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Does Low Education Delay Structural Transformation?

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Why do some countries industrialize later than others? Recent literature suggests that the prime reason is low agricultural productivity. This paper argues that the initial level of human capital could also be a contributing factor. We construct a neoclassical growth model, which predicts that countries with a greater initial knowledge gap industrialize later. We use this model as a baseline and calibrate it to historical data for the United Kingdom. We find that our baseline model performs well in replicating actual historical U.K. gross domestic product series during the postindustrialization era. The same model also explains a significant fraction of past and recent cross-country variations in per capita income levels.

JEL Classification: O1, E1

1. Introduction

What determines the pace of industrialization is a highly debatable topic in the macrodevelopment literature. Hansen and Prescott (2002) and, subsequently, Gollin, Parente, and Rogerson (2002, 2007a, b) highlight the role of agricultural productivity in the process of industrialization. The former develop a model in which the transition from agriculture to industry is brought about by faster technological progress in the industrial sector (which ultimately makes this sector more cost effective) and is slowed by higher productivity in the agricultural sector. On the other hand, the key point made by Gollin, Parente, and Rogerson is that most of the late industrializing countries began the process of industrialization late because of low agricultural productivity. Their models show that once a society produces the basic nutritional requirement of food, labor starts moving from agriculture to industry. From that point onward, agriculture loses its importance asymptotically, and a Solow technology prevails in the long-run. While these papers provide useful insights about the process of industrialization, they remain largely silent about the role of human capital, knowledge, and skills as factors determining the pace of industrialization.

We construct a neoclassical growth model that builds on Gollin, Parente, and Rogerson (2002) and places particular emphasis on the role of human capital in determining the pace of

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industrialization. Specifically, the return to the investment in education drives the initial human capital and the productivity of raw labor of a preindustrial society. The model aims to explain why the process of industrialization is delayed in economies with low initial human capital and low agricultural productivity.

In a nutshell, our model is characterized both by a food subsistence constraint and a human capital constraint on the pace of industrialization of the economy: To industrialize and make a transition to long-run growth, a society needs to provide the minimum subsistence level of food to its people, and to invest enough in education to cross a threshold level of skill. Because a fixed amount of time is assumed to be allocated to the production of goods and the accumulation of human capital, a society embarking on the path of industrialization has to face a painful tradeoff between the food subsistence requirement and the minimum human capital requirement. We starkly portray this tradeoff in terms of a belt-tightening strategy of industrialization, whereby agents consume just the bare subsistence amount of food and invest the surplus in education until their offspring will have accumulated the threshold human capital necessary to achieve long-run growth. Industrialization is therefore the result of a generational belt-tightening strategy. This is an endeavor the society finds optimal. A lower initial human capital and a lower agricultural productivity will both lead to a longer belt-tightening period, which, in turn, will lead to a slower pace of industrialization. Thus, agricultural productivity and initial human capital are both important determinants of the pace of structural transformation of an economy.[1]

We next set up a baseline model calibrated to historical data for the United Kingdom to trace out the path of gross domestic product (GDP) during the pre- and postindustrialization phase (1830–2001). Our interest in this paper is in the Second Industrial Revolution, which started roughly in the late nineteenth century, following the discovery of electricity, and which also initiated the era of modernization in both the United Kingdom and the United States (Devine 1983; Atkeson and Kehoe 2007). Our calibration exercise suggests that, for empirically plausible parameter values, a belt-tightening strategy of industrialization is optimal. Our calibrated model performs well in replicating actual historical U.K. real GDP per capita series during the era following the Second Industrial Revolution. The model also has useful insights about the cross-country correlations between agricultural productivity, education, and the degree of industrialization observed in the data. Finally, the same model explains reasonably well past and recent cross-country variations in per capita income levels.

Although we do not explicitly model fertility, our model has some indirect connections with the neo-Malthusian growth literature dealing with human capital and fertility. A recent wave of this literature (Becker, Murphy, and Tamura 1990; Galor and Weil 2000) shows that, in response to technological progress and higher returns to child quality, the process of industrialization is accompanied by a substitution of quality for quantity of children.[2] Our model introduces two investment-specific technology parameters (one for the pre- and the other

[1] According to our model, countries with higher initial human capital industrialize earlier. Thus, initial between-country educational inequality matters, but eventually, in the long-run, all countries attain a balanced growth rate and inequality disappears. A similar outcome is obtained by Galor and Moav (2004), who construct a model in which inequality permits the advancement of the process of industrialization in early stages of development, and only in later stages of development does equality dominate.

[2] Going one step further, Doepke (2004) assesses whether education subsidies and child labor restrictions impact the fertility decline that accompanies the transition to growth. See Galor (2005) for a full account of the literature analyzing the factors that trigger the transition from an agricultural to an industrial economy.

for the postindustrialization phase), which characterize the returns to human capital and may be seen as proxies for the returns to child quality. Nations with higher returns to human capital carry out the process of transformation from a preindustrial to an industrial state faster.[3]

The rest of the paper is laid out as follows: In the following section, we present some stylized facts aimed at providing empirical support for our hypothesis that both agricultural productivity and initial schooling are important determinants of the pace of industrialization of countries. In section 3, we lay out our theoretical model. Section 4 calibrates the model to the structural transformation of the United Kingdom over the period 1830–2001. Section 5 illustrates the model's predictions about the role of differences in initial human capital in explaining past and recent variations in cross-country levels of per capita income. Section 6 concludes.

2. Some Stylized Facts

In this section we report some stylized facts about the time path of cross-country human capital and some cross-country correlations between global human capital, agricultural productivity, and the rate of industrialization. This exercise is motivated by our hypothesis that a combination of agricultural productivity and initial level of human capital may determine the pace of industrialization of countries.

We measure the degree of industrialization of a country using its share of agriculture in GDP (i.e., its ratio of value added coming from agriculture to GDP): More industrialized countries (or countries that have industrialized earlier) will display lower shares of agriculture. Agricultural productivity is measured by the agriculture value added per worker. Both agricultural productivity and share of agriculture to GDP data are taken from the World Bank Development Indicators (2002). Human capital for a given country is proxied by average total schooling years (including primary, secondary, and higher education) of the population aged 15 and over in that country.[4] These data are taken from the Barro and Lee (2000) data set, which covers the period 1960–1999.

We average our data over nonoverlapping five-year periods, so that, data permitting, there are eight observations per country (1960–1964, 1965–1969, 1970–1974, 1975–1979, 1980–1984, 1985–1989, 1990–1994, 1995–1999). We take five-year averages of all our variables because the schooling years variable is available only at such intervals. Our data set is, therefore, a panel made up of 90 countries over eight time periods. A full list of the 90 countries can be found in Appendix 1.

An important clarification is in order here. Given that industrialization is a prolonged process dating back to the eighteenth century, one needs to be cautious in interpreting the available data, which start from 1960. We do not claim that all the countries in our sample started industrializing in or after the common reference year of 1960. Nor do we claim that the forces that drive the change in the share of agriculture or schooling are identical for all countries in the sample. In the same spirit as Lucas (2003), we perform our statistical exercise

[3] Our model differs fundamentally from Hansen and Prescott's (2002). In Hansen and Prescott, total factor productivity in the Solow sector (industry) is the prime mover; whereas, in our model, the investment-specific technology in the preindustrial sector is the kingpin of transformation, as it impacts both the initial human capital and agricultural productivity.

[4] In section 4, we posit a human capital-schooling years technology, which establishes a connection between schooling years and human capital.

Table 1. Time Paths of Human Capital and the Share of Agriculture in GDP

Year	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Average human capital	3.70	3.81	4.17	4.40	4.88	5.21	5.64	6.05
Average share of agriculture	0.32	0.27	0.25	0.23	0.20	0.19	0.18	0.17

Average human capital is measured in terms of average total years of schooling (including primary, secondary, and higher education) and is taken from the Barro and Lee (2000) data set. The average share of agriculture represents the share of the value added coming from agriculture and is taken from the World Bank Development Indicators (2002).

with a 40-year span of data assuming that the initial year in the sample (1960) is just a part of the period of transition from preindustrial to industrial growth, which started a long time ago.

