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Inequality and Industrialization

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ABSTRACT

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 inequality of human capital could also be a contributing factor to the delayed process of industrialization characterizing some countries. We develop a neo-classical growth model which predicts that countries with a greater initial knowledge gap between rich and poor agents industrialize slowly, and that human capital inequality, although declining, tends to be persistent. Our cross-country data lend support to these predictions.

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1. Introduction

What determines the stage and pace of industrialization is a highly debatable topic in the macro development literature. In a recent paper, Gollin et al. (2002) highlight the role of agricultural productivity in the process of industrialization. The key point made in their paper is that most of the late industrializing countries began the process of industrialization late because of low agricultural productivity. Their model shows that only once the society produces the basic nutritional requirement of food, labor starts moving from agriculture to industry. From that point onwards, agriculture loses its importance asymptotically and a Solow technology is adopted in the long run. Hansen and Prescott (1999) also reach similar conclusions. While all these papers provide useful insights about the process of industrialization, they remain largely silent about the evolution of within-country inequality during the course of industrialization.

The latter issue is important because of a recent wave of literature exploring the evolution of inequality. There is now a near unanimity among growth economists that growth and inequality are inversely correlated.[2] Thus one expects that as countries industrialize, inequality should fall. A recent paper by Sala-i-Martin (2002) indirectly corroborates this fact by documenting a decline in world inequality.

A parallel emerging literature, however, paints a different picture about the course of inequality in the long run. A number of papers including Mookherjee and Ray (2002), Banerjee and Newman (1993), Galore and Zeira (1993), and Bandyopadhyay (1993) argue that a combination of credit market failure and initial unequal distribution of human capital could make inequality a stable and persistent phenomenon. Along similar lines, Solon (1992) and Zimmerman (1992) provide estimates, which suggest that intergenerational mobility in the US is much lower than expected. According to these findings, it is likely that the child of poor parents will live in poverty.

In this paper, we attempt to integrate the literature dealing with the process of industrialization, and that dealing with the evolution of inequality. Our line of research builds on models in the tradition of Banerjee and Newman (1993), and Galore and Zeira (1993), where credit market imperfections may give rise to persistent inequality. We construct an aggregative growth model, which lays out the

[2]See for example, Castelló and Doménech (2001) for a recent estimate of growth-inequality correlations.

time path of knowledge inequality as a country industrializes. In particular, our model extends Gollin et al.'s (2002) focusing both on the initial distribution of human capital and agricultural productivity as two major determinants of the process of industrialization and the resulting inequality.

Rather than income inequality, our model focuses primarily on knowledge or human capital inequality within a representative country in the world economy.[3] As in Gollin et al. (2002) and Hansen and Prescott (1999), in our model, the process of industrialization is perceived as the diminishing importance of agriculture, while all residents of a country start adopting an industrial production technology.

In our model, there are two types of altruistic agents: the poor who have a low initial human capital, and the rich characterized by a high initial human capital. Due to the initial distribution of human capital and to imperfectly functioning credit markets, the poor cannot operate the industrial technology because they do not have the minimum necessary skill. In this environment, there exists an optimal waiting time (which we call belt-tightening time) for the poor to become entrepreneurs, and therefore rich.

Our calibrated model predicts that the process of industrialization will be considerably slower in economies with a highly unequal initial distribution of human capital and a low agricultural productivity. Quantitative exercises with the model also suggest that as the poor grow, knowledge inequality declines and converges to a level whose magnitude again depends on the state of agricultural productivity and the initial distribution of human capital. The model thus rationalizes how a declining inequality could be consistent with the emergence of a long run stable inequality.

The rest of this paper is laid out as follows. In the section that follows, we present some stylized facts aimed at motivating our theoretical analysis. In section 3 we lay out our theoretical model and its predictions regarding the relationship between inequality and industrialization. Section 4 presents some quantitative implications from the model and connects them to the stylized facts. Section 5 concludes.

[3] See Glomm and Ravikumar (1992), Saint-Paul and Verdier (1993), and Galor and Tsiddon (1997) for alternative models where inequality stems from the distribution of human capital. Also note that since

2. Some stylized facts

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

We measure the degree of industrialization of a country by its share of agriculture in GDP. The agricultural productivity and share of agriculture to GDP data are taken from the World Bank Development Indicators (2002)[4]. Our measure of human capital inequality is given by a human capital Gini coefficient, which refers to the population aged 15 and over, and is calculated as in Castelló and Doménech (2002, p. C189) using the following formula:

$$Gini15 = \frac{1}{2\bar{H}} \sum_{i=0}^{3} \sum_{i=0}^{3} \left| \hat{x}_i - \hat{x}_j \right| n_i n_j ,$$

where $\bar{H}$ represents the average schooling years of the population aged 15 and over; i and j stand for different levels of education; n_i and n_j are the shares of population with a given level of education; and $\hat{x}_i$ and $\hat{x}_j$ are the cumulative average schooling years of each educational level. Four levels of education are considered: no schooling, primary, secondary, and higher education.

