-\rho)l^{*\,-1}(1-l^*)^2\\
&+\Big(1-(\beta'+\beta)\rho\Big)(1+\rho)(1-l^*)\\
&+\frac{\rho\Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)l^{*\,-1}(1-l^*)^3}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
&-\frac{\rho\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)l^*(1-l^*)}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
=&\frac{(1-\rho)\Big(1-(\alpha'+\alpha)\rho\Big)^2l^{*\,-1}(1-l^*)^3+(1-\rho)\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)(1-l^*)^2}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
&+\frac{(1+\rho)\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)(1-l^*)^2+(1+\rho)\Big(1-(\beta'+\beta)\rho\Big)^2l^*(1-l^*)}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
&+\frac{\rho\Big(1-(\alpha'+\alpha)\rho\Big)\Big(2-(\alpha'+\alpha)\rho\Big)l^{*\,-1}(1-l^*)^3}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}
\end{aligned}
$$

$$
\begin{aligned}
&- \frac{\rho\Big(1-(\beta'+\beta)\rho\Big)\Big(2-(\beta'+\beta)\rho\Big)l^*(1-l^*)}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
=&\frac{\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)l^{*\,-1}(1-l^*)^3+2\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)(1-l^*)^2}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}\\
&+\frac{\Big(1-(\beta'+\beta)\rho\Big)\Big(1-\rho-(\beta'+\beta)\rho\Big)l^*(1-l^*)}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*)+\Big(1-(\beta'+\beta)\rho\Big)l^*}>0
\end{aligned}
$$

if $[1+(\beta'+\beta)]\rho\leq 1$. Otherwise, notice that the last inequality holds if

$$
\begin{aligned}
&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)l^{*\,-1}(1-l^*)^3+2\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)(1-l^*)^2\\
&+\Big(1-(\beta'+\beta)\rho\Big)\Big(1-\rho-(\beta'+\beta)\rho\Big)l^*(1-l^*)>0 \iff\\
&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)(1-l^*)^2+2\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)l^*(1-l^*)\\
&+\Big(1-(\beta'+\beta)\rho\Big)\Big(1-\rho-(\beta'+\beta)\rho\Big)l^{*\,2}\\
=&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)\\
&+2l^*\Big(1-(\alpha'+\alpha)\rho\Big)\Big[\Big(1-(\beta'+\beta)\rho\Big)-\Big(1+\rho-(\alpha'+\alpha)\rho\Big)\Big]\\
&+\Big[\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)+\Big(1-(\beta'+\beta)\rho\Big)\Big(1-\rho-(\beta'+\beta)\rho\Big)\\
&-2\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\beta'+\beta)\rho\Big)\Big]l^{*\,2}\\
=&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)-2\rho l^*\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\\
&\rho^2\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)l^{*\,2}>0
\end{aligned}
$$

since,

(i) if $\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\leq 0$, then $\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)<0$, so that the inequality holds;

(ii) if $\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)\geq 0$, and $[1-(\alpha'+\alpha)+2(\beta'+\beta)]\rho\leq 1$, then $\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)>0$ and the inequality holds, as

$$
\begin{aligned}
&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)-2\rho l^*\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\\
&\rho^2\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)l^{*\,2}\\
>&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1+\rho-(\alpha'+\alpha)\rho\Big)-2\rho\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\\
&\rho^2\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)l^{*\,2}\\
=&\Big(1-(\alpha'+\alpha)\rho\Big)\Big(1-\rho-(\beta'+\beta)\rho+[(\alpha'+\alpha)-(\beta'+\beta)]\rho\Big)\\
&\rho^2\Big(1-(\alpha'+\alpha)+(\beta'+\beta)\Big)\Big((\beta'+\beta)-(\alpha'+\alpha)\Big)l^{*\,2}>0.
\end{aligned}
$$

■

Proposition G.6. *If* $\alpha'/\alpha > \beta'/\beta$, $\lim_{d\to\infty} |b'(d)/b(d)| < \infty$, *and*

$$\bar{l} \equiv \frac{1-(\alpha'+\alpha)\rho}{\rho\left\{\beta\left[\frac{\alpha'}{\alpha}-\frac{\beta'}{\beta}\right]+(\beta'+\beta)-(\alpha'+\alpha)\right\}} \in (0,1),$$

then there exists an economy $\bar{d} \geq 0$ *such that the profile of stationary growth rates is decreasing on* $\mathcal{D} = [0, \bar{d}]$ *and increasing on* $\mathcal{E} \setminus \mathcal{D}$.