Table 1 reports the cross-country average human capital and the cross-country average share of agriculture for our eight time periods. These numbers provide a broad measure of the level of global human capital and the degree of global industrialization (based on our sample). The table suggests that, over our 40-year time span, both the global knowledge and the global rate of industrialization have risen.[5]

Table 2 reports cross-country correlations between the time average of the share of agriculture, the time average of agricultural productivity, and the initial (start of period) human capital level. It appears that countries with lower initial human capital and lower average agricultural productivity exhibit higher shares of agriculture to GDP and are therefore less industrialized. This lower level of industrialization suggests that these countries have started the industrialization process late.

Although not necessarily indicators of any cause-effect relationship, these stylized facts are consistent with our hypothesis that both agricultural productivity and initial human capital can determine the pace of industrialization of countries. In the following section, we develop a model that broadly accords with these stylized facts.

3. The Model

The Basic Framework

Preferences

There are two types of goods in the economy: agricultural goods (denoted with the subscript a), which can be intended as food, and manufacturing goods (denoted with the subscript m). Following Gollin, Parente, and Rogerson (2007b), the instantaneous utility function for agents is given by

$$\begin{aligned} U(c_a, c_m) &= c_a && \text{when } \omega \leq c_a < \bar{a} \\ &= \bar{a} + \frac{c_m^{1-\gamma} - 1}{1-\gamma} && \text{when } c_a \geq \bar{a}, \end{aligned} \tag{1}$$

[5] The latter fact is reflected by the decline in the world average share of agriculture.

Table 2. Cross-Country Correlations between Initial Human Capital, Agricultural Productivity, and the Share of Agriculture in GDP

	Average Share of Agriculture in GDP	Average Agricultural Productivity	Initial Human Capital
Average share of agriculture in GDP	1.00		
Average agricultural productivity	−0.583	1.00	
Initial human capital	−0.661	0.699	1.00

Human capital is measured in terms of average total years of schooling (including primary, secondary, and higher education) and is taken from the Barro and Lee (2000) data set. The share of agriculture in GDP represents the share of the value added coming from agriculture to GDP and is taken from the World Bank Development Indicators (2002). Agricultural productivity is given by the agriculture value added per worker and is also taken from the World Bank Development Indicators (2002).

where c_a and c_m denote consumption of agricultural and manufacturing goods, respectively, and $\gamma \geq 0$. Here ω represents the minimum subsistence level of consumption below which agents fail to survive, and $\bar{a}$ is a saturation level of agricultural consumption; once that level is reached, agents start caring about manufacturing goods.

Agents maximize the following lifetime utility function

$$\sum_{t=0}^{\infty} \beta^t U(c_{at}, c_{mt}), \tag{2}$$

where β is the subjective discount factor.

Production

The production structure builds on Basu and Guariglia (2007).[6] There are two distinct stages of development: a preindustrial stage (stage 1, indexed with 1) and an industrial stage (stage 2, indexed with 2). There is a single reproducible input called human capital (or effective labor), which is used for the production of the two types of goods (food and manufacturing goods). Investment takes the form of human capital accumulation. There is a representative agent who has one unit of time, which she allocates between the production of goods and human capital formation (i.e., education). This kind of time allocation gives rise to endogenous growth in a similar spirit as in Lucas (1988).

During the preindustrial stage, the economy has poor infrastructures. There are institutional barriers to the diffusion of knowledge, such as a poor public school system or a lack of Internet access.[7] These impediments are reflected in diminishing returns to education or knowledge. During the industrial stage, because of the absence of these barriers, the return to education is no longer diminishing. We assume that the modern investment technology is subject to constant returns. In addition, we assume that there is a nonconvexity in the industrial technology: To access it, one requires a minimum amount of human capital, h_{min}.

[6] While Basu and Guariglia (2007) examine the effect of foreign direct investment on inequality, the scope of the present paper is to understand different stages of industrialization in terms of human capital endowments.

[7] Sanderson (1995) and Carpentier (2003) describe the inadequacy of public schooling in the United Kingdom during the mid-nineteenth century. Carpentier documents that only 0.01% of GDP was spent on education in 1833.

Let us denote with h_t human capital at time t; with N_{at} and N_{mt} the time spent at time t on the production of food and manufacturing goods, respectively; with δ the rate of depreciation; and with z and A the investment-specific technology (IST) parameters characterizing the returns to human capital during the preindustrial and industrial stages, respectively.[8]

The preindustrial and industrial technologies are, therefore, the following: First, *preindustrial technology* (operating when $h_t < h_{min}$):

$$c_{at}^{(1)} = N_{at}^{(1)} h_t^{(1)}, \tag{3}$$

$$h_{t+1}^{(1)} = (1-\delta)h_t^{(1)} + z\left(1 - N_{at}^{(1)}\right)^{\alpha} h_t^{(1)\alpha}, \quad \text{where } 0 < \alpha < 1. \tag{4}$$

In stage 1, because the initial human capital stock is lower than h_{min}, the country produces food only with the technology given by Equation 3. At time t the agent allocates $N_{at}^{(1)}$ units of her time to the production of food, and $(1 - N_{at}^{(1)})$ units to education, which is augmented through the IST parameter z.[9]

Second, *industrial technology* (operating when $h_t \geq h_{min}$):

$$\bar{a} = N_{at}^{(2)} h_t^{(2)}, \tag{5}$$

$$c_{mt}^{(2)} = N_{mt}^{(2)} h_t^{(2)}, \tag{6}$$

$$h_{t+1}^{(2)} = (1-\delta)h_t^{(2)} + A\left(1 - N_{at}^{(2)} - N_{mt}^{(2)}\right) h_t^{(2)}. \tag{7}$$

In stage 2 the country produces both food and manufacturing goods because it can operate the technologies illustrated in Equations 5 and 6. During this industrialized phase, the agent derives utility from both food and manufacturing goods. Because of the utility function (1), the agent just produces and consumes $\bar{a}$ units of food and invests resources just sufficient to sustain this saturation level of food. Specifically, at time t, $N_{at}^{(2)}$ units of the agent's time are allocated to the production of food; $N_{mt}^{(2)}$ units, to the production of manufacturing goods; and $(1 - N_{at}^{(2)} - N_{mt}^{(2)})$ units, to education, which is augmented through the IST parameter A.

Initial Stock of Human Capital

A preindustrial economy starts off with a low level of human capital, $h_0^{(1)}$, which is insufficient to access the modern technology. In other words, we assume that $h_0^{(1)} < h_{min}$.

Resource Constraints

For stage 1, combining Equations 3 and 4 yields the following human capital accumulation equation:

$$h_{t+1}^{(1)} = (1-\delta)h_t^{(1)} + z\left(h_t^{(1)} - c_{at}\right)^{\alpha}. \tag{8}$$

[8] We borrow the term IST from Cummins and Violante (2002) and Fisher (2006), who use parameters similar to our z and A in the context of physical capital accumulation. Gollin, Parente, and Rogerson (2004) also use a similar parameter in the context of physical capital formation. In our model the only reproducible capital is human capital.

[9] The parameter z basically determines the cost of human capital formation relative to food production, and, through this channel, it impacts the pace of investment-specific technological change. A variety of factors, such as returns to child quality and fiscal policies (tax policies and educational subsidies), could influence z.

Similarly, for stage 2, combining Equations 5, 6, and 7, one gets the following sequential resource constraint:

$$\bar{a} + c_{mt} + h^{*(2)}_{t+1} - (1 - \delta)h^{*(2)}_{t} = Ah^{*(2)}_{t}, \quad \text{where } h^{*(2)}_{t} = h^{(2)}_{t} \big/ A. \tag{9}$$

Growth in the Industrial Stage

We first characterize the equilibrium growth during the stage 2 phase of industrialization. In this case the country has attained the minimum human capital, h_{min}, and has access to the technologies illustrated in Equations 5 and 6. The industrial agent thus maximizes Equation 2 subject to Equation 9. Given this structure, we have the following proposition:

Proposition 1. For a sufficiently large h_{min} (i.e., $h_{min} > A\bar{a}/(A - \delta)$), the human capital of the industrial agent grows and reaches an asymptotic rate given by $[\beta(A + 1 - \delta)]^{1/\gamma}$.

