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From agriculture to manufacturing: How does geography matter?

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Abstract This article advances a theory to show that geographical advantage for agricultural production helps an economy to become more prosperous in the predominantly agricultural regime, but delays the timing of transition to manufacturing production (i.e., the timing of industrialization). It also delays the change in labor structure toward an increase in proportion of skilled labor, and hence, the economy may be overtaken in the development process by another with less geographical advantage for agriculture. This theoretical result is in accordance with recent empirical evidence and helps explain the reversals of national fortune, which are documented in economic history. Within its analytical framework, the article also enriches the existing literature by explaining the decline in fertility and the evolution of labor structure, along with technological progress, in the development process.

Keywords Agricultural sector · Manufacturing sector · Labor structure · Technological progress · Geographical advantage for agriculture · Reversal of fortune

JEL Classification J11 · J13 · O11 · O41

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1 Introduction

The development processes from agriculture to manufacturing, along with the demographic transition and the different timings of industrialization, which have lead to economic divergence as well as the reversal of fortune across countries, are long-standing and interesting topics that have been the subject of intensive research in recent years. This article aims to contribute a simple mechanism that helps to explain the development from the agricultural to the manufacturing regime. This occurs together with a decline in fertility and a change in labor structure toward an increasing proportion of skilled labor. Moreover, the article provides an additional understanding of the role of geographical advantage for agricultural production in shaping the patterns of economic development, contributing to the divergence and reversals in economic performance across societies. It shows that when the technological level is low enough, only agricultural production is operative. Over time, when the technological level becomes sufficiently high, manufacturing production becomes economically viable, and the proportion of skilled labor increases with the accumulation of technology. This article sheds light on the fact that a geographical advantage for agriculture helps an economy to become more prosperous within the agricultural regime but delays its industrialization and decline in fertility. Moreover, economic performances may be reversed from those countries with greater geographical advantage for agriculture to those who benefit less in this way. One may encounter each ingredient of the model presented in this article within existing literature, *but* the combination of ingredients and the mechanism which leads to the reversal in economic performances across countries are new.

The closest literature to this article may be Galor and Mountford (2006), “Trade and the Great Divergence: The Family Connection,” and Ashraf and Galor (2012), “Cultural Diversity, Geographical Isolation, and the Origin of the Wealth of Nations.” This article, however, differs significantly from Galor and Mountford (2006) in at least two aspects: (1) Galor and Mountford (2006) show international trade to be a prime cause of the “Great Divergence” in per capita income across countries in the last two centuries, while here we argue that geography is a fundamental cause; (2) while this article explains the switching from agricultural production to manufacturing production, along with a decline in fertility, as being due to technological progress during the development process, Galor and Mountford (2006) focus on the specializations in production between countries under the international trade regime. This article also differs significantly from Ashraf and Galor (2012) in at least two fundamental aspects: (1) Ashraf and Galor (2012) consider the exogenous effects of geographical isolation on cultural diversity, affecting the creation of knowledge, to explain the asymmetric evolution across societies. This article, however, explains the asymmetric evolution across societies by considering the entire geographical environment and resources, which are advantageous for agricultural production; (2) Ashraf and Galor (2012) do not take into account the decline in fertility in explaining the development process across societies, whereas this article considers such an effect. It is interesting to note an alternative mechanism recently advanced by Litina (2014) to explain comparative development across the globe. Litina argues that societies with high natural land productivity have reduced incentives between people to cooperate in establishing agricultural infrastructure, which is translated into social capital, relative to those with lower natural land productivity. The lack of social capital, in turn, affects the technological progress in the industrial (manufacturing) sector. Hence, through the channel of social capital formation and its positive effect on the technological progress in the industrial sector, Litina (2014) points out a similar hypothesis to this article: Locations with higher natural land productivity could be overtaken in the transition to the industrial era by those with lower natural land productivity. In this article however, rather than social capital, labor (or human capital) structure[1] is the stimulus for technological progress.[2]

The two last centuries are characterized by the significant technological progress associated with the industrial revolution, the demographic transition, and the generalization of basic education. As a consequence, most societies extracted themselves from Malthusian stagnation and experienced a considerable increase in the income per capita and human capital. This was coupled with a decline in the growth rate of population as depicted in Fig. 1 for the case of USA. The different timings of the transition from agricultural production to manufacturing production across societies have considerably shaped the contemporary world economy (as depicted in Fig. 2) and need to be explained. The divergence across societies in the two last centuries is also marked by the divergence in the per capita level of industrialization (measuring per capita volume of industrial production in Fig. 3), which is also explained in this article.

Historical evidence shows the reversals of national fortune and economic performance across societies such as China and Europe, and within the Western agricultural core which includes Europe, North Africa, the Middle East, and Southwest Asia. Indeed, it is well known that China was ahead of Europe until around fourteenth century. Nonetheless, China had been overtaken and Europe started industrializing before China (see Mokyr 1990). In a similar pattern, countries in the Fertile Crescent, with an earlier transition to agricultural production, were ahead of European countries in fortune in the early agricultural regime but have been overtaken, witnessing a great divergence in incomes.[3] Olsson and Paik (2013) even show that the reversal of fortune within the Western core had started before the era of European colonization, implying the existence of a deep reason and a mechanism for this reversal.

This article introduces a geographical advantage for agriculture in a growth model to theoretically explain some of the historical facts mentioned and depicted above. The rest of the article is organized as follows: Sect. 2 reviews the related literature. Section 3 introduces the model. Section 4 analyzes the equilibrium in the labor market. The effects of technology on fertility and labor structure are analyzed in Sect. 5, and the competitive equilibrium and dynamical system are presented in

[1] Throughout this article, we define "labor structure" as the fraction of skilled labor in the labor force, reflecting the human capital intensity of an economy.

[2] In the connection between geographical environment and technological progress, Mokyr (1990, p. 159–162) mentions the persistent effects of different geographical environment in creating technology, leading to different development paths. He introduces two contrary theories which coexist regarding the relationship between natural resources and technological progress. One of these two theories is in favor of the view point in this article and in Litina (2014) that the scarcity of natural resources encourages the search for substitutions, hence fostering technological progress. Bloch (1966) provides examples of technological innovations in Medieval Europe, which suited the geographical environment in agricultural production. For instance, "the advent and triumph of the watermill" which, lead to development in the long run.

[3] For more examples about the reversals of national fortune, see Diamond (2014).

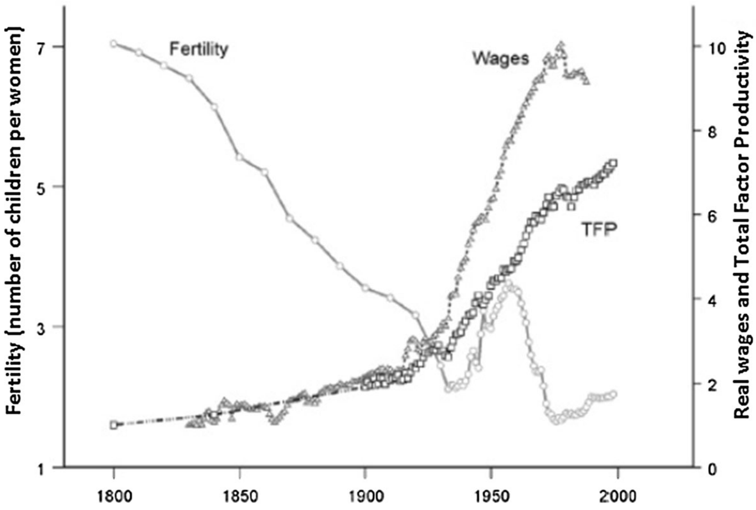

Fig. 1 Technology, fertility, and wages: USA 1800–2000. Quoted in Greenwood and Seshari (2005)

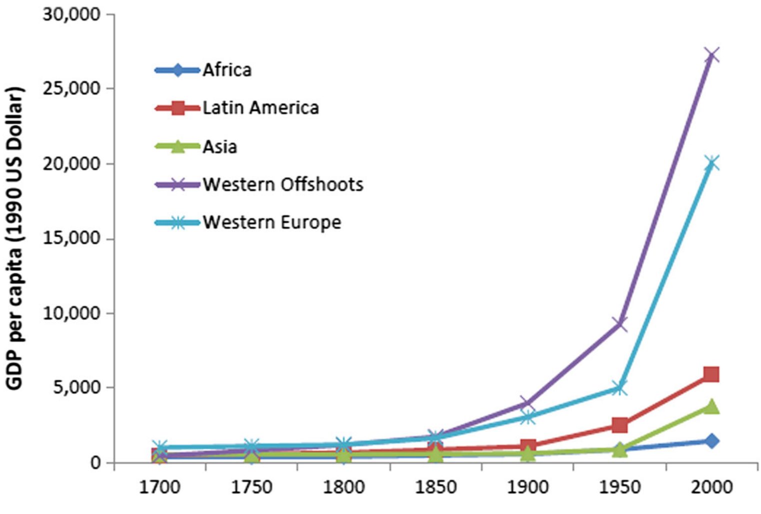

Fig. 2 The differential timings of the takeoff across regions. *Source*: Maddison (2003)

Sect. 6. Section 7 discusses the role of geography, and a tale of two countries, and illustrates the analysis with a numerical exercise. Section 8 concludes the article.

2 Literature review

There is a huge literature in the research field of this article. This section tries to review two related strands of economic growth and development literature: (1) the emergence of human capital and the demographic transition in unified growth models and (2) the causes of economic growth, great divergence, and reversal of fortune.