Proof. Clearly $G(d)$ is continuous and differentiable. The derivative of equation (27) with respect to d is

$$\begin{aligned} G'(d) = &\left\{ g^{\frac{1-\rho}{\rho}} \left[(\alpha'+\alpha)\gamma l^{*\,(\alpha'+\alpha)\rho-1} - (\beta'+\beta)\delta(1-l^*)^{(\beta'+\beta)\rho-1} \right] \right\} \frac{\partial l^*}{\partial d} \\ &+ g^{\frac{1-\rho}{\rho}} \frac{b'(d)}{b(d)} \delta(1-l^*)^{(\beta'+\beta)\rho} \end{aligned} \tag{35}$$

Notice that

$$\lim_{d\to\infty} g^{\frac{1-\rho}{\rho}} \frac{b'(d)}{b(d)} \delta(1-l^*)^{(\beta'+\beta)\rho} = 0.$$

From the first order condition (30), equation (34), and the assumption that $\alpha'/\alpha > \beta'/\beta$ it follows that

$$\begin{aligned} G'(d) = &- \frac{\rho \frac{b'(d)}{b(d)} g^{\frac{1-\rho}{\rho}} \beta \left[\frac{\alpha'}{\alpha} - \frac{\beta'}{\beta}\right] \delta l^* (1-l^*)^{(\beta'+\beta)\rho}}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*) + \Big(1-(\beta'+\beta)\rho\Big) l^*} + g^{\frac{1-\rho}{\rho}} \frac{b'(d)}{b(d)} \delta(1-l^*)^{(\beta'+\beta)\rho} \\ =& g^{\frac{1-\rho}{\rho}} \frac{b'(d)}{b(d)} \delta(1-l^*)^{(\beta'+\beta)\rho} \left[1 - \frac{\rho\beta\left[\frac{\alpha'}{\alpha} - \frac{\beta'}{\beta}\right] l^*}{\Big(1-(\alpha'+\alpha)\rho\Big)(1-l^*) + \Big(1-(\beta'+\beta)\rho\Big) l^*} \right] \end{aligned}$$

The second term in brackets is a strictly decreasing function of l^*, and is equal to 1 if $l^* = 0$. Since, l^* is increasing in d, for the existence of U-shape it is necessary that the second term be negative at $l^* = 1$, which is ensured by condition (U). Define $\bar{d}$ as the value of d such that second term is equal to zero if it exists, and $\bar{d} = \infty$ if no such d exists.[34] Thus, $G'(\bar{d}) = 0$, and $G'(d) \gtreqless 0$ if and only if $d \gtreqless \bar{d}$. ∎

H The Effect of Initial Technology Levels

I have previously shown that the initial levels of technology on each economy have been irrelevant to the determination of the path of growth rates and their stationary levels.[35] Clearly, this does not hold

[34] Notice that this definition of $\bar{d}$ allows for the possibility of $\bar{d} < 0$. This implies that the growth rate is an increasing function of distance.