Proof. The intertemporal first-order condition of the industrial agent is given by

$$\frac{c^{(2)}_{mt+1}}{c^{(2)}_{mt}} = G, \tag{10}$$

where $G = [\beta(A + 1 - \delta)]^{1/\gamma}$. Plugging Equation 9 into Equation 10, we obtain the following second-order difference equation in $h^{(2)}_{t}$:

$$h^{(2)}_{t+2} - (B + G)h^{(2)}_{t+1} + BGh^{(2)}_{t} = (G - 1)A\bar{a}, \tag{11}$$

where $B = A + 1 - \delta$. The general solution to this difference equation is given by

$$h^{(2)}_{t} = A_1 B^t + A_2 G^t + \frac{A\bar{a}}{A - \delta}, \tag{12}$$

where A_1 and A_2 are determined by the initial and terminal conditions.[10] The initial condition is characterized by h_{min}. The terminal condition is given by the transversality condition (TVC) as follows:

$$\lim_{T \to \infty} \beta^T \frac{h^{(2)}_{T+1}}{c^{(2)\,\gamma}_{mT}} = 0. \tag{13}$$

We next show that the TVC requires that A_1 in Equation 12 must equal zero. We prove this by contradiction. If not, then $h^{(2)}_{t}$ grows at a rate B because $B > \beta B$. On the other hand, $c^{(2)}_{mt}$ grows at a rate G as in Equation 10. Thus, the left-hand side of Equation 13 inside the limit operator reduces to

$$\beta^T \frac{h^{(2)}_{0} B^{T+1}}{c^{(2)^\gamma}_{m0} (\beta B)^T} = \frac{h^{(2)}_{0}}{c^{(2)^\gamma}_{m0}} B, \tag{14}$$

[10] See Appendix 2 for a derivation of Equation 12.

which does not converge to zero as T approaches infinity if $\gamma \geq 1$. Consequently, if $h_t^{(2)}$ grows at rate $(A + 1 - \delta)$, the TVC is violated.

We have thus established that the optimal solution for $h_t^{(2)}$ must be

$$h_t^{(2)} = A_2(G)^t + \frac{A\bar{a}}{A - \delta}, \tag{15}$$

where A_2 is characterized by the initial stock of human capital as follows:

$$A_2 = h_0^{(2)} - \frac{A\bar{a}}{A - \delta}. \tag{16}$$

Next, note that $h_0^{(2)} = h_{min}$, because the industrial country starts its trajectory when it achieves h_{min}. As long as $h_{min} > A\bar{a}/(A - \delta)$, human capital in the modern sector will grow and eventually reach an asymptotic rate G. QED.

In order to grow, the country must have initial human capital in excess of the amount necessary to sustain the agricultural production of $\bar{a}$. This explains why $h_0^{(2)}$ must exceed $A\bar{a}/(A - \delta)$.

Preindustrial Stage: A Belt-Tightening Strategy of Industrialization

We now analyze the time path of human capital during the preindustrial phase. What conditions will ensure that a country will industrialize starting from a preindustrial phase with low human capital $h_0^{(1)}$? In order to industrialize, the country must invest sufficiently in human capital to attain h_{min}. We will now analyze two alternative scenarios: one in which industrialization is not achieved and one in which it takes place.

No Industrialization

We first analyze a scenario in which no industrialization takes place. The following lemma characterizes this scenario:

Lemma 1. For a sufficiently large h_{min} or a sufficiently low agricultural IST parameter z, a country cannot industrialize simply by maximizing lifetime utility from food consumption.

Proof. If the preindustrial agent just maximizes lifetime utility from food consumption, that is, maximizes Equation 2 subject to Equations 3 and 4, the first-order condition is

$$M_t = \alpha\beta z^{1/\alpha} + \beta(1 - \delta)M_{t+1}, \tag{17}$$

where

$$M_t = \left[h_{t+1}^{(1)} - (1 - \delta)h_t^{(1)}\right]^{(1-\alpha)/\alpha}. \tag{18}$$

Solving Equation 17 recursively forward, one gets the following optimal time path for human capital:

$$h_{t+1}^{(1)} = (1 - \delta)h_t^{(1)} + \delta h^{*(1)}, \tag{19}$$

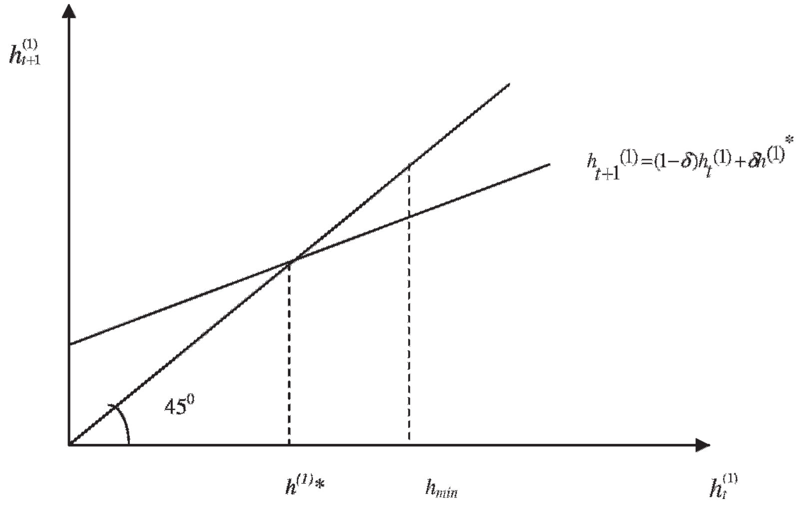

Figure 1. Dynamics of the Preindustrial Economy

where

$$h^{*(1)} = \frac{1}{\delta}\frac{(\alpha\beta)^{\alpha/(1-\alpha)}z^{1/(1-\alpha)}}{[1-\beta(1-\delta)]^{\alpha/(1-\alpha)}}. \tag{20}$$

Figure 1 draws the phase diagram illustrating the dynamics of the preindustrial economy. If z is sufficiently low or h_{min} is sufficiently high in the sense that $h_{min} > h^{*(1)}$, then the preindustrial economy will never acquire the minimum skill by just specializing in food production. *QED*.

The upshot of this lemma is that a country with a low agricultural IST parameter (z) will not be able to attain the minimum human capital h_{min} necessary to access modern technology simply by maximizing the lifetime utility from food consumption. The country may therefore need a different strategy of industrialization.

A Belt-Tightening Strategy of Industrialization

Let us now consider an alternative strategy of industrialization, which consists of agents consuming just the subsistence level, ω, for several generations and accumulating human capital until their offspring reach the h_{min} units of human capital necessary to operate the modern technology. We call such a strategy a belt-tightening strategy. Is this generational belt-tightening a feasible strategy for industrialization? We have the following lemma:

Lemma 2. Let the agent set the consumption plan $c_{at}^{(1)} = \omega$, where ω is a small quantity. For a sufficiently large value of $h_0^{(1)}$ or for a sufficiently small h_{min}, such a belt-tightening strategy is feasible.

Proof. For $c_{at}^{(1)} = \omega$, the time path of human capital in the preindustrial stage based on Equation 8 is given by the following difference equation:

$$h_{t+1}^{(1)} = (1-\delta)h_t^{(1)} + z\left(h_t^{(1)} - \omega\right)^{\alpha}. \tag{21}$$

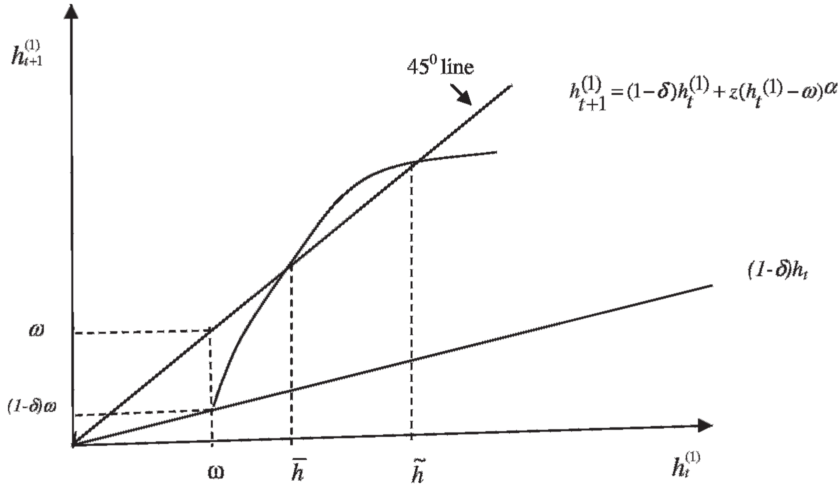

Figure 2. Phase Diagram for the Belt-Tightening Strategy

Figure 2 plots the phase diagram for Equation 21. For this belt-tightening strategy to be feasible, it is necessary that $h_0^{(1)} > \bar{h}$ and $h_{min} < \tilde{h}$. *QED*.