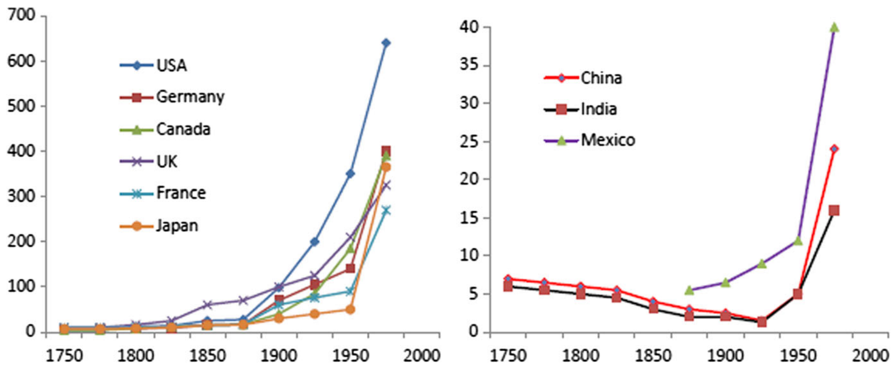

Fig. 3 Per capita levels of industrialization (That level of UK in 1900 is normalized at 100). *Source*: Bairoch (1982)

2.1 Human capital and demographic transition in unified growth models

The role of human capital formation on the demographic transition leading to the great divergence across societies has been emphasized in the unified growth theories advanced by Galor and Weil (2000), Galor and Moav (2002), and recently Cervellati and Sunde (2013). This theory is confirmed empirically by Glaeser et al. (2004), and more recently by Becker and Woessman (2009) and Becker et al. (2010, 2011). These papers generally show, theoretically and quantitatively, that the increase in technologically driven demand for human capital and its effect on educational investment play a central role in the transition from Malthusian stagnation, through the demographic transition, to modern sustained economic growth. Doepke (2004) advances a unified growth model to examine whether government policies on education and child labor can account for cross-country variations in fertility decline. He shows that accounting for child labor regulation is an important factor, while education subsidies have only minor effects. Dao (2013) proposes a mechanism linking technology, gender inequality, and fertility in a unified growth model. This explains the demographic transition accompanied by accelerated growth and highlights the role of technological progress not only in freeing women from housework, but also in improving the equality in human capital between males and females. Hence, this contributes significantly to the demographic transition during the development process.

Hansen and Prescott (2002) advance a two-sector and one-good overlapping generations model. This is close to the model in this article and explains the transition from Malthusian technology to Solow technology along with the change in labor structure (the fraction of labor in the Solow sector) and the demographic transition. The model in this article, however, differs from that of Hansen and Prescott (2002) in some fundamental aspects: (1) our model considers a fertility choice in the utility maximization of the individual, while in Hansen and Prescott (2002), fertility is a consequence of consumption by young households; (2) unlike our model, Hansen and Prescott (2002) do not take into account the heterogeneity of children; and (3) in Hansen and Prescott (2002), technological progress in both sectors is exogenous, while our model endogenizes technological progress, particularly from the onset of industrialization.

2.2 The causes of economic growth, great divergence, and reversal of fortune

The factors that triggered economic growth, the reasons why some countries are so rich and some others so poor, or why some were richer in the past and have been overtaken by others are controversial topics in the literature of economic growth. There is a conventional wisdom that explanations for the difference in income per capita based on the differences across countries in technology, physical capital, as well as human capital are incomplete. If, however, technology, and physical and human capital are so important in understanding the differences between the wealth of nations, then a fundamental question should be asked: "why do some countries not improve their technology, accumulate physical capital, and invest in human capital as much as others?" Indeed, these factors are consequences and mechanisms of growth, but not growth; there must be other and deeper fundamental causes of economic growth. So what could these fundamental causes be? Innumerable suggestions have been proposed in the literature by economists, historians, and social scientists. There are at least three main hypotheses that have been at the center of the debate to explain the remarkable transformation of world income distribution over last two centuries. The first is culture hypothesis, which was originally pioneered by Weber (1905, 1922) and promoted later by Hall (1986), Lal (1998), and Landes (1998, 2006), among others. The second is institution hypothesis, which was first proposed by North and Thomas (1973), and then advanced by North (1981), Landes (1998), and recently by Acemoglu et al. (2002, 2005), and Acemoglu and Robinson (2012). The last is geography hypothesis, which is considered intensively in this article to better understand the role of geography on comparative development across societies.

The effects of geography on economic growth and divergence between societies have been highlighted by Jones (1981), Diamond (1997), Gallup et al. (1999), and Ashraf and Galor (2012), among others. The geography hypothesis, first and foremost, is based on the fact that not all regions of the world are equally suited for living and production. "Nature," i.e., the ecological and geographical environment of nations, may play a major role in their economic experiences. There are at least three main branches of geography hypotheses, each emphasizing a different mechanism for how geography affects prosperity. The first one, and also the earliest one, was proposed by Montesquieu ([1748], 1989) in which he believed that climate, in particular heat, shaped human attitudes and effort, and through this channel it affects both economic and social outcomes. The second one, which was developed by Gunnar Myrdal, emphasizes the impact of geography on the technologies available to a society, especially in agriculture. Myrdal (1968, p. 2121) wrote: "Serious study of the problems of underdevelopment should take into account the climate and its impacts on soil, vegetation, animals, humans and physical assets—in short, on living conditions in economic development." The third variant of the geography hypothesis, which is proposed by Jeffrey Sachs, links poverty in many areas of the world to their disease burden: "the burden of infectious disease is higher in the tropics than in the temperate zones" (Sachs 2001). In the article at hand, the geographical factor is likely to be closer to the second version of geography hypothesis.

In the widely popular book "Guns, Germs, and Steel," Diamond (1997) provides a historical account along with research results from other sciences such as biology, geography, archeology, and epidemiology, to explain why the world becomes so unequal across communities. It also explains why some regions, peoples, and cultures developed more quickly than others. Diamond pushes the series of causes and consequences back 13,000 years to reach the conclusion that the origin of the great divergence is initial differences in geographical and biological conditions. In common with the second view of the geography hypothesis, he argues that geographical differences between the Americas and Eurasia determined the timing and nature of settled agriculture and, by means of this channel, shaped whether societies were able to develop complex organizations and advanced civilian and military technologies.[4] Following Diamond (1997), many researches have confirmed the hypothesis of the positive effect of geographical advantage for agriculture in prehistory on current income levels across the globe. An incomplete list for this literature is Hibbs and Olsson (2004), Olsson and Hibbs (2005), Putterman (2008), Putterman and Weil (2010), Bleaney and Dimico (2011). However, as pointed out in Olsson and Paik (2013), this hypothesis is valid when we compare the comparative development *between* agricultural core regions, but it is invalid *within* regions such as the Western core, Saharan Africa, and East Asia where the reversals of fortune between societies have been witnessed. Diamond (1997) does not explain such reversals.

Other approaches to explain the asymmetric economic evolution across the globe cite the roles of ethnic, linguistic, religious fractionalization, and human genetic diversity. The effects of ethnolinguistic fractionalization on comparative development across societies are examined empirically by Easterly and Levine (1997) and Alesina et al. (2003). These papers have demonstrated that geopolitical factors, which brought a high degree of ethnic fractionalization in some regions of the world, led to the implementation of poor institutions and, hence, to a divergence in the development process across societies. Ashraf and Galor (2012) advance and empirically establish an "Out-of-Africa" hypothesis that, in the prehistoric emergence of *Homo-sapiens* out of Africa, the variation in migratory distance to various destinations across the globe has affected genetic diversity and has had a persistent hump-shaped effect on comparative economic development. Ashraf and Galor (2013) show that the low diversity of Native American populations and the high diversity of African populations have been detrimental for the development process of these regions, while the intermediate levels of diversity of Europeans and Asians have been conducive for their development process.[5]

3 The model

In this article, we focus on the geography hypothesis proposed by Myrdal (1968) as mentioned in the literature review section. In this respect, we consider the impact of geography on the technology available to a society, especially in agriculture. We set

[4] Whether the study of human societies can be scientifically pursued is still controversial. The work of Diamond depicts the most general picture of human history during the last 13,000 years and shows a way for other sciences to pursue theories of development.

[5] The "Out-of-Africa" hypothesis has been recently confirmed by the empirical research of Ashraf et al. (2014, 2015) with data at both country and ethnic group levels in which the authors use "night-time light intensity" as a more appropriate proxy for the standard of living rather than income per capita.

up discrete time competitive overlapping generations economies in the process of development with two sectors of production, i.e., agriculture and manufacture, and one final output. Let's assume that the factors of production in the agricultural sector are land and unskilled labor; and the only factor of production in the manufacturing sector is skilled labor, reflecting human capital intensity in this sector. We define industrialization as a process that transits from agricultural production to manufacturing production.

For the sake of simplification, we only consider closed economies, i.e., there is no international labor mobility and/or technological diffusion across countries. This assumption is plausible when the main focus of this research is on the time period from a predominant agricultural production regime until the appearance of reversals of fortune which, as pointed out in Olsson and Paik (2013) in the case of societies within the Western agricultural core, occurred even before the era of European colonization. At that time, both international labor mobility and technological diffusion across countries were very limited, particularly between countries with long migration distance.[6] The role of international trade in creating the great divergence between countries was addressed significantly in Galor and Mountford (2006, 2008). However, we extract international trade here in order to focus on the role of geographical advantage for agriculture in determining the timing of industrialization and timing of the decline in fertility as well as the overtaking in economic performance between countries.[7]

3.1 Environmental resources for agriculture

By "land," we mean the entire geographical environment and natural resources of the economy supporting agricultural production, such as quality of soil, temperature, light condition, humidity, and water resource. Due to technological constraints, an economy may not make the most of the available "land" for agricultural production, e.g., people may just occupy the part of their territory and resources that are the most suitable for agriculture. This "part of land" is called "productive land" whose size in period t, X_t, is determined by

$$X_t = \chi(A_t)X \tag{1}$$

[6] Thanks to data developed by Comin and Hobijn (2004), World Bank (2008) estimates the process of technological diffusion over the long run for several essential technologies such as shipping, railway, vehicle, telegram, telephone, spindle, steel, and electrification. The authors report that over the period 1750–1900, the average time for diffusion, following discovery until technology reached 80 % of reporting countries, is 106.9 years (World Bank 2008, Table 2.14), reflecting very low speed of technological diffusion before twentieth century.

[7] It is a fact that this article and Galor and Mountford (2006, 2008) focus on different periods of time. Galor and Mountford (2006, 2008) implicitly focus on the period of time long after the timing of industrialization in Western Europe when, as mentioned in Galor (2005), international trade enhanced the industrialization of developed countries. This article, on the contrary, focuses on the period for societies with very limited volume of trade as they transit from a predominantly agricultural production regime to being overtaken in economic performance (proxied by income per capita) through industrialization.

where $\chi(A_t) \in [0, 1)$ is the level of accessibility to the "land" depending on the level of technology in period t, A_t; $\chi'(A_t) > 0$ and $\chi''(A_t) < 0$ for all $A_t > 0$; X is the entire natural resources and geographical environment for agricultural production. Without loss of generality, we normalize $X = 1$ for simplicity. Hereafter, therefore, the natural resources and geographical environment available for agricultural production in period t are $X_t = \chi(A_t)$.