[35] Unlike other models in the literature I do not focus on the effects of the *technological distance to the frontier* on the allocation of resources between imitation and creation (Acemoglu et al., 2006, 2010; Acemoglu and Zilibotti, 2001). Clearly, both types of distances affect these allocations and both types of models are complementary. One could generalize the model in this paper in order to include both distances by defining the technological distance $a(d) = \frac{\bar{A}}{A(d)}$, where $\bar{A}$ is the technological level in the frontier and by replacing $b(d)$ for $b(d) \cdot a(d)$ (or more generally for $b(d, a(d))$). Although the formal inclusion of both types of distances makes the solution method more cumbersome, since the technological distance varies each period, one can show that the results of this paper's model remain qualitatively unchanged as long as certain initial conditions hold. For example, if the derivative of $b(d, a(d))$ with respect to d is negative at the initial conditions, then there will exist a U-shaped relation between d and $g(d)$.

for income levels, since in period t the income in economy d is

$$y_t(d) = \left(\prod_{i=1}^{t} G_i(d) \right) A_0(d). \tag{36}$$

If the economy starts in the stationary equilibrium, then this amounts to

$$y_t^*(d) = (G(d))^t A_0(d). \tag{37}$$

This is an increasing function of $G(d)$, and since $y_t^*(d)$ is exponential in t, for any positive profile $\{A_0(d)\}_{d\in\mathcal{E}}$ there always exists a value $t' \geq 0$, so that for all $t \geq t'$ the profile of incomes $y_t^*(d)$ is qualitatively similar to the profile of growth rates. Now, since in equilibrium $G_t(d) \to G(d)$ as $t \to \infty$, it is not difficult to show that there exists $t'' \geq 0$ such that for all $t \geq t''$ the profile of incomes $\{y_t(d)\}_{d\in\mathcal{E}}$ is qualitatively similar to the profile of stationary growth rates $\{G(d)\}_{d\in\mathcal{E}}$. Let's write this more formally:

Proposition H.1. *Let the initial technology profile* $\{A_0(d)\}_{d\in\mathcal{E}}$ *be positive and* $t^* = \max\{t', t''\}$. *Then for all* $t \geq t^*$ *the income profiles* $\{y_t(d)\}_{d\in\mathcal{E}}$ *and* $\{y_t^*(d)\}_{d\in\mathcal{E}}$ *are such that for all economies* $d \in [0, \bar{d}]$ *incomes are falling as* d *increases. On the other hand, for all economies* $d > \bar{d}$ *incomes are rising as* d *increases.*

Proof of theorem H.1. Consider an economy $d \leq \bar{d}$ and define $y_t^u(d) = \sup_{d'\in(d,\bar{d}]} \{y_t^*(d')\}$. Notice that $y_t^u(d)$ is finite and bounded for any d and $t < \infty$, since

$$y_t^u(d) \leq G(0)^t \sup_{d'\in[0,\bar{d}]} \{A_0(d)\}.$$

Let $T(d) = \inf\{t \in \mathbb{R}_+ \mid y_t^*(d) \geq y_t^u(d)\}$. The fact that $G(d) > G(d')$ for all $d' \in (d, \bar{d}]$, implies $T(d) < \infty$. Furthermore, define $y_t^l(d) = G(d)^t \inf_{d'\in[0,\bar{d}]} \{A_0(d)\}$ and $T^l(d) = \inf\left\{t \in \mathbb{R}_+ \mid y_t^l(d) \geq y_t^u(d)\right\}$. Then $T(d) \leq T^l(d) < \infty$. It is not difficult to see that $T^l(d)$ is continuous, so that there exists $T_1^l = \sup_{d\in 0[,\bar{d}]} \left\{T^l(d)\right\}$. Let $T_1 = \sup\{T(d)\} \leq T_1^l < \infty$, so that for any $t \geq T_1$ incomes are a decreasing function of d. Similarly, for $d > \bar{d}$ let $y_t^u(d) = \sup_{d'\in[\bar{d},d)} \{y_t^*(d')\}$. By a similar argument as before one can show there exist T_2 and T_2^l, finite, such that incomes are increasing in d in every period $t > T_1$. Letting $t' = \max\{T_1, T_2\}$ one obtains the desired result.

The proof for the non-stationary case is similar and is omitted. ∎

Thus, the U-shaped relation between growth and distance from the frontier translates into a U-shaped relation between income levels and distance from the frontier for big enough t. Notice that this result does not depend on any specific form of the profile of initial technologies and implies that there will not exist a tendency for convergence among economies and might generate reversal of fortunes for certain initial conditions.

Appendix References

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