Is Belt-Tightening Optimal?

We hereafter assume that the feasibility conditions for industrialization set forth in Lemma 2 hold. Let us now pose the question: Given that this belt-tightening industrialization strategy is feasible, is it optimal for a country to follow such a strategy?

We answer this question in two steps. First, we determine the value function (V_{NI}) of the country if it does not industrialize. Next, we determine the corresponding value function ($V_I(T)$) if it industrializes at some arbitrary date T by following a belt-tightening strategy. Comparing V_{NI} and V_I, we determine whether a belt-tightening strategy is optimal.

We have the following lemma:

Lemma 3. The life-time utility of not industrializing (V_{NI}) is given by

$$V_{NI} = \frac{\left(h_0^{(1)} - h^{*(1)}\right)}{1 - \beta(1-\delta)} + \frac{1}{(1-\beta)}\left[h^{*(1)} - \left(\frac{\delta h^{*(1)}}{z}\right)^{1/\alpha}\right]. \tag{22}$$

Proof. Note that

$$V_{NI}\left(h_0^{(1)}\right) = \sum_{t=0}^{\infty} \beta^t c_{at}. \tag{23}$$

Plugging Equation 19 into Equation 8, we obtain the following optimal consumption policy of the preindustrial agent:

$$c_{at} = h_t^{(1)} - \left[\frac{\alpha\beta z}{1 - \beta(1-\delta)}\right]^{1/(1-\alpha)}. \tag{24}$$

Plugging Equation 24 into Equation 23 and solving the difference Equation 19, we obtain

$$V_{NI}\left(h_0^{(1)}\right) = \sum_{t=0}^{\infty} \beta^t \left[\left(h_0^{(1)} - h^{*(1)} \right)(1-\delta)^t + h^{*(1)} - \left[\frac{\alpha\beta z}{1-\beta(1-\delta)} \right]^{1/(1-\alpha)} \right],$$

which, after simplification, yields Equation 22. *QED*.

We now characterize the value function when the country adopts a belt-tightening strategy of industrialization. If the country follows such a strategy, a time T comes when the human capital h_{min} necessary for industrialization is attained. Until date T, the preindustrial agent just consumes the subsistence level ω. Beyond T, she consumes the saturation level of food $\bar{a}$ and makes a transition to the growing manufacturing sector. The value function associated with such a belt-tightening strategy, which makes the agent transform from a preindustrial to an industrial state at some arbitrary date T, is given by

$$V_I(T) = \left[\frac{1-\beta^T}{1-\beta} \right] \omega + \sum_{s=T}^{\infty} \beta^s \left[\bar{a} + \frac{c_{ms}^{1-\gamma} - 1}{1-\gamma} \right]. \tag{25}$$

From date T onwards, the manufacturing consumption grows at the rate G, as in Equation 10. We thus have the following lemma:

Lemma 4. The value function for industrialization at date T is given by

$$\begin{aligned} V_I(T) &= \frac{\omega}{1-\beta} + \frac{\beta^T}{1-\beta}\{\bar{a} - \omega\} \\ &\quad + \frac{\beta^T}{1-\beta G^{1-\gamma}} \left[\frac{\left(c_{mT}^{1-\gamma} - 1\right)}{1-\gamma} + \left(\frac{\beta}{1-\beta}\right) \frac{(G^{1-\gamma} - 1)}{1-\gamma} \right], \end{aligned} \tag{26}$$

where

$$c_{mT}^{(2)} = (A + 1 - \delta - G)\left[\left(\frac{h_{min}}{A} \right) - \left(\frac{\bar{a}}{A-\delta} \right) \right].^{11}$$

From Equation 26, it is straightforward to verify that if γ is close to unity, V_I is monotonically decreasing in T.[12] Based on Lemmas 3 and 4, and on the monotonicity of V_I, the immediate implication is that there exists a T^* for which the country residents are indifferent between industrializing and not industrializing (i.e., $V_I = V_{NI}$). Figure 3 characterizes T^* as the point where the downward sloping V_I schedule intersects V_{NI}.

We are now in a position to determine whether it is optimal for a country to follow a belt-tightening strategy of industrialization. Suppose the belt-tightening strategy of industrialization is feasible. Based on Equation 26, it follows that there exists a time $\hat{T}$ such that the country achieves h_{min}.[13] Plugging $T = \hat{T}$ into Equation 26, one can easily calculate the value of

[11] The algebraic derivation of Equation 26 is available from the authors on request. The expression for $c_{mT}^{(2)}$ is obtained by plugging Equation 15 into Equation 9 and noting that as soon as the country transforms itself, $h_0^{(2)} = h_{min}$. We also assume that the convergence condition ($\beta G^{1-\gamma} < 1$) holds.

[12] To see this, note that for γ close to unity, the expression in the last square bracket in Equation 26 approaches [ln c_{mT} + ($\beta/(1-\beta)$)ln G], which is positive for plausible parameter values.

[13] $\hat{T}$ can be seen as the smallest possible time period necessary to attain h_{min}.

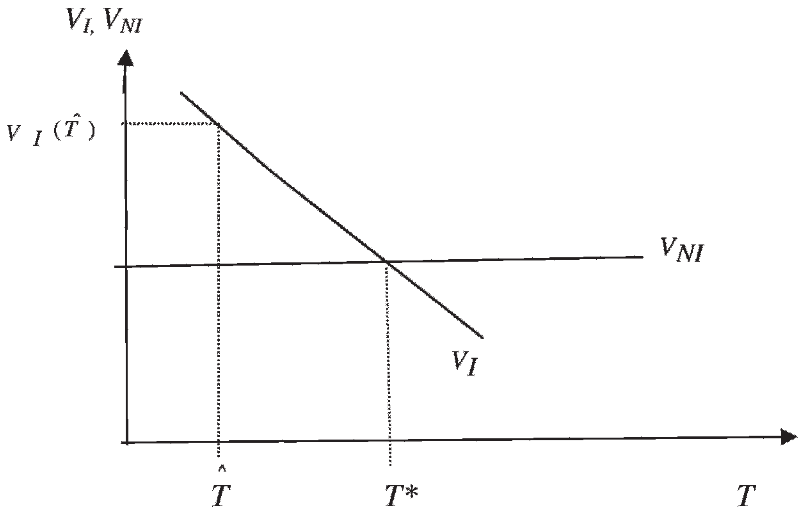

Figure 3. The Optimal Time to Industrialize

industrializing at date $\hat{T}$. In other words, let us define $\hat{V}_I = V_I(\hat{T})$. Note that belt-tightening is optimal up to $\hat{T}$ if $\hat{V}_I > V_{NI}$. Given that V_I is monotonically decreasing in T, using Figure 3, one can easily verify the following proposition:

PROPOSITION 2. If $\hat{T} < T^*$, a belt-tightening strategy of industrialization is optimal.

In the section that follows, we calibrate the model to the experience of the United Kingdom over the period 1830–2001 and show that the model reasonably predicts the long-run historical behavior of U.K. real GDP per capita during the postindustrial revolution era, following a takeoff. We then use the calibrated structure to examine how the model performs in predicting the cross-country correlations between agricultural productivity, education, and the degree of industrialization, as well as past and recent cross-country income differences.

4. Model Calibration

Our first task is to calibrate the model parameters in such a way that the model broadly matches the pre- and postindustrial history of the United Kingdom. This will form our baseline model, which we will then use to predict cross-country income differences.