3.2 Production

In every period t, output can be produced in the agricultural sector and/or in the manufacturing sector. The agricultural sector uses unskilled labor and "land" as factors of production to produce output according to the Cobb–Douglas production technology

$$Y_t^a = \chi(A_t)^\alpha (L_t^u)^{1-\alpha}; \quad \alpha \in (0, 1) \tag{2}$$

where L_t^u is the aggregate amount of unskilled labor of the economy in period t.

Indeed, the way the use of "land" for agricultural production is modeled here differs from that in Ashraf and Galor (2012) in the way it depends on technology. In Ashraf and Galor (2012), land for agricultural production is always fixed at $X = 1$ regardless of the level of technology. However, they introduce a level of technology specific to agriculture whose dynamics can be traced to the geographical isolation of the economy. That is to say Ashraf and Galor (2012) consider the effect of a geographical factor differing from that in this article for agricultural production.

We assume that, in the context of an early stage of development, there are no property rights to "land" (i.e., geographical environment and resources), so that the return to land is zero[8] and the return to labor, or *the inverse demand for labor*, in the agricultural sector in period t is

$$w_t^u = \left(\frac{\chi(A_t)}{L_t^u}\right)^\alpha \equiv W(L_t^u, A_t) \tag{3}$$

In common with Ashraf and Galor (2012), the output of the manufacturing sector in period t is determined by linear, constant returns to scale production technology such that

$$Y_t^m = A_t L_t^s \tag{4}$$

where L_t^s is the aggregate amount of skilled labor of the economy in period t. The return to labor, or *the inverse demand for labor*, in the manufacturing sector in period t is

[8] We can justify the assumption of "no property rights to land" as: (1) "land" in our model stands for the entire geographical environment and resources then basically "land" is collectively owned with the proceeds distributed as a lump sum to the population; (2) we consider a completely aggregate economy, so the model disregards the heterogeneity across households, say laborers and "landlords"; and in addition, (3) although there are no property rights to these resources, the economy cannot engage in the over-exploitation of common resources known as the "tragedy of commons" because the accessibility to these resources is constrained by the technological level through the function $\chi(A)$.

$$w_t^s = A_t \tag{5}$$

The total labor force of the economy in period t is

$$L_t = L_t^u + L_t^s \tag{6}$$

Hereafter, we use superscripts "u" and "s" to denote unskilled and skilled labor, respectively.

3.3 Technology

The technological level in period $t + 1$ is determined by

$$A_{t+1} = (1 + g_t)A_t \tag{7}$$

where g_t is the rate of technological progress between periods t and $t + 1$. As in Galor and Mountford (2006, 2008), we also assume that g_t depends on the average skill of labor in the economy, i.e., it is determined by the fraction of skilled labor in the economy. In particular,

$$g_t = g(h_t)$$

where $h_t = L_t^s/L_t$ is the fraction of skilled labor over the total labor force (i.e., the labor structure) of the economy in period t; $g(h) > 0$, $g'(h) > 0$, $\forall h \geq 0$. This assumption reflects the obvious importance of skill intensity of the workforce in technological progress.[9]

3.4 Individuals

Basically, the individual's problem in this article follows from Galor and Mountford (2006). In every period $t \in \mathbb{N}$, a generation consists of L_t^u identical unskilled individuals working in the agricultural sector and L_t^s identical skilled individuals working in the manufacturing sector. Individuals live for two periods. In the first period, say childhood, they consume a fraction of their parent's time. In the second period, say adulthood, they work for their consumptions and raise their children. In child rearing, adult individuals in the economy choose numbers of skilled children and unskilled children, as will become apparent latter, depending on the expected structure of labor so as to, with consumption, maximize individual's utility.

As in Galor and Mountford (2006), the utility of an adult $i \in \{s, u\}$ in period t comes from consumption and the total potential income of his/her children. In particular,

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

[9] Note that, in this model it is not necessary to assume that $g(0)$ is strictly positive. We set $g(0) > 0$ in accordance with the existing literature Galor and Weil (2000) and Hansen and Prescott (2002) with a fact that technological progress still occurs in the Malthusian regime. The qualitative results do not change crucially if $g(0) = 0$.

where $n_t^{s,i}$ and $n_t^{u,i}$ are the number of children to become skilled and unskilled workers, respectively; w_{t+1}^s and w_{t+1}^u are their wages in period $t+1$, respectively; c_t^i is total consumption of agricultural and manufacturing goods by individual i. We assume that these two kinds of goods are perfectly substitutable.

The budget constraint of an adult i in period t is

$$c_t^i + w_t^i\left(\phi^s n_t^{s,i} + \phi^u n_t^{u,i}\right) \leq w_t^i \tag{9}$$

where ϕ^s, $\phi^u > 0$ are costs in time to raise one offspring to be a skilled worker and a unskilled worker, respectively. We assume that $\phi^s > \phi^u$, implying that raising a skilled child is more costly than raising an unskilled one.

An adult individual $i \in \{s, u\}$ in period t chooses the number of skilled and unskilled children and consumption under the budget constraint (9) so as to maximize his/her utility in (8). The optimal choices of an adult individual $i \in \{s, u\}$ are stated in the following lemma.

Lemma 1 *In any period t, the optimal choices of adult individual* $i \in \{s, u\}$ *are characterized by*

$$c_t^i = (1-\gamma)w_t^i \quad \text{and} \quad n_t^{s,i}\phi^s + n_t^{u,i}\phi^u = \gamma$$

where

$$\begin{aligned}
&n_t^{s,i} = 0,\ n_t^{u,i} = \frac{\gamma}{\phi^u} \quad \text{if } \frac{w_{t+1}^s}{\phi^s} < \frac{w_{t+1}^u}{\phi^u}\\
&n_t^{s,i} = \frac{\gamma}{\phi^s},\ n_t^{u,i} = 0 \quad \text{if } \frac{w_{t+1}^s}{\phi^s} > \frac{w_{t+1}^u}{\phi^u}\\
&n_t^{s,i} > 0,\ n_t^{u,i} > 0 \quad \text{only if } \frac{w_{t+1}^s}{\phi^s} = \frac{w_{t+1}^u}{\phi^u}.
\end{aligned}$$

Proof See "Proof of Lemma 1" section in "Appendix".

It is obvious from the homotheticity of preferences that the fertility and the composition of the family between skilled and unskilled children do not depend on the income of their parents. Hence, hereafter in every period t, we remove the superscript i from variables $n_t^{s,i}$ and $n_t^{u,i}$ to write as n_t^s and n_t^u, respectively. To guarantee the population never collapses, i.e., $n_t^s + n_t^u \geq 1$, we introduce the following plausible assumption

Assumption 1 $\gamma/\phi^s \geq 1$.

Assumption 1 guarantees that the growth rate of the population is always nonnegative. This assumption is consistent with the widely observed reality that population grows in most countries.

We know from (3) that the return to unskilled labor in period $t+1$ depends on the size of the unskilled population, L_{t+1}^u. It will be apparent in Sect. 4 (in Corollary 1) that the viability of the manufacturing sector in period $t+1$ depends on the size of population, L_{t+1}. When the manufacturing sector is viable in period $t+1$, the individuals will be indifferent between raising skilled and unskilled children when it holds $w^s_{t+1}/\phi^s = w^u_{t+1}/\phi^u$. That is to say, the choices of numbers of skilled children and unskilled children of individuals in period t depend on the expected structure of labor in period $t+1$. We assume that individuals in period t have a perfect foresight on the structure of labor in period $t+1$, h^e_{t+1}. Hence, from the perspective of individuals, the choices of skilled and unskilled children are determined by

$$n^s_t\phi^s + n^u_t\phi^u = \gamma \quad \text{and} \quad \frac{n^s_t}{n^s_t + n^u_t} = h^e_{t+1}$$

i.e., we have

$$n^s_t = \frac{\gamma h^e_{t+1}}{(\phi^s - \phi^u)h^e_{t+1} + \phi^u} \quad \text{and} \quad n^u_t = \frac{\gamma(1 - h^e_{t+1})}{(\phi^s - \phi^u)h^e_{t+1} + \phi^u}$$

4 Equilibrium in the labor market

In the early stages of development, when the technological level is so low that the labor productivity of the manufacturing sector is lower than that of the agricultural sector, then output is only produced by the agricultural sector. However, in later stages of development, with a higher level of technology and improved labor productivity in the manufacturing sector, then the manufacturing sector becomes economically viable.

The inverse demand for labor in the agricultural sector, as in (3), increases without bound when employment in that sector decreases. This implies that in a closed economy the agricultural sector is operative in every period. In contrast to the agricultural sector, the manufacturing sector is operative if and only if the productivity in this sector is high enough. Proposition 1 and Corollary 1 below state the condition under which the manufacturing sector is economically viable.

Proposition 1 *In any period t, there exists a unique threshold of the technological level, $\hat{A}_t = \hat{A}(L_t)$, such that the manufacturing sector is operative if and only if:*

$$A_t \geq \hat{A}(L_t) \quad \text{where}\, \hat{A}'(L_t) < 0$$

Proof See "Proof of Proposition 1" section in "Appendix."