Identifying the Date of Industrialization for the United Kingdom

We first identify the date at which the United Kingdom industrialized. To do so, we focus on the Second Industrial Revolution, which occurred sometime between 1860 and 1900 and was characterized by the invention of a large number of technologies based on electricity, which ultimately led to an economy characterized by a faster productivity growth (Devine 1983; Atkeson and Kehoe 2007). It is not entirely clear exactly when this transformation took place in the United Kingdom. We set 1880 as the date of this transformation, as this was the date in which education was made compulsory throughout the United Kingdom for children aged 5 to

10, establishing, for the first time, a formal schooling system and therefore fostering human capital formation and technical progress.

The establishment of a compulsory formal schooling system in the United Kingdom in 1880 can be interpreted as the establishment of a main channel of human capital formation, replacing the informal acquisition of skills, which previously took place mainly through on-the-job training. This was an important breakthrough in the United Kingdom, where the development of a national public system of education lagged behind that of the Continental countries (Sanderson 1995). We use 1880 as our proxy for $\hat{T}$ because we feel that making education compulsory played a fundamental role in fostering human capital formation and technical progress in the United Kingdom.[14]

Schooling Years: Human Capital Technology

We next face the challenge that there is no empirical counterpart of the broadly measured human capital stock, h_t, used in our model. Conventionally, average years of schooling are used as a proxy for human capital (see, e.g., Bils and Klenow 2000). However, the problem in using such a proxy arises from the fact that the human capital state variable is unbounded in our model; whereas, the schooling years are upward bounded. One thus needs to convert bounded schooling years (s_t) into unbounded human capital stock (h_t), consistent with our semi-endogenous growth model. To this end, we posit the following functional form for our human capital technology:

$$h_t = Q \frac{\bar{s}^{\theta}}{(\bar{s} - s_t)^{\theta}}, \tag{27}$$

where $0 \leq s_t \leq \bar{s}$, $\bar{s} > 1$, $\theta > 0$, and $Q > 0$. Here $\bar{s}$ is the upper bound for schooling years, which is fixed at 18 years, encompassing postgraduate education. The parameters Q and θ represent the quality of schooling: Both impact the marginal contribution of schooling to human capital in different ways. Given Q and θ, as s_t approaches its upper bound $\bar{s}$, human capital approaches infinity. The parameter θ determines how fast human capital approaches infinity, while Q is just a scale parameter.[15] We next calibrate the baseline parameters of our model.

[14] Alternatively, we could have chosen 1870 as a measure for $\hat{T}$. The year 1870 was when the government assumed responsibility for ensuring universal elementary education (Green 1990). Another alternative could have been to choose 1890, the year in which education was made free for children under the age of 10. Finally, we could have chosen 1893 as a measure for $\hat{T}$, which corresponds to the year in which the compulsory years of education rose from five to six (Birke and Browne 2007). Our predictions about the relevant macroeconomic aggregates are robust to using these alternative dates.

[15] This functional form is borrowed from Basu and Guariglia (2007). Bils and Klenow (2000) posit a more general human capital production function, which includes cohort and experience effects. Ours is a simplified version of their technology, which shows a direct relationship between schooling years and human capital, excluding cohort and experience effects. Note that our schooling technology does not alter the internal working of the model. Once the time path of human capital is determined, using technology (Eqn. 27) allows us to trace out the time path of schooling years. This schooling technology is needed only for the purpose of obtaining our cross-country income differences predictions reported in section 5.

Choice of Baseline Parameters

The next step is to calibrate the model parameters on the basis of some observables. There are four preference parameters (β, γ, $\bar{a}$, and ω); four technology parameters (α, δ, z, A); and four human capital parameters (h_0, h_{min}, Q, and θ).

Calibrating the Preference Parameters

Consistent with a real interest rate of 5% as in Gollin, Parente, and Rogerson (2002), and noting that the economy is stationary during the preindustrial phase, we fix β at 0.95. We set the value of γ at 1.01, which approximates logarithmic preferences.[16] Regarding the other two preference parameters, $\bar{a}$ and ω, only one of them can be normalized. We choose to normalize $\bar{a}$ to unity and then find the value of ω, which is consistent with the minimum nutritional requirement of an individual of average height, weight, and age. Numerous nutritional studies (see, e.g., Somer 2004) and consultations with U.K. National Health Service practitioners suggest that the ratio of minimum to maximum calorie intake of such an average individual is about ½. We therefore fix ω at 0.5.[17]

Calibrating the Technology Parameters

We have four technology parameters: α, δ, A, and z. Ideally, one would like to find an observable corresponding to each of these parameters. This is not always possible in the context of our model. We therefore adopted the following strategy. We searched for values of α and δ, which kept the belt-tightening strategy just feasible. Doing so, we arrived at α equal to 0.69 and δ equal to 0.01. The parameter α is conceptually close to the value of output elasticity of human capital in Bandyopadhyay and Basu (2005). Regarding the depreciation parameter, note that $(1 - \delta)$ can be interpreted as the rate of intergenerational spillover of knowledge in the tradition of Mankiw, Romer, and Weil (1992) and Benabou (2000). A low value of δ means that the rate of intergenerational spillover of knowledge is high. When calibrating cross-country growth-inequality correlations, Bandyopadhyay and Basu (2005) use a value of δ similar to ours.

Coming to the IST parameters, we fix A consistently with the post-1880 average annual GDP growth rate of 1.4% documented in Maddison (2003).[18] The IST parameters z and A are closely related to labor productivities in the agriculture and manufacturing sectors, respectively. Using Mitchell (1992), we observe that the relative labor productivity of manufacturing with respect to agriculture was 1.229 in 1880. Given the close link between labor productivities and IST parameters, we take this relative productivity as a proxy for the ratio of A to z. The year 1880 is chosen because, according to our model, from this year onwards, both pre- and postindustrial technologies became accessible to the U.K. economy. In this way, we obtain a value of z equal to 0.063.

[16] Changing the value of γ in the vicinity of 1 does not significantly alter the main baseline calibration results.
[17] Changing the value of ω in the vicinity of 0.5 does not significantly alter the main baseline calibration results.
[18] Specifically, given the values of β, δ, and γ, we fix A such that the long-run growth rate of $[\beta(A + 1 - \delta)]^{1/\gamma}$ equals 1.4% (see Proposition 2). This implies a value for A of 0.0775.

Calibrating the Human Capital Parameters

The next task is to fix the values of the initial human capital, $h_0^{(1)}$, and the threshold human capital, h_{min}. The value of $h_0^{(1)}$ is fixed at the preindustrial steady state level, $h^{*(1)}$. Using Equation 20, this leads to a value of 2.87. Regarding the calibration of h_{min}, we first fix the terminal human capital stock in 2001 using the share of agriculture in GDP, which is equal to 1% in that year (World Bank Development Indicators 2005). This gives us a terminal human capital stock equal to 100.[19] In the next step we iterate the optimal investment policy rule (Eqn. 15) backwards until we hit 1880, which is our proposed date of second industrialization in the United Kingdom. The stock of human capital in 1880 obtained in this way is our h_{min}, which, given the other baseline parameter values, is found to be 19.78.

Since the United Kingdom is our baseline model, we compute the schooling technology parameters Q and θ based on the minimum schooling years in the United Kingdom in 1880 (five years), which are associated with human capital equal to h_{min}, and the recent minimum schooling years (11 years), which are associated with our terminal human capital stock.[20] Based on Equation 27, and given that h_{min} is equal to 19.78, and the terminal human capital stock to 100, we obtain two equations, one for $s_t = 5$, and the other for $s_t = 11$, which we solve for the two unknown parameters Q and θ. This implies a value for Q of 8.44 and a value for θ of 2.62. Table 3 summarizes these baseline parameter values.

Baseline Calibration Results

Using the calibrated parameter values and assuming that the initial stock of human capital is fixed at the preindustrial steady state, we use the model to estimate the year in which the United Kingdom started to belt-tighten. We find that the time to industrialize is 92 years for the U.K. economy, meaning that in order to acquire h_{min} in 1880, the United Kingdom started its belt-tightening in 1788. For the same set of parameter values, we also find that T^* is equal to 110 years, which means that the optimality condition set forth in Proposition 2 holds.