Corollary 1 *Given $A_t > 0$, there always exists a unique threshold size of population, $\hat{L}_t$, such that the manufacturing sector is operative in period t if and only if*

$$L_t \geq \hat{L}_t = \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\chi(A_t)}{A_t^{1/\alpha}}.$$

Proof It is straightforward from the necessary and sufficient conditions for the manufacturing sector to be operative, i.e., $A_t/\phi^s \geq \left(\frac{\chi(A_t)}{L_t}\right)^{\alpha}/\phi^u$. □

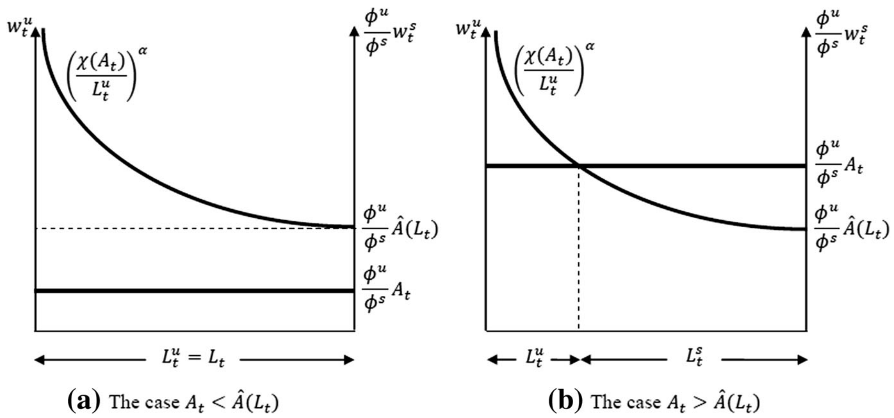

Fig. 4 The equilibrium in the labor market

Figure 4 presents the equilibrium in the labor market and shows intuitively when the manufacturing sector is viable.

The economic implication, which is depicted in Fig. 4, behind Proposition 1 and Corollary 1 is intuitive and very important. It indicates the conditions of technology and population size under which skilled labor appears in the economy. It is necessary to note that this economic implication is consistent with the viewpoint of technologically driven demand for human capital in unified growth theory literature, e.g., Galor and Weil (2000), Galor and Moav (2002), and recently Dao and Dávila (2013). However, the mechanism that triggers human capital investment here differs from the literature cited above. Indeed, human capital is eroded by an increasing rate of technological progress in Galor and Weil (2000), Galor and Moav (2002), and by an increasing technological level in Dao and Dávila (2013). Then, people invest in human capital if and only if the growth rate of technology or the level of technology is high enough. That is because people need to be invested in education in order to offset the adverse effect of technology. On the contrary, in this model we do not assume the erosion effect of technology on human capital. The mechanism that leads to investment in human capital in this model, i.e., raising skilled children, is due to the competition in the labor market between economic sectors and the asymmetric complements of technology on skilled and unskilled labors. In the next section, we will analyze and study this mechanism in more detail and examine the trade-off between quantity and quality of fertility under the effect of technological progress.

5 Impact of technology on fertility and the composition of labor

Before examining the dynamical system of the economy, it is helpful to analyze the impact of technological progress on fertility and the structure of labor. This analysis will help us to better understand the simultaneous evolution of fertility and the structure of labor along with technology.

When the manufacturing is viable, then at the equilibrium it holds

$$\frac{w_t^s}{\phi^s} = \frac{w_t^u}{\phi^u} \quad \text{i.e. } \frac{A_t}{\phi^s} = \frac{\left(\frac{\chi(A_t)}{L_t^u}\right)^\alpha}{\phi^u} \Longleftrightarrow L_t^u = \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\chi(A_t)}{A_t^{1/\alpha}} \tag{10}$$

So the fraction of skilled labor is determined by

$$h_t = 1 - \frac{L_t^u}{L_t} = \begin{cases} 0 & \text{if } A_t \leq \hat{A}(L_t) \\ 1 - \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\chi(A_t)}{A_t^{1/\alpha} L_t} & \text{if } A_t \geq \hat{A}(L_t) \end{cases} \equiv h(A_t, L_t) \tag{11}$$

Equations (10) and (11) are intuitive. Equation (10) tells us that the size of unskilled population L_t^u is decreasing in contemporary technological level A_t of the economy when A_t is sufficiently high, i.e., when $A_t > \hat{A}(L_t)$. That is because of the lifetime utility maximization behavior of the households in period $t-1$ under perfect foresight on structure of labor h_t^e. The increase in technological level makes technology more complementary to skilled labor rather than to unskilled labor. Under these circumstance, households will raise more skilled children and raise less unskilled children so as to equalize marginal utilities from skilled and unskilled offspring after controlling the costs of raising each kind of child, i.e., when it holds $w_t^s/\phi^s = w_t^u/\phi^u$. Through this mechanism, the size of skilled population L_t^s is increasing in A_t when A_t is sufficiently high. This causes the fraction of skilled labor in the labor force to increase, which is represented explicitly in Eq. (11). The cost in time of raising one skilled child is higher than that of raising one unskilled child, while (from Lemma 1) the total time for child rearing is constant. This means that, along with the change in labor structure with an increase in technological level, there is a decline in total fertility. Indeed, we can formulate these arguments analytically as follows.

We have

$$h_A(A_t, L_t) = \begin{cases} 0 & \text{if } A_t < \hat{A}(L_t) \\ \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\frac{1}{\alpha}\chi(A_t) - \chi'(A_t)A_t}{A_t^{\frac{1+\alpha}{\alpha}} L_t} > 0 & \text{if } A_t > \hat{A}(L_t) \end{cases}$$

and

$$\lim_{A_t \to +\infty} h_t = \lim_{A_t \to +\infty} \left[1 - \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\chi(A_t)}{A_t^{1/\alpha} L_t}\right] = 1$$

We know from Lemma 1, lagged one period, that

$$n_{t-1}^s \phi^s + n_{t-1}^u \phi^u = \gamma \tag{12}$$

The fertility rate of the economy in period $t-1$ is

$$n_{t-1} = n^s_{t-1} + n^u_{t-1} \tag{13}$$

With perfect foresight competitive equilibrium, we have $h^e_t = h_t$. Therefore, the fraction of skilled labor in period t can be rewritten as

$$h_t = \frac{n^s_{t-1}}{n^s_{t-1} + n^u_{t-1}} \tag{14}$$

From (11), (12), (13), and (14), we have

$$n^s_{t-1} = \frac{\gamma h(A_t, L_t)}{(\phi^s - \phi^u)h(A_t, L_t) + \phi^u} \equiv n^s(A_t, L_t) \tag{15}$$

$$n^u_{t-1} = \frac{\gamma[1 - h(A_t, L_t)]}{(\phi^s - \phi^u)h(A_t, L_t) + \phi^u} \equiv n^u(A_t, L_t) \tag{16}$$

$$n_{t-1} = \frac{\gamma}{(\phi^s - \phi^u)h(A_t, L_t) + \phi^u} \equiv n(A_t, L_t) \tag{17}$$

As in (11), when $A_t \leq \hat{A}(L_t)$ then $h(A_t, L_t) = 0$, therefore, in this case

$$n^s_{t-1} = 0 \quad \text{and} \quad n_{t-1} = n^u_{t-1} = \frac{\gamma}{\phi^u}$$

While when $A_t > \hat{A}(L_t)$, note that $h_A(A_t, L_t) > 0$, it is straightforward from (15), (16), and (17) that

$$n^s_A(A_t, L_t) > 0, \quad n^u_A(A_t, L_t) < 0, \quad n_A(A_t, L_t) < 0$$

and

$$\lim_{A_t \to +\infty} n_{t-1} = \lim_{A_t \to +\infty} n^s_{t-1} = \frac{\gamma}{\phi^s} \quad \text{and} \quad \lim_{A_t \to +\infty} n^u_{t-1} = 0.$$

Figure 5 intuitively presents the impact of technology on fertility and labor structure.

The theoretical results in this section are consistent with the sizable literature on the trade-off between quantity and quality of fertility driven by technological progress, e.g., Galor and Weil (2000), Galor and Moav (2002), Galor and Mountford (2006, 2008), and recently Dao (2013), among many others. Interestingly, it can be noted that the intermediate mechanism that leads to the quantity–quality trade-off of fertility in this article is similar to that in Galor and Mountford (2006, 2008) but, however, it is different from those in the other papers cited here. Indeed, in Galor and Weil (2000) and Galor and Moav (2002), individuals reduce fertility in order to invest in education for their offspring to offset the adverse effect of the increasing rate of technological progress on human capital. The decline of fertility in Dao (2013) is due to technological progress leading to the reduction in the relative income gap between men (husbands) and women (wives) which reduces the demand

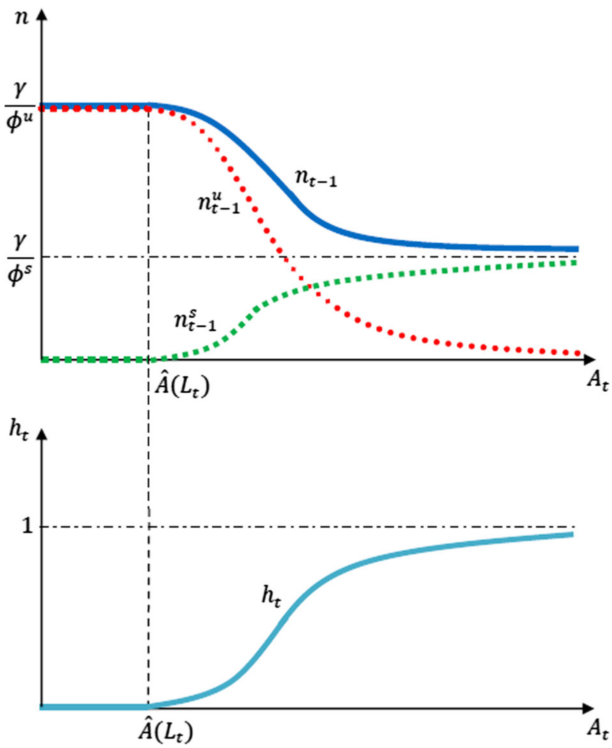

Fig. 5 Fertility and structure of labor against technology

of raising children physically because the opportunity cost of raising children increases relative to the household income. In addition, technological progress not only increases a return to labor but also improves the gender equality in education, significantly improving the average human capital in the economy. In the article at hand, the quantity–quality trade-off of fertility is due to the increase in demand for skilled labor in the manufacturing sector as a result of technological progress.

6 Competitive equilibrium and dynamical system

The perfect foresight competitive equilibrium of the economy is characterized by (1) the household utility maximization under constraints, (2) the equilibrium in labor markets, (3) the dynamics of the technological level, and (4) the dynamics of population and the structure of labor. Therefore, the perfect foresight competitive equilibrium is a sequence of $\{c_t^i,\ n_t^s,\ n_t^u,\ w_t^s,\ w_t^u,\ A_{t+1},\ L_{t+1}, h_{t+1}\}_{t\geq 0}$ and is determined by the following system of equations

$$
\begin{aligned}
c_t^i &= (1-\gamma)w_t^i \quad i \in \{s,u\} \\
n_t^s &= \frac{\gamma h_{t+1}^e}{(\phi^s-\phi^u)h_{t+1}^e+\phi^u} \\
n_t^u &= \frac{\gamma(1-h_{t+1}^e)}{(\phi^s-\phi^u)h_{t+1}^e+\phi^u} \\
w_t^s &= A_t \\
w_t^u &= \left(\frac{\chi(A_t)}{L_t(1-h_t)}\right)^{\alpha} \\
A_{t+1} &= [1+g(h_t)]A_t \\
L_{t+1} &= \frac{\gamma L_t}{(\phi^s-\phi^u)h_{t+1}+\phi^u} \\
h_{t+1}^e &= h_{t+1} \\
h_{t+1} &= \begin{cases} 0 & \text{if } A_{t+1} \le \hat{A}(L_{t+1}) \\ 1-\left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha}\frac{\chi(A_{t+1})}{A_t^{1/\alpha}L_{t+1}} & \text{if } A_{t+1} \ge \hat{A}(L_{t+1}) \end{cases}
\end{aligned}
$$

given A_0, L_0, and h_0; where $\hat{A}(L_{t+1})$ is the unique solution to $\frac{\hat{A}(L_{t+1})}{\chi(\hat{A}(L_{t+1}))^{\alpha}} = \frac{\phi^s}{\phi^u}L_{t+1}^{-\alpha}$ given L_{t+1} (see more on the "Proof of Proposition 1" in "Appendix").

The perfect foresight competitive equilibrium can be fully characterized by the following reduced system describing the equilibrium dynamics of technological level, population size, and structure of labor.

$$A_{t+1} = [1+g(h_t)]A_t \tag{18}$$

$$L_{t+1} = \frac{\gamma L_t}{(\phi^s-\phi^u)h_{t+1}+\phi^u} \tag{19}$$

$$h_{t+1} = \begin{cases} 0 & \text{if } A_{t+1} \le \hat{A}(L_{t+1}) \\ 1-\left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha}\frac{\chi(A_{t+1})}{A_{t+1}^{1/\alpha}L_{t+1}} & \text{if } A_{t+1} \ge \hat{A}(L_{t+1}) \end{cases} \tag{20}$$

given initial conditions A_0, L_0, and h_0.

This system defines $\{A_{t+1}, L_{t+1}, h_{t+1}\}$ to be a function of its lagged value $\{A_t, L_t, h_t\}$. In effect, when $A_{t+1} \le \hat{A}(L_{t+1})$ then

$$
\begin{aligned}
A_{t+1} &= [1+g(h_t)]A_t \\
L_{t+1} &= \frac{\gamma L_t}{\phi^u} \\
h_{t+1} &= 0,
\end{aligned}
$$

while when $A_{t+1} \ge \hat{A}(L_{t+1})$, we have

$$A_{t+1} = [1 + g(h_t)]A_t$$
$$L_{t+1}[(\phi^s - \phi^u)h_{t+1} + \phi^u] = \gamma L_t$$
$$L_{t+1}(1 - h_{t+1}) = \left(\frac{\phi^s}{\phi^u}\right)^{1/\alpha} \frac{\chi([1 + g(h_t)]A_t)}{([1 + g(h_t)]A_t)^{1/\alpha}},$$

implying that an equilibrium always exists.

We now study the development process of a country transiting from an agricultural regime to a dominant manufacturing regime (or so-called industrial regime) through the industrialization process. Consider an economy in its early stages of development characterized by a sufficiently low level of technology, i.e., $A_0 < \hat{A}_0 = \hat{A}(L_0)$ such that only the agricultural sector is operative. In this regime, fertility is very high and constant at a rate γ/ϕ^u, and the entire labor force is unskilled, because individuals have no economic incentive to raise skilled offspring, leading to a slow rate of growth in technology of $g(0)$.

Over time, from date t onwards, when improvements in technology have become sufficient to guarantee the viability of the manufacturing sector, i.e., $A_t \geq \hat{A}_t$, then individuals raise fewer unskilled offspring in favor of more skilled ones. This is a result of the individual's utility maximization behavior and the increase in the level of technology and in turn increases the fraction of skilled workers in the labor force. The cost in time of raising skilled offspring is higher than that of raising unskilled ones, so the increase in the technological level leads to a decrease in fertility accompanied by an increase in the fraction of skilled workers. The greater fraction of skilled workers, in turn, speeds up the technological progress. This feedback loop between technology and the fraction of skilled workers accelerates the industrialization of the economy, which is characterized by the expansion of the manufacturing sector along with the simultaneous reduction in the agricultural sector. Over time, the fertility converges to a constant low rate γ/ϕ^s, and the fraction of skilled labor converges to 1.

7 Geography and a tale of two countries

In this section, we consider the effects of geographical advantage for agricultural production on the timings of industrialization and demographic transition as well as on the comparative development across societies. For expositional purposes, without loss of any generality, we rewrite $\chi(A)$ as follows

$$\chi(A) = \hat{\chi}(\theta, A)$$

where $\theta \in \mathbb{R}$ is an index which measures the natural suitability of a geographical environment for agricultural production, and $\hat{\chi}_\theta(\theta, A) > 0$ for all θ and $A > 0$, implying that for a given level of technology A, the higher the suitability of geographical environment for agricultural production θ, the larger the size of "productive land" for agriculture.[10]

7.1 From an agricultural regime to the advent of industrialization

We define industrialization as beginning when the manufacturing sector starts to be economically viable, i.e., when it holds

$$A_t/\phi^s = \left(\frac{\hat{\chi}(\theta, A_t)}{L_t}\right)^{\alpha} / \phi^u$$

We know from the Proposition 1 that the manufacturing sector is economically viable if and only if

$$\frac{A_t}{\phi^s} \geq \left(\frac{\hat{\chi}(\theta, A_t)}{L_t}\right)^{\alpha} / \phi^u \quad \text{i.e} \; \frac{A_t}{\hat{\chi}(\theta, A_t)^{\alpha}} \geq \frac{\phi^s}{\phi^u L_t^{\alpha}}$$

Proposition 2 below demonstrates the effect of geographical advantage for agricultural production on the timing of industrialization and the timing of demographic transition.[11]

Proposition 2 *In an overlapping generations economy starting from initial conditions* A_0 and L_0 *such that* $A_0/\phi^s < \left(\frac{\hat{\chi}(\theta, A_0)}{L_0}\right)^{\alpha} / \phi^u$, *i.e., the initial level of technology* A_0 *and initial size of population* L_0 *are so low that the manufacturing sector cannot be operative, then:*

[10] This idea of modeling "land" which captures its natural suitability for living and production was recently introduced in Dao and Dávila (2013). An example of the functional form of $\hat{\chi}(\theta, A)$ which satisfies all basic assumptions on $\chi(A)$ is $\hat{\chi}(\theta, A) = \frac{\theta A}{a + \theta A}$, where $\theta, a > 0$.

[11] Note that sometimes we use the term "timing of demographic transition," which is equivalent to the "timing of decline in fertility" in this article. The demographic transition, particularly in Western Europe, consists of three main stages corresponding to three main regimes of development: (1) Malthusian stage (before 1500 BC) that is characterized by very low and stable population growth; (2) Post-Malthusian stage (from around 1500 BC to mid-1800's) that is characterized by a faster growth in population; and (3) modern growth stage (mid-1800's until present day) that is characterized by a decline in the growth rate of population. The modern growth stage can sometimes be divided into two substages, which are characterized, respectively, by a sharp decline in population growth and a convergence to a constant population. It is well known that such a very long development process is indeed characterized by the transition from a world of high fertility and high mortality (including high infant mortality) to one of low fertility and low mortality. That is to say, the prediction of high fertility rate before the timing of industrialization in this article is in accordance with historical fact. In this article, however, our main focus is the explanation for the different timings of industrialization under different geographical advantage for agriculture which leads to reversals of national fortune as well as divergence between countries. In order to keep the model as simple as possible, we ignore the infant mortality factor which is important in explaining the demographic transition. Indeed, endogenizing infant mortality, by assigning it to dependance on consumption and/or level of technology, can help explain demographic transition more precisely. It would, however, make the model more complicated, requiring heavy simulations, without substantially changing the results for our purposes. We mention the term *demographic transition* here, instead of *decline in fertility*, to refer implicitly to the potential power/extension of the model.

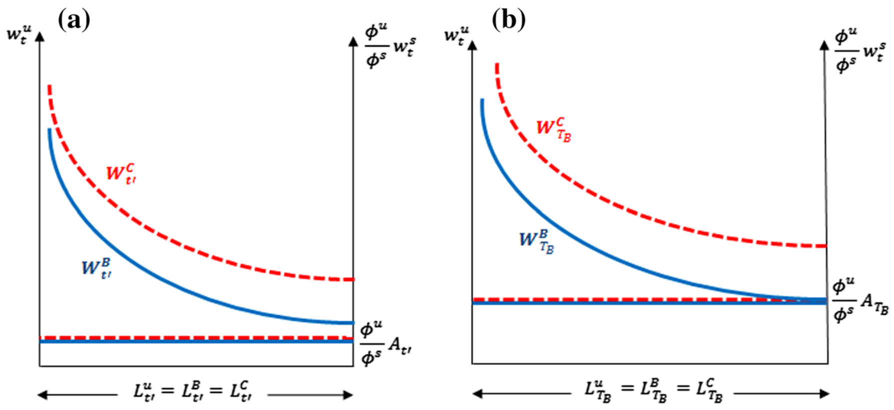

Fig. 6 **a** Before industrialization in both countries, **b** differential timings of industrialization

(i) *there exists a time* $T > 0$ *such that from T onwards the manufacturing sector is economically viable;*
(ii) *the greater geographical advantage for agriculture, the later the timing of industrialization and demographic transition.*

Proof See "Proof of Proposition 2" section in "Appendix."

Proposition 2 provides an interesting economic implication that geographical advantage for agriculture benefits an economy in the agricultural regime but it is harmful for the transition to the manufacturing regime. This is because it delays the timing of industrialization and hence delays the change in labor structure toward an increasing fraction of skilled labor. The labor structure with a lower fraction of skilled labor, in turn, accelerates less technological progress. Under the feedback loop between labor structure and technology, from Proposition 2 one can predict that an economy with more natural endowment for agricultural production may be overtaken in the development process by another with less such advantage when the level of technology is high enough. The mechanism for differential timings of industrialization and the point at which the economy of one society overtakes another, as depicted in Figs. 6 and 7, are presented analytically in the next subsection.