Figure 4 plots the GDP index, based on the baseline model, and compares it with the corresponding real data for the U.K. economy over the period 1830–2001.[21] By construction of the model, output experiences a discrete jump in 1880, when the critical minimum human capital h_{min} is attained, and then merges with the long-run growth path in 1881.[22] This discrete jump in output is due to the stylized nature of the model. Despite its stylized nature, the baseline model performs well in matching the historical post-1880 U.K. GDP series.

On other fronts the model also performs reasonably well. For example, it predicts a secular decline in the share of agriculture in GDP. Figure 5 plots the U.K. share of agriculture in GDP predicted by the model since 1801 and compares it with the actual data taken from Mitchell (1992). Because of the stylized nature of the model, the predicted share of agriculture is

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[19] GDP is defined as consumption plus investment. In the context of our model, it is given by $\bar{a} + c_{mt} + h_{t+1}^{(2)} - (1 - \delta)h_t^{(2)}$, i.e., consumption of agricultural and manufacturing goods plus investment in schooling. Using the resource constraint (Eqn. 9), the share of agriculture in GDP is equal to $\bar{a}/h_t^{(2)}$. After equating this expression to its 2001 value (1%), we obtain a terminal capital stock equal to 100 in 2001.

[20] Information on the minimum schooling years in the United Kingdom was taken from Birke and Browne (2007).

[21] The GDP index in year x is defined as the ratio between real per capita GDP in year x and real per capita GDP in 1900. We chose the period 1830–2001, as this is the period for which the Maddison (2003) series for U.K. real per capita GDP are available.

[22] The discrete jump in output is due to the absence of adjustment cost of capital in our model.

Table 3. Baseline Parameters

Parameters	Value	Comments
Preference parameters:		
β: discount factor	0.95	Consistent with a 5% real interest rate
γ: utility function curvature parameter	1.01	Conventional level, approximating logarithmic preferences
$\bar{a}$: saturation level of food	1	Normalization
ω: subsistence	0.5	Based on nutritional studies such as Somer (2004)
Technology parameters:		
α: labor share in agriculture	0.69	Chosen to ensure the feasibility of the belt-tightening strategy. Close to the estimate in Bandyopadhyay and Basu (2005).
δ: depreciation rate	0.01	Chosen to ensure the feasibility of the belt-tightening strategy. Close to the estimate in Bandyopadhyay and Basu (2005).
A: IST parameter in manufacturing	0.0775	Chosen to reproduce the 1.4% annual average growth rate of U.K. GDP during the post-1880 period.
z: IST parameter in agriculture	0.063	Chosen to replicate the relative productivity of manufacturing with respect to agriculture, equal to 1.229 in 1880 (Mitchell 1992).
Human capital parameters:		
$h_0^{(1)}$: initial human capital	2.87	Fixed at the preindustrial steady state $h^{*(1)}$ (see Eqn. 20)
h_{min}: minimum level of human capital necessary to enter the industrial stage	19.78	Consistent with a 1% share of agriculture in GDP in 2000
Schooling–human capital technology parameters	$Q = 8.44$; $\theta = 2.62$	Consistent with the observed minimum schooling years in 1880 and 2001

significantly higher than the actual share before the industrialization date. This happens because the model economy is primarily an agrarian economy during the preindustrial phase: GDP mainly consists of food production. The model predicts the agriculture share much better during the post-1880 phase after the economy catches up with the modern technology. The sharp drop in the share of agriculture right after 1880 basically mirrors the upward drift in GDP in 1880 reported in Figure 4.

The model also predicts a secular rise in the share of expenditure on education in GDP from 1% in the preindustrial steady state to 3.41% in the industrial state.[23] This compares reasonably with the actual share of expenditure on education in GDP, which, according to Carpentier (2003), rose from 0.01% in 1833 to 4.31% in 1999.

It should be noted that, because of its stylized nature, the model does not always succeed in quantitatively reproducing some of the stylized facts observed in the economy. However, it

[23] According to the model, in the preindustrial steady state, the share of expenditure on education in GDP is given by $\delta h^{*(1)} / \left(c_a^* + \delta h^{*(1)} \right)$, which is the replacement human capital investment divided by the steady state GDP. Using Equation 3, this reduces to $\delta/(N_a + \delta)$.

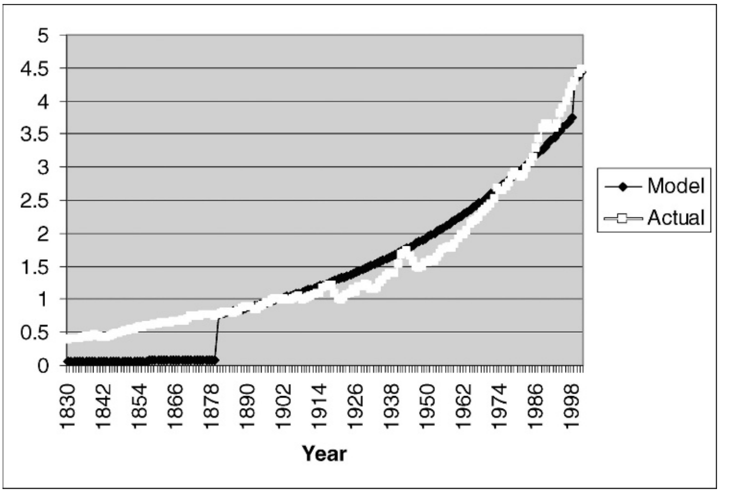

Figure 4. Per capita real GDP index (relative to 1900), model and actual. Note: The GDP index in year x is defined as the ratio between real per capita GDP in year x and real per capita GDP in 1900. The actual data are taken from Maddison (2003).

qualitatively predicts the secular movement in those key variables reflecting the structural transformation of the economy.

5. Taking the Baseline Model to Cross-Country Data

How does the baseline model accord with the cross-country data? We approach this issue in two steps. First, we investigate whether the model has any useful insights about the cross-country correlations between agricultural productivity, education, and the degree of industrialization documented in section 2. Second, we examine how the baseline model performs in predicting past and recent cross-country income differences.

Agricultural Productivity, Education, and Time to Industrialize

The model can rationalize the cross-country correlations between agricultural productivity, initial human capital, and the extent of industrialization documented in Table 2. To see this, note from Equations 3 and 20 that the steady state level of human capital in Equation 20 is nothing but the agricultural labor productivity (c_a/N_a), which, in the preindustrial economy, crucially depends on the IST parameter z. Given their dependence on the IST variable z, both the agricultural labor productivity, c_a/N_a, and the initial human capital stock $h_0^{(1)}$ (which is assumed to be equal to $h^{*(1)}$) are endogenous. A lower agricultural IST parameter lowers labor productivity. This results in a lower initial human capital and delayed industrialization, which is reflected by a higher share of agriculture in GDP, as shown in Footnote 19.

Table 4 summarizes how a change in z impacts the time to industrialize via its effects on agricultural productivity. The time to industrialize is sensitive to the IST parameter: A 10% increase in z starting from the baseline level raises the agricultural productivity by about 22% and speeds up the time to industrialize by 20 years. This broadly accords with the stylized facts

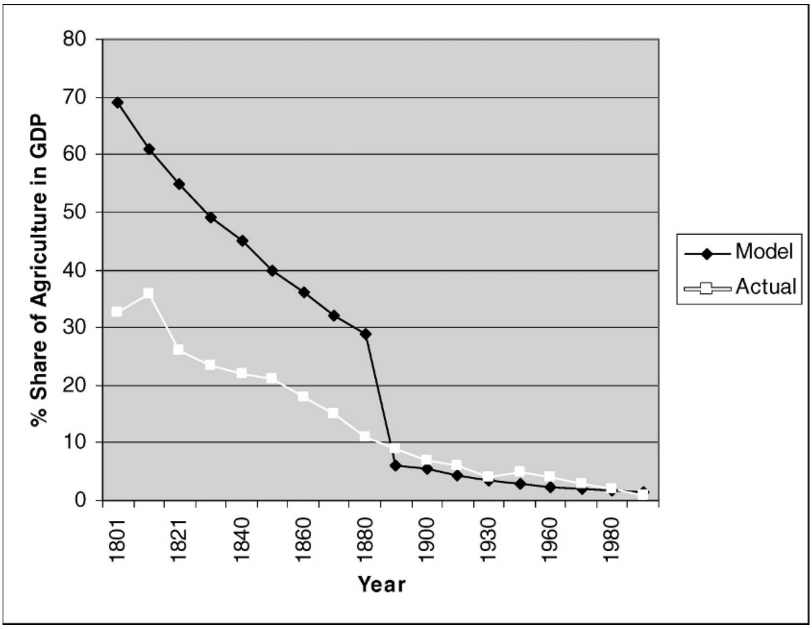

Figure 5. Percentage share of agriculture in GDP, model and actual. Note: The actual data for the share of agriculture to GDP are taken from Mitchell (1992).

presented in Table 2, according to which countries with lower agricultural productivity and low initial human capital are less industrialized.