7.2 A tale of two countries with one overtaking the other

For expositional purposes, we consider two closed economies B and C with the same initial conditions $A_0 > 0$, $L_0 > 0$, and $h_0 = 0$ which satisfy the condition $A_0/\phi^s < \left(\frac{\hat{\chi}(\theta^i, A_0)}{L_0}\right)^\alpha / \phi^u$ for $i \in \{B, C\}$. Both countries start from a predominantly agricultural production regime, and the two countries are identical except that country C is endowed with a greater geographical advantage for agricultural production than country B, i.e., $\theta^C > \theta^B$. Before the manufacturing sector is

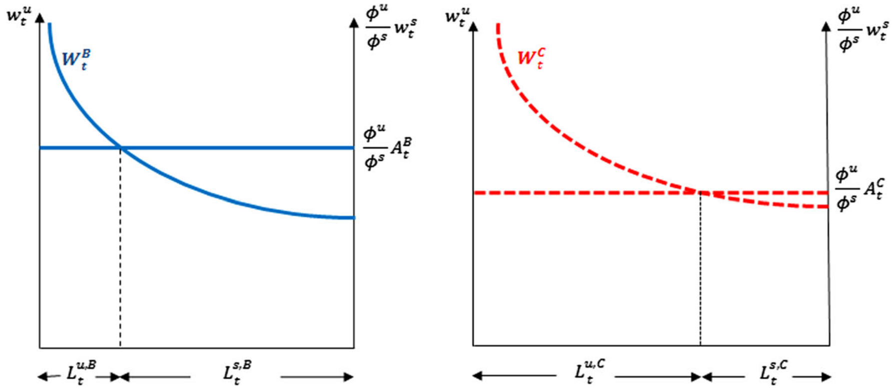

Fig. 7 Overtaking by a country with less geographical advantage for agricultural production

operative, the income per capita (which is determined by the income in the agricultural sector) in country C is always higher than in country B. This is reflected by the curve of inverse demand for agricultural labor in country C, $W_{t'}^C$, being above that of country B, $W_{t'}^B$, as in Fig. 6a. During this regime, the population grows at a constant rate γ/ϕ^u. This means that the populations of countries B and C are the same during the agricultural development process until one country begins manufacturing production. During this process, the technological growth rates in the two countries are the same at a constant $g(0)$. Since $\theta^C > \theta^B$, then, as stated in statement (ii) in the Proposition 2, the manufacturing sector is operative in country B before country C. This is because, during the agricultural development process, the return to labor in agricultural production in country B is always less than that in country C, while the returns to labor in the manufacturing sectors, if they were operative, in both countries would be the same as they have the same levels of technological development. So, although in the agricultural development process country C is more prosperous than country B, country C needs a higher level of technology (than country B) to start industrializing. In other words, country C needs more time for technological accumulation to incentivize individuals to raise skilled offspring, as depicted in Fig. 6b. As a result, the timing of industrialization in country B precedes that of country C, i.e., $T_C > T_B > 0$, where T_B and T_C are the timings of industrialization in countries B and C, respectively.

The industrialization in country B triggers a decline in fertility, along with the change in the labor structure toward an increase in the fraction of skilled labor, before country C. The increase in the proportion of skilled labor in country B speeds up its technological progress. Hence, country B begins to industrialize its economy with a reduction in the fertility rate, an increase in the fraction of skilled labor, and an accelerated technological progress, while C continues its agricultural development with a high fertility rate and slow technological progress. The difference in timings of industrialization, therefore, leads to the asymmetric evolution in technology, population, structure of labor, and returns to labors between countries B and C. This asymmetric evolution may open an opportunity for country B to overtake country C in terms of income per capita as shown in Fig. 7. The overtaking of country B over country C will be visualized through a numerical exercise in the next subsection.

Interestingly, these theoretical predictions about the differential timings of industrialization and the reversal of incomes between societies during the development process are consistent with empirical evidence, which has been advanced recently by Olsson and Paik (2013) and Litina (2014). Indeed, Olsson and Paik (2013) propose a hypothesis of the adverse effect on current economic performances of the timing of transiting to agriculture. These are reflected in contemporary heterogeneous levels of income within the Western agricultural core. We may translate the year since transition to agriculture in Olsson and Paik (2013) into the "suitability" of geographical environment for agriculture (i.e., the earlier transition to agriculture reflects the more geographical advantage for agriculture)[12] to understand the persistent impact of geography on comparative development between societies. Olsson and Paik (2013) even indicate that the reversal of fortune within the Western core began before the era of European colonization which highlights the crucial role of geographical advantage for agriculture in shaping the asymmetric development processes. In the analytical section, the authors propose a model including three basic causal links: (1) "time since transition to agriculture" will determine (2) "institutions," and institutions, in turn, will determine (3) "current economic performance." However, since the institutional factors are not always readily observable, their econometric strategy mainly focuses on the data on "time since transition to agriculture" and "current economic performance." The authors point out the highly statistically significant negative effect of time since transition to agriculture on current level of income within Western agricultural core, after properly controlling for the institutional effects of the Ottoman, Roman, and Byzantine empires, as well as of the Soviet Union and others.

In a different setup, Litina (2014) argues that a high natural suitability of land for agricultural production in the past reduced the incentives for cooperation in agricultural sector in the creation of social capital. A low level of social capital, in turn, inhibits technological progress in the industrial sector and hence generates an adverse effect on economic development. Based on this analytical framework, the author also empirically points out such a negative effect of natural suitability of land for agriculture on long-run development, contributing to explain asymmetric evolution across globe. Note again that the article at hand differs from Litina (2014) in the channel linking effect of high suitability of land for agricultural production with economic performance in the manufacturing regime, i.e., the human capital channel versus the social capital channel.

[12] Indeed, according to Diamond (1997), until the end of the last Ice Age and before the Neolithic revolution, around 11,000 BC, people from all continents were hunter-gatherers, reflecting the fact that technological levels at that time were basically the same across globe. Hence, the timing of transition to agriculture may reflect the geographical advantage for agriculture across societies.

7.3 Numerical exercise

This subsection provides a numerical illustration for the results of the model, and in this way it particularly highlights the mechanism that links the lower geographical advantage for agriculture with being overtaken in economic performance.

From the competitive equilibrium and the dynamic system, which are characterized in Sect. 6, we rewrite and obtain crucial equations for technology A_{t+1}, labor structure h_{t+1}, fertility n_t, income per capita w_t, and industrialization level per capita d_t as follows:

$$
\begin{aligned}
A_{t+1} &= [1 + g(h_t)]A_t \\
h_{t+1} &= \max\left\{0, \frac{\gamma L_t A_{t+1}^{1/\alpha} - (\phi^s/\phi^u)^{1/\alpha}\phi^u \hat{\chi}(\theta, A_{t+1})}{\gamma L_t A_{t+1}^{1/\alpha} + (\phi^s/\phi^u)^{1/\alpha}(\phi^s - \phi^u)\hat{\chi}(\theta, A_{t+1})}\right\} \\
n_t &= \frac{\gamma}{(\phi^s - \phi^u)h_{t+1} + \phi^u} \\
w_t &= h_t A_t + (1 - h_t)\left(\frac{\hat{\chi}(\theta, A_t)}{(1 - h_t)L_t}\right)^{\alpha} \\
d_t &= h_t A_t
\end{aligned}
$$

The equations above are important and we will simulate the model based upon them. So far we have been presented the model in which the functions $\hat{\chi}(\theta, A)$ and $g(h)$ are implicitly defined. In order to simulate the model, we have to assign parametric functional forms for these functions. The following simple forms seem intuitive and satisfy the basic assumptions of the model:

$$
\begin{aligned}
\hat{\chi}(\theta, A) &= \frac{\theta A}{a + \theta A}; \quad a, \theta > 0 \\
g(h) &= \varepsilon + b h^{\rho}; \quad b, \varepsilon, \rho > 0
\end{aligned}
$$

We set each period to last for around 25–30 years, corresponding to the length of one generation, which is standard in the overlapping generations model literature. The land share of agricultural output, α, is set at 0.3, which is close to that in Hansen and Prescott (2002). The time cost for raising an unskilled child $\phi^u = 0.16$. This parameter can be interpreted roughly that the physical up-bring of each child (excluding education) accounts for 16 % of parent's income. This setting is generally consistent with the estimate in Haveman and Wolfe (1995) for the case of USA in 1992.[13] The weight on fertility in the utility function γ and the time cost for raising one skilled child ϕ^s are set so that the population will be constant in the modern growth regime. Hence, we set $\phi^s = \gamma = 0.222$, and note that $\gamma = 0.222$ is

[13] Haveman and Wolfe (1995) estimate the total expenditure on children of the USA in 1992 as being nearly 15 % GDP. Note that in this estimation elementary and secondary education are included but higher education (which is crucial component for raising skilled children) is not included. Note also that, according to the data from World Bank, in 1992 the number of children per fertile woman is 2 which reflects that population growth in that year remained almost unchanged. Therefore, 15 % US GDP devoted to the total expenditure on children can be translated into 15 % parent's income per child.

very close to that in Lagerlöf (2006). We set ε, b, and ρ such that the growth rate of technology per annum during the Malthusian regime is very low (almost zero) and that during the modern growth regime fits the growth rate of income per capita, which is estimated around 2.4 % per annum in Hansen and Prescott (2002). Hence, we choose $\varepsilon = 0.015$, $b = 0.7$, and $\rho = 2.5$. The parameter representing natural suitability of "land," which varies across countries, and even the functional form of "productive land" do not exist in the literature for simulation. We will simulate the evolutions from the Malthusian regime (characterized by predominant agricultural production) to the modern growth regime (characterized by predominant manufacturing production) of two identical countries B and C, except that country C is endowed more geographical advantage for agriculture than country B, i.e., $\theta^C > \theta^B$. The parameters and initial conditions of the model are summarized below.

Parameters	$\alpha = 0.3$	$\gamma = 0.222$	$\phi^u = 0.16$	$\phi^s = 0.222$	$\varepsilon = 0.015$
	$a = 100$	$b = 0.7$	$\rho = 2.5$	$\theta^B = 8$	$\theta^C = 50$
Initial conditions	$A_0 = 0.5$	$L_0 = 0.5$	$h_0 = 0$		

We simulate two economies B and C simultaneously beginning with period 0 for 12 periods. Figures 8 and 9 show the evolutions of the fertility and labor structure between countries B and C. From these figures, we can see the different timings of decline in fertility and timings of industrialization between the two countries due to the difference in their geographical advantage for agriculture. These simulation results illustrate the theoretical predictions of the model that geographical advantage for agriculture delays the timing of industrialization and the timing of demographic transition.

Figures 10 and 11 confirm the most interesting result of the model, i.e., an overtaking of country B over country C in fortune and economic performance while country C has more geographical advantage for agriculture. The mechanism for the overtaking is that the greater geographical advantage for agriculture of country C delays the timing of its industrialization compared to country B, i.e., it delays changing its labor structure toward an increasing fraction of skilled labor compared to that of country B, as depicted in Fig. 9. The higher fraction of skilled labor accelerates technological progress in country B, causing the economic performance of country B to overtake that of country C resulting in the divergence in fortune between these countries.

8 Conclusion

This article develops a simple growth model to show that geographical advantage for agriculture helps an economy to be more prosperous in the agricultural regime, but delays the timing of industrialization and the timing of demographic transition. It also delays the change in labor structure toward an increasing fraction of skilled

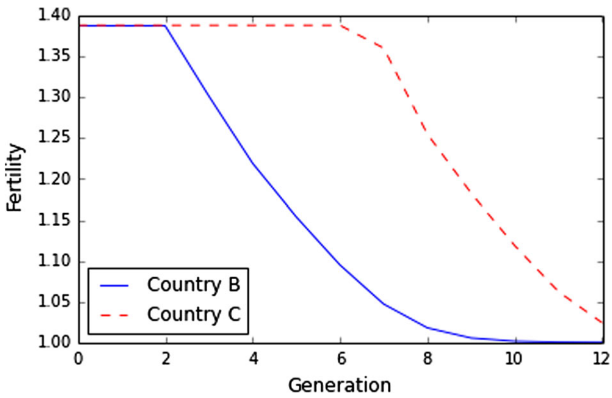

Fig. 8 Different timings of demographic transition

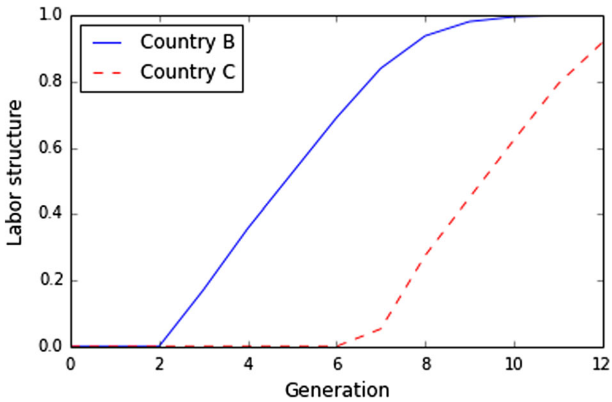

Fig. 9 Evolutions of labor structures reflect different timings of industrialization

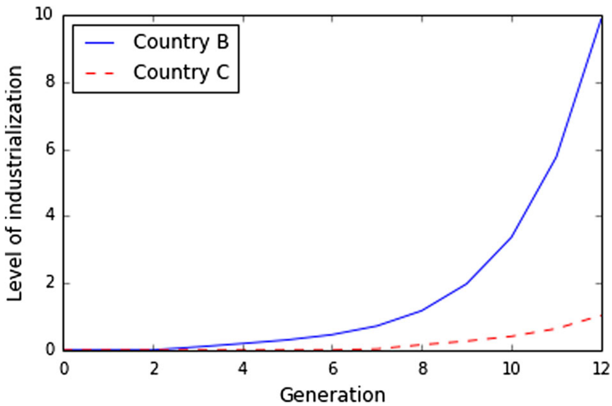

Fig. 10 Asymmetric evolutions in levels of industrialization

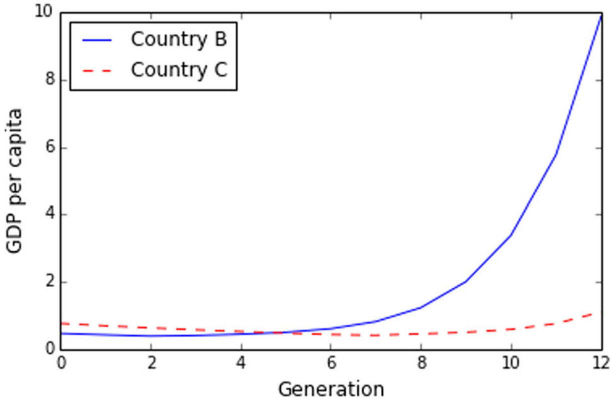

Fig. 11 Overtaking and divergence

labor, hence inhibiting technological progress. In this way, it contributes, to the literature, an explanation for reversals of national fortune, which are well documented in economic history, for example the reversals between countries within the Western agricultural core, between China and Europe, between societies within sub-Sahara Africa, etc. This article points to geography as a fundamental cause of growth and divergence across societies. This theoretical prediction is in accordance with empirical evidence advanced recently by Olsson and Paik (2013) and Litina (2014). Within its analytical framework, the article also explains the development from agriculture to manufacturing along with the demographic transition and an increasing fraction of skilled workers in the labor force which is consistent with the phase of industrial revolution and beyond in Western Europe and Western offshoots.

One could embrace the apparent contradiction with the African experience and make the point that, given the theory described, the African growth tragedy becomes an even bigger puzzle. Although this argument is interesting and thoughtful, this article does not intend to explain the case of Africa. More precisely, this article proposes a mechanism by which geographical advantage for agriculture may play a crucial role in long-run comparative development. Moreover, in order to focus on the role of this geographical factor, the article ignores other (endogenous and/or exogenous) factors, which may considerably affect the development process. That is to say, the case of Africa above is not necessarily a counterfactual example against the theory of this article. In addition, note that cases such as Africa and other continents in comparative development are excellently explained by Diamond (1997) in “Guns, Germs, and Steel: The Fates of Human Societies.” Diamond (1997) explains the divergence across societies at continental scale, i.e., the divergence *between* Europe and other continents. This article, however, in line with Olsson and Paik (2013), explains the asymmetric development of societies *within* a continent or the asymmetric development between specific societies. That is also to say, the theory in this article does not necessarily contradict Diamond (1997).

This article builds on Galor and Mountford (2006) and Ashraf and Galor (2012) introducing geographical advantage for agriculture in a single setup. This single setup, however, has some implications, which are absent in both Galor and Mountford (2006) and Ashraf and Galor (2012), for empirical investigations. They are: (1) a high total factor productivity in agriculture delays demographic transition and industrialization; (2) fertility, the structure of labor, and growth are all shaped by a geographical advantage for agriculture.

In order to make stand out the importance of the interplay between technology and labor structure, this article abstracts from a direction of physical capital, i.e., physical capital as an input of production and/or its effect on technological progress. By taking into account this direction, a country with geographical advantage for agriculture has an advantage for physical capital accumulation from the agricultural regime which, in turn, stimulates technological progress and may maintain the country's position in the development process. Hence, a unified theory in determining a *possible threshold* of geographical advantage that is helpful in long-run comparative development would be very interesting. This article is also based on the assumption that the economies are closed, which is plausible for the focus of the research, to explain reversals of fortune between countries. Relaxing this assumption by considering labor mobility, technological diffusion, and/or international trade across countries promises challenging and interesting alternative scenarios in comparative economic development. Indeed, on the one hand, international labor mobility leads to the equalization of the returns to labors that reduces the gap in income across countries. On the other hand, technological diffusion may reinforce the benefit of geographical advantage for agriculture, preventing an advantaged country from being overtaken by others with lower advantage. As pointed out in Galor and Mountford (2006, 2008), international trade enhanced the industrialization of developed countries, generating a great divergence through the specializations in production between industrial (advanced) and agricultural (less advanced) countries. However, an alternative scenario may prevail if we take into account the fact that countries may observe the development paths of others enabling them to adopt advanced technology through technological diffusion and international trade. By this way, the less developed countries with favorable natural land productivity may rapidly catch up the developed countries with less natural land productivity in the development process. "What are the exact mechanisms for possible scenarios above?" remains an open question within this topic.

Of course, geography, particularly geographical advantage for agriculture in this article, is just a fundamental cause that explains the development process and divergence across societies. However, this article contributes an additional geographical viewpoint to the literature. Other viewpoints, also based on geography, culture, institutions, ethnic, linguistic, religious fractionalization, etc. explaining the asymmetric development across globe, as well as open research issues mentioned above, are left for future theoretical and empirical research.