The model has some indirect implications for fertility and time to industrialize. Although fertility is not explicitly modeled, nations with a lower fertility can be envisaged as those with higher returns to child quality (following the quality-quantity tradeoff discussed in Becker, Murphy, and Tamura 1990), that is, a higher z. The model predicts that nations with higher returns to child quality industrialize faster.

Predictions about Past and Recent Cross-Country Income Differences

We now analyze the extent to which our baseline model calibrated to the U.K. economy helps predict past and recent cross-country income differences. A key implication of the baseline model is that the U.K. economy industrialized early because it started belt-tightening early. If all countries shared the same preferences and technology, the model would imply that the reason why some countries are laggards in terms of growth and per capita income is that they did not begin belt-tightening early enough. In this section we use cross-country schooling

Table 4. Agricultural IST Parameter (z), Agricultural Productivity, and Time to Industrialize (T)

z	0.063	0.069	0.077	0.081
Agricultural productivity	2.79	3.74	5.34	6.28
T	92	72	51	49

Other parameters are fixed at the same level as in Table 3. For all these z values, the belt-tightening strategy was found to be optimal.

years data to predict the cross-country difference in the initial belt-tightening years and the resulting effects on past and recent cross-country income differences.

Sample Selection Issues

Cross-country data for schooling years are limited and do not date back too far: The Barro and Lee (2000) data set contains schooling years that go back only to 1960. In this section we focus on those countries whose schooling years in 1960 are less than the critical threshold necessary to attain the U.K. h_{min} (5 years). According to our baseline model, these countries were not fully industrialized at that time.

We then omit a number of outliers from our sample. For 1960 these include Greece, Italy, Spain, Trinidad and Tobago, and Venezuela (for which the average actual scaled per capita real income is equal to 3.44, compared to 0.64 for the other countries). For 2005 the outliers that we omit include Greece, Italy, Spain, Portugal, Trinidad and Tobago, Singapore, Korea, and Mexico (for which the average actual scaled per capita real income is equal to 6.75, compared to 0.77 for the other countries); and Mali, Nepal, Niger, and Togo (for which the average scaled GDP predicted by the model is equal to 0.11, compared to 1.19 for the other countries). This leaves us with a sample made up of 43 countries in 1960 and 47 countries in 2005.[24]

Inferring the Date at which Countries Started Belt-Tightening

For each of the countries, we plug the respective average schooling years in 1960 into Equation 27 and obtain an estimate of the corresponding human capital in 1960. Given such human capital in 1960 and assuming that all countries start from the same preindustrial U.K. baseline steady state $h^{*(1)}$, we then infer when each of these countries started belt-tightening by simulating the belt-tightening path given in Equation 21. These initial years of belt-tightening for our countries are summarized in Table 5. Not surprisingly countries whose schooling years in 1960 are closer to the minimum level of five years necessary to attain h_{min} started the belt-tightening early. For example, a country like Panama that has the highest average schooling years of 4.64 in the sample started its belt-tightening in 1872, as opposed to Togo, which has average schooling years of 0.22 and started its belt-tightening only in 1914.[25]

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[24] For each country, both the actual and the predicted real per capita GDP figures are scaled by the corresponding figures for Algeria. Actual real per capita GDP figures are taken from the World Bank Development Indicators (2005). Note that the sample used in this section contains fewer countries than the sample used in section 2, as out of the initial 90 countries, only 59 had information for years of schooling in 1960 (i.e., for the initial years of schooling) and had less than five initial years of schooling. These 59 countries are highlighted in bold in Appendix 1 (the 13 outliers mentioned above are in bold and italics). Data for cross-country per capita GDP in 1960 were not available for the underlined countries in Appendix 1. All stylized facts illustrated in section 2 also hold for the restricted samples of 59 or 43/47 (excluding the outliers) countries used in this section.

[25] Since we use the same baseline parameters for all the countries in the sample, by default, the belt-tightening strategy is optimal for these countries. The countries in our sample are characterized by schooling years in 1960, which are less than the critical threshold necessary to attain the U.K. h_{min} (five years): their belt-tightening years are therefore less than the U.K. belt-tightening period of 92 years.

Comparing the Model Predictions with the Actual Data for Real GDP per Capita in 1960 and 2005

In a similar spirit as in Gollin, Parente, and Rogerson (2007b), we let the model predict the level of per capita income of our countries, which are assumed to differ only in terms of the initial belt-tightening year.[26] The countries' per capita income predicted by the model for 1960 and 2005 is then compared with the actual per capita income of these countries in the same years. Figure 6 presents the scatter plot of the model predictions against the actual scaled per capita real GDP in 1960, and Figure 7 presents the corresponding scatter plot for 2005. The correlation coefficient between the model and the actual data is 0.47 for 1960 and 0.42 for 2005. Given that the cross-country income variation still perplexes growth economists, this correlation between the model and actual per capita income is reasonable.

This exercise of cross-country income predictions using a stylized model of U.K. industrialization has to be interpreted with caution because of inherent country heterogeneity. In addition to human capital and agricultural productivity, there are numerous other economic and institutional factors at work in determining cross-country income differences.[27] Because the central focus of this paper is on education as an important determinant of the pace of industrialization, we abstract from these factors.

6. Conclusion

In this paper we have analyzed whether, in addition to differences in agricultural productivity, differences in initial years of schooling can explain why some countries industrialize later than others. We have constructed a neoclassical growth model, which predicts that countries with a greater initial knowledge gap industrialize later. We have used this model as a baseline and calibrated it to U.K. historical data. We found that our baseline model performs well in replicating actual historical U.K. real GDP per capita series during the era following the Second Industrial Revolution. Moreover, we found that the model has useful insights about the cross-country correlations between agricultural productivity, education, and the degree of industrialization observed in the data. Finally, assuming that the countries in the sample start belt-tightening at different dates, we have shown that our model performs reasonably well in predicting cross-country income variations.

Better predictions of recent cross-country income differences could be obtained by including in our model other economic and institutional factors. Furthermore, our model could be extended by making population size endogenous. This would allow a comprehensive understanding of the complex interactions between fertility, human capital, agricultural productivity, and the pace of industrialization. These extensions to our model are on the agenda for future research.

[26] An alternative hypothesis could be that the countries' initial belt-tightening years are the same, but each country started off from a different steady state $h^{*(1)}$. This could be attributed to different values of the preindustrial IST parameter z in different countries. Our cross-country predictions do not change much if we allow z to change across countries.

[27] Bandyopadhyay and Basu (2005) explore other determinants of cross-country differences in growth and inequality.

Table 5. Initial Year of Belt-Tightening Inferred from Schooling Years in 1960

Country	*s*	Initial Year of Belt-Tightening	Country	*s*	Initial Year of Belt-Tightening
Algeria	0.982	1909	Mexico	2.756	1893
Bangladesh	0.612	1911	Mozambique	0.478	1912
Botswana	1.719	1903	Nepal	0.116	1915
Brazil	2.852	1892	Nicaragua	2.257	1898
Cameroon	1.739	1902	Niger	0.278	1914
Central African Republic	0.565	1912	Pakistan	0.74	1910
Colombia	3.197	1889	Panama	4.643	1872
Costa Rica	4.035	1879	Papua New Guinea	1.146	1907
Dominican Republic	2.696	1894	Paraguay	3.64	1884
Ecuador	3.225	1888	Peru	3.302	1888
El Salvador	1.995	1900	Philippines	4.237	1877
Ghana	0.966	1909	Portugal	1.859	1901
Guatemala	1.498	1904	Senegal	1.742	1902
Guyana	4.484	1874	Sierra Leone	0.656	1911
Haiti	0.78	1910	Singapore	4.298	1876
Honduras	1.872	1901	South Africa	4.286	1876
India	1.684	1903	Sri Lanka	3.938	1880
Indonesia	1.553	1904	Swaziland	2.132	1899
Iran	0.796	1910	Syria	1.351	1906
Jamaica	2.54	1895	Tanzania	3.51	1885
Jordan	2.333	1897	Thailand	4.297	1876
Kenya	1.531	1904	Togo	0.225	1914
Korea, Republic of	4.246	1877	Tunisia	0.605	1911
Lesotho	3.483	1886	Turkey	1.915	1901
Malawi	1.91	1901	Uganda	1.149	1907
Malaysia	2.879	1892	Venezuela	2.905	1892
Mauritius	3.128	1889	Zambia	2.52	1895

s denotes total schooling years (including primary, secondary, and higher education) in 1960 and is taken from the Barro and Lee (2000) data set.

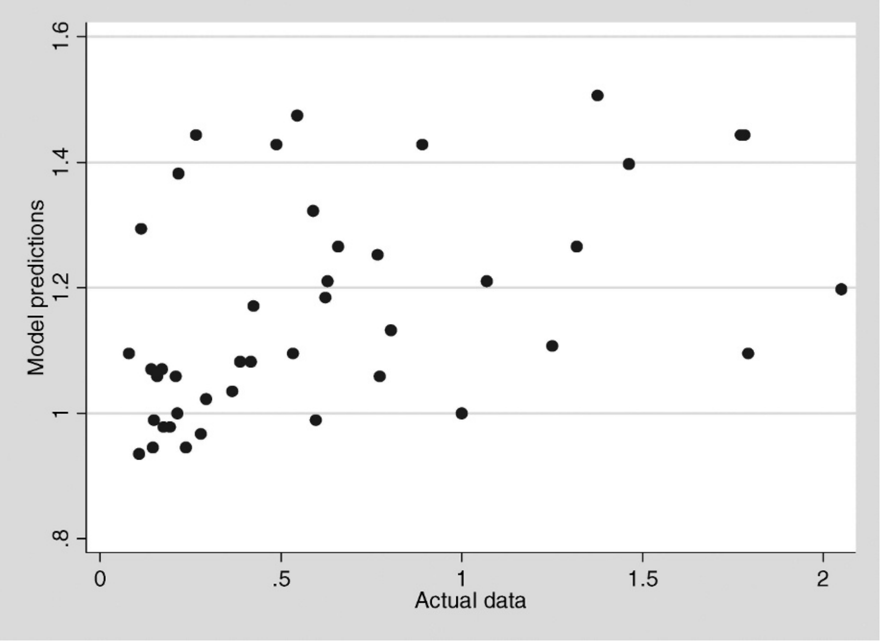

Figure 6. Per capita real GDP, model and actual (1960). Note: For each country both the actual and the predicted GDP figures are scaled by the corresponding figures for Algeria. The actual per capita GDP figures for 1960 are taken from the World Bank Development Indicators (2005).

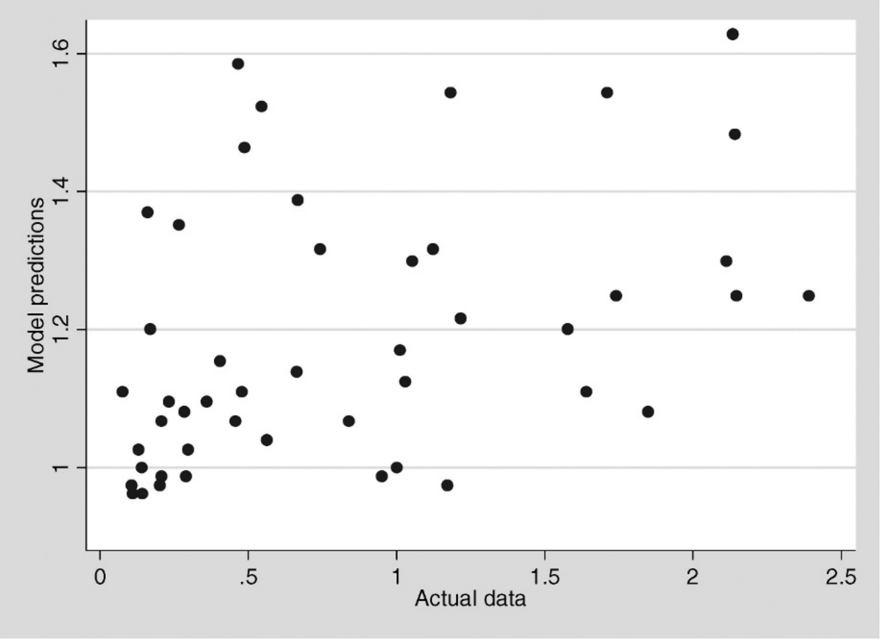

Figure 7. Per capita real GDP, model and actual (2005). Note: For each country, both the actual and the predicted GDP figures are scaled by the corresponding figures for Algeria. The actual per capita GDP figures for 2005 are taken from the World Bank Development Indicators (2005).

Appendix 1: List of Countries Used in Section 2 (All Countries) and Section 5 (Countries in Bold; Outliers Are in Italics; Countries for which Observations Were not Available in 1960 Are Underlined)

1. **Algeria**
2. Argentina
3. Australia
4. Austria
5. Bahrain
6. **Bangladesh**
7. Barbados
8. Bolivia
9. **Botswana**
10. **Brazil**
11. **Cameroon**
12. Canada
13. **Central African Republic**
14. Chile
15. **Colombia**
16. **Costa Rica**
17. Cyprus
18. Denmark
19. **Dominican Republic**
20. **Ecuador**
21. **El Salvador**
22. Fiji
23. Finland
24. France
25. Germany
26. **Ghana**
27. ***Greece***
28. **Guatemala**
29. **Guyana**
30. **Haiti**
31. **Honduras**
32. Hong Kong, China
33. Hungary
34. Iceland
35. **India**
36. **Indonesia**
37. **Iran**
38. Ireland
39. Israel
40. ***Italy***
41. **Jamaica**
42. Japan
43. **Jordan**
44. **Kenya**
45. ***Korea, Republic of***
46. Kuwait
47. **Lesotho**
48. **Malawi**
49. **Malaysia**
50. ***Mali***
51. **Mauritius**
52. ***Mexico***
53. **Mozambique**
54. ***Nepal***
55. The Netherlands
56. New Zealand
57. **Nicaragua**
58. ***Niger***
59. Norway
60. **Pakistan**
61. **Panama**
62. **Papua New Guinea**
63. **Paraguay**
64. **Peru**
65. **Philippines**
66. Poland
67. ***Portugal***
68. **Senegal**
69. **Sierra Leone**
70. ***Singapore***
71. **South Africa**
72. ***Spain***
73. **Sri Lanka**
74. **Swaziland**
75. Sweden
76. Switzerland
77. **Syria**
78. **Tanzania**
79. **Thailand**
80. ***Togo***
81. ***Trinidad and Tobago***
82. **Tunisia**
83. **Turkey**
84. **Uganda**
85. United Kingdom
86. United States
87. Uruguay
88. ***Venezuela***
89. **Zambia**
90. Zimbabwe

Appendix 2: Derivation of Equation 12

The solution of Equation 11 consists of two parts: the solution for the nonhomogenous part (particular integral) and the solution for the homogenous part (complementary solution).

We initially conjecture a solution:

$$h_t^{(2)} = Q \quad \text{for all } t. \tag{A1}$$

We then plug Equation A1 into Equation 11 and solve for Q to obtain

$$Q = \frac{A\bar{a}}{A - \delta}, \tag{A2}$$

which solves the particular integral part. The homogenous part of Equation 12 is given by

$$h_{t+2}^{(2)} - (A + 1 - \delta + G)h_{t+1}^{(2)} + (A + 1 - \delta)Gh_t^{(2)} = 0. \tag{A3}$$

The two characteristic roots of Equation A3 are given by

$$\lambda_1, \lambda_2 = (A + 1 - \delta), G. \tag{A4}$$

The general solution, which is the sum of the solutions for the nonhomogenous and homogenous parts, is thus given by Equation 12. *QED*.

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