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Appendix

Proof of Lemma 1

The utility maximization of individual $i \in (s, u)$ in period t is

$$\max_{c_t^i > 0;\, n_t^{s,i}, n_t^{u,i} \geq 0} \gamma \ln\left(w_{t+1}^s n_t^{s,i} + w_{t+1}^u n_t^{u,i}\right) + (1-\gamma)\ln c_t^i \quad \text{subject to}$$
$$c_t^i + w_t^i\left(n_t^{s,i}\phi^s + n_t^{u,i}\phi^u\right) \leq w_t^i$$

Since the maximization problem is convex, then the first-order Kuhn–Tucker conditions are necessary and sufficient for a maximum. It is fairly straightforward that we obtain the following equations from the first-order conditions with respect to c_t^i, $n_t^{s,i}$, and $n_t^{u,i}$

$$c_t^i = (1-\gamma)w_t^i \quad \text{and} \quad n_t^{s,i}\phi^s + n_t^{u,i}\phi^u = \gamma$$

Now, we will clarify under which conditions on w_{t+1}^s and w_{t+1}^u that each corresponding case occurs. We know from the two last equations that the allocation of resources between raising children and consumption is always constant. The last equation shows that the total time for raising children is also always constant. The optimization problem of individuals therefore boils down to determining the optimal choice between skilled and unskilled children so as to maximize their total income, $w_{t+1}^s n_t^{s,i} + w_{t+1}^u n_t^{u,i}$, under the constraint $n_t^{s,i}\phi^s + n_t^{u,i}\phi^u = \gamma$. From the last equation, we know that

$$0 \leq n_t^{s,i} \leq \frac{\gamma}{\phi^s} \quad \text{and} \quad 0 \leq n_t^{u,i} \leq \frac{\gamma}{\phi^u}$$

We also have

$$w_{t+1}^s n_t^{s,i} + w_{t+1}^u n_t^{u,i} = \left(w_{t+1}^s - w_{t+1}^u \frac{\phi^s}{\phi^u}\right) n_t^{s,i} + w_{t+1}^u \frac{\gamma}{\phi^u}$$

Therefore,

- If $\frac{w_{t+1}^s}{\phi^s} < \frac{w_{t+1}^u}{\phi^u}$, then $\left(w_{t+1}^s n_t^{s,i} + w_{t+1}^u n_t^{u,i}\right)_{\max} = w_{t+1}^u \frac{\gamma}{\phi^u}$ when $n_t^{s,i} = 0$ and $n_t^{u,i} = \frac{\gamma}{\phi^u}$.
- If $\frac{w_{t+1}^s}{\phi^s} > \frac{w_{t+1}^u}{\phi^u}$, then $\left(w_{t+1}^s n_t^{s,i} + w_{t+1}^u n_t^{u,i}\right)_{\max} = \left(w_{t+1}^s - w_{t+1}^u \frac{\phi^s}{\phi^u}\right)\frac{\gamma}{\phi^s}$ when $n_t^{s,i} = \frac{\gamma}{\phi^s}$ and $n_t^{u,i} = 0$.

- If $\frac{w^s_{t+1}}{\phi^s} = \frac{w^u_{t+1}}{\phi^u}$, then any composition satisfying $n^{s,i}_t \phi^s + n^{u,i}_t \phi^u = \gamma$ is an optimal solution.

In summary, we have

$$\begin{aligned} n^{s,i}_t &= 0,\ n^{u,i}_t = \frac{\gamma}{\phi^u} \quad \text{if } \frac{w^s_{t+1}}{\phi^s} < \frac{w^u_{t+1}}{\phi^u} \\ n^{s,i}_t &= \frac{\gamma}{\phi^s},\ n^{u,i}_t = 0 \quad \text{if } \frac{w^s_{t+1}}{\phi^s} > \frac{w^u_{t+1}}{\phi^u} \\ n^{s,i}_t &> 0,\ n^{u,i}_t > 0 \quad \text{only if } \frac{w^s_{t+1}}{\phi^s} = \frac{w^u_{t+1}}{\phi^u} \end{aligned}$$

□

Proof of Proposition 1

It follows from (3), (5), and Lemma 1 that:

(i) If $\frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L^u_t}\right)^\alpha / \phi^u$ then $n^s_{t-1} > 0$, and (ii) $n^s_{t-1} > 0$ only if $\frac{A_t}{\phi^s} \geq \left(\frac{\chi(A_t)}{L^u_t}\right)^\alpha / \phi^u$.

Now, we prove that

$$n^s_{t-1} \begin{cases} > 0 & \text{if } \frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha / \phi^u \qquad (a) \\ = 0 & \text{if } \frac{A_t}{\phi^s} \leq \left(\frac{\chi(A_t)}{L_t}\right)^\alpha / \phi^u \qquad (b) \end{cases}$$

(Note that in the denominators there is L_t instead of L^u_t).

The statement (a) can be rewritten as: If $\frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha / \phi^u$, then $L^u_t < L_t$ (i.e., $L^s_t > 0$ or $n^s_{t-1} > 0$). We prove (a) by a contradiction. In effect, if $L^u_t = L_t$ (i.e., $L^s_t = 0$ or $n^s_{t-1} = 0$), then

$$\frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha / \phi^u \Longleftrightarrow \frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L^u_t}\right)^\alpha / \phi^u$$

which implies [from (i) above] that $n^s_{t-1} > 0$, leading to a contradiction with $n^s_{t-1} = 0$.

The statement (b) can be rewritten as: If $\frac{A_t}{\phi^s} \leq \left(\frac{\chi(A_t)}{L_t}\right)^\alpha / \phi^u$ then $L^u_t = L_t$ (i.e., $L^s_t = 0$ or $n^s_{t-1} = 0$). We prove (b) by establishing its negation. In effect, if $L^u_t < L_t$ (i.e., $L^s_t > 0$ or $n^s_{t-1} > 0$) then, from (ii) it holds

$$\frac{A_t}{\phi^s} \geq \left(\frac{\chi(A_t)}{L^u_t}\right)^\alpha / \phi^u.$$

Moreover, since $L_t^u < L_t$ then $\left(\frac{\chi(A_t)}{L_t^u}\right)^\alpha/\phi^u > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha/\phi^u$, from which we have $\frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha/\phi^u$ which is the negation of the condition $\frac{A_t}{\phi^s} \le \left(\frac{\chi(A_t)}{L_t}\right)^\alpha/\phi^u$.

Hence, the manufacturing sector is economically viable in period t (i.e., $n_{t-1}^s > 0$) if and only if the marginal return to labor in that sector per unit of time raising skilled labor, A_t/ϕ^s, is higher than in the agricultural sector per unit of time raising unskilled labor, $\left(\frac{\chi(A_t)}{L_t}\right)^\alpha/\phi^u$, when the entire labor force is employed in the agricultural sector, i.e.,

$$\frac{A_t}{\phi^s} > \left(\frac{\chi(A_t)}{L_t}\right)^\alpha/\phi^u \Longleftrightarrow \frac{A_t}{\chi(A_t)^\alpha} > \frac{\phi^s}{\phi^u}L_t^{-\alpha}$$

Let $\psi(A_t) = \frac{A_t}{\chi(A_t)^\alpha}$, which is monotonically increasing in A_t. In effect,

$$\psi'(A_t) = \frac{\chi(A_t) - \alpha A_t \chi'(A_t)}{\chi(A_t)^{\alpha+1}} > 0$$

since $\chi(A_t) \in (0,1)$ is strictly increasing concave and $\alpha \in (0,1)$, it holds $\chi(A_t) - \alpha A_t \chi'(A_t) > 0$. Moreover,

$$\psi(0) = 0 \quad \text{and} \quad \lim_{A_t \to +\infty} \psi(A_t) = +\infty$$

Therefore, given L_t, there exists a unique $\hat{A}_t$ such that $\frac{\hat{A}_t}{\chi(\hat{A}_t)^\alpha} = \frac{\phi^s}{\phi^u}L_t^{-\alpha}$. By applying the implicit function theorem, we have

$$\hat{A}_t = \hat{A}(L_t) \quad \text{where}\, \hat{A}'(L_t) = \frac{-\alpha\phi^s}{L_t^{1+\alpha}\phi^u}\frac{\chi(\hat{A}_t)^{1+\alpha}}{\chi(\hat{A}_t) - \alpha\hat{A}_t\chi'(\hat{A}_t)} < 0$$

□

Proof of Proposition 2

(i) Let T is the timing of industrialization of the economy, then T is the solution to

$$\frac{A_T}{\hat{\chi}(\theta, A_T)^\alpha} = \frac{\phi^s}{\phi^u L_T^\alpha}$$

i.e., (note that $A_T = [1 + g(0)]^T A_0$ and $L_T = \left(\frac{\gamma}{\phi^u}\right)^T L_0$)

$$\mathcal{F}(\theta, T) = \frac{[1 + g(0)]^T A_0}{\hat{\chi}(\theta, [1 + g(0)]^T A_0)^\alpha} - \frac{\phi^s}{\phi^u \left[\left(\frac{\gamma}{\phi^u}\right)^T L_0\right]^\alpha} = 0 \tag{21}$$

Since (from the Assumption 1) $\gamma/\phi^u > 1$ and the from the concavity of $\hat{\chi}(\theta, A)$ in A, it is straightforward that $\mathcal{F}(\theta, T)$ is strictly increasing in T, i.e., $\mathcal{F}_T(\theta, T) > 0$. We also have

$$\mathcal{F}(\theta, 0) = \frac{A_0}{\hat{\chi}(\theta, A_0)^\alpha} - \frac{\phi^s}{\phi^u L_0^\alpha} < 0 \quad \text{and} \quad \lim_{T \to +\infty} \mathcal{F}(\theta, T) = +\infty$$

Therefore, there exists a unique $T > 0$ solving (21). We also have

$$\frac{A_t}{\hat{\chi}(\theta, A_t)^\alpha} = \frac{A_T \prod_{j=T}^{t}\left[1 + g(h_j)\right]}{\hat{\chi}\left(\theta, A_T \prod_{j=T}^{t}\left[1 + g(h_j)\right]\right)^\alpha} > \frac{A_T}{\hat{\chi}(\theta, A_T)^\alpha} \quad \forall t > T \tag{22}$$

because $g(h_j) > 0$ and $\hat{\chi}(\theta, A_t)$ is strictly increasing concave in A_t, while

$$\frac{\phi^s}{\phi^u L_t^\alpha} = \frac{\phi^s}{\phi^u \left[L_T \prod_{j=T}^{t}(n_j^u + n_j^s)\right]^\alpha} \leq \frac{\phi^s}{\phi^u L_T^\alpha} \quad \forall t > T \tag{23}$$

since $n_j^u + n_j^s \geq \gamma/\phi^s \geq 1$ (by the Assumption 1). Hence, from (22) and (23) we have

$$\frac{A_t}{\hat{\chi}(\theta, A_t)^\alpha} > \frac{\phi^s}{\phi^u L_t^\alpha} \quad \forall t > T$$

That is to say, from period T onwards the manufacturing sector is economically viable.

(ii) It is straightforward from (21) that $\mathcal{F}_\theta(\theta, T) < 0$, while $\mathcal{F}_T(\theta, T) < 0$ as stated above. Hence, by applying the implicit function theorem for (21) with respect to θ and T, we have

$$\frac{\partial T}{\partial \theta} = -\frac{\mathcal{F}_\theta(\theta, \mathcal{T})}{\mathcal{F}_\mathcal{T}(\theta, \mathcal{T})} > 0$$

i.e., the more geographical advantage for agriculture, the later the timing of industrialization and hence the later the timing of demographic transition. □

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