We average our data over non-overlapping five-year periods, so that data permitting, there are eight observations per country (1960-65, 1965-1970, 1970-75, 1976-80, 1981-85, 1986-90, 1991-95, 1996-99). We take five-year averages of all our variables because the human capital inequality variables are only available at such intervals. Our dataset is, therefore, a panel made up of 90 countries over 8 time periods[5]. A full list of the 90 countries can be found in Appendix 1.

Table 1 reports the cross-country average human capital Gini coefficient, and the cross-country average share of agriculture for our eight time periods. These numbers provide a broad measure of human capital inequality and the degree of industrialization of a representative country in the world economy (based on our

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human capital is the only reproducible input in our model, income inequality and knowledge inequality are positively correlated in our setting.

[4] The share of agriculture in GDP is calculated as the share of the value added coming from agriculture to GDP. Agricultural productivity is given by the agriculture value added per worker.

sample). The Table suggests that over our forty year time span, the knowledge inequality among the citizens of the representative country has fallen as the country has industrialized (as evident by a declining share of agriculture). It is noticeable, however, that although inequality shows a declining trend, even after forty years, the Gini coefficient remains quite high (about 36%)[6].

In the next step, we turn our attention to the persistence of within-country knowledge inequality and to whether it differs across countries. The dynamic panel regression reported in Table 2 shows that inequality appears to be a generally persistent phenomenon. Furthermore, the fact that the coefficient associated with the lagged dependent variable is higher for countries with lower agricultural productivity suggests that this persistence is magnified in countries with lower agricultural productivity[7].

Table 3 reports cross-country correlations between the time average of the share of agriculture, the time average of the share of agricultural productivity, the initial (start of period) inequality, and the terminal (end of period) inequality. It appears from the Table that countries with higher initial inequality of human capital have a higher share of agriculture (meaning a lower degree of industrialization). Moreover, countries with low agricultural productivity also have a higher share of agriculture. The initial and terminal Gini coefficients have a high correlation (0.88), corroborating the persistence of inequality reported in Table 2.

The stylized facts that emerge from Tables 1 to 3 can be summarized as follows:

(i) The knowledge gap generally shows a world-wide decline over the forty-year course of industrialization spanned by our data.

(ii) Inequality is a persistent process despite its overall decline. The persistence is higher for countries with low average agricultural productivity.

(iii) Countries with higher human capital inequality and lower average agricultural productivity are less industrialized.

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[5] Note that the last time period only contains four years, namely 1996-99.

[6] Adopting a more formal approach, we ran a fixed-effects regression of the Gini coefficient on a time trend and found that the latter variable attracted a negative and statistically significant coefficient.

[7] Note that because of first-differencing and using lagged variables as instruments in the GMM specifications in Table 2, a number of observations is lost.

In the section that follows, we develop a model, which attempts to explain these stylized facts.

3. The model

3.1 The basic framework

Production

Consider a dual economy with two sectors: traditional (indexed *a*) and modern (indexed *m*). The traditional sector (say, agriculture) produces output (food) with raw labor (l_a), human capital (h_a), and land. Since land is fixed in supply (normalized at unit level), the traditional sector is subject to diminishing returns. The modern sector produces output with raw labor (l_m) and human capital (h_m). The technology in the modern sector is subject to constant returns.[8] To start production in sector *m*, one needs a minimum amount of human capital, h_{min}. The production functions in these two sectors are therefore,

(1) $y_{at} = z(l_{at}h_{at})^{\alpha}$ with $0<\alpha<1$;

(2) $y_{mt} = A(l_{mt}h_{mt})$ for $h_{mt} \geq h_{\min}$

$= 0$ otherwise,

where $0<\alpha<1$. $l_{at}.h_{at}$ and $l_{mt}h_{mt}$ represent effective labor supplied in the traditional and modern sectors respectively; and *z* and *A* are the total factor productivities (TFP) in the two sectors. Raw labor is inelastically supplied, and l_{at} and l_{mt} are therefore normalized at unit levels.

Preferences

Following Gollin et. al. (2002), the instantaneous utility function for both types of agents is given by:

(3) $U(c_a, c_m) = c_a$ when $\omega \leq c_a < \bar{a}$

$= \bar{a} + \log c_m$ when $c_a \geq \bar{a}$

[8] A linear Rebelo (1991) type technology in the modern sector is assumed to ensure self-sustained growth. This means that growth in the modern sector is endogenous. Alternatively, one could have an exogenously growing modern sector. The qualtitative and quantititative implications of the model remain the same regardless of how growth is specified in the modern sector.

c_a and c_m denote consumption of agricultural (food) and manufacturing goods respectively. $\bar{a}$ is a saturation level of consumption of food.[9] Until that level is reached, all agents care about is food. Once that level is reached, agents do not derive any more utility from additional food.[10] They then start caring about manufacturing goods. Let ω be the minimum subsistence level of consumption below which the agent fails to survive.

Agents are connected across generations by altruistic bequest motives. Thus, they maximize the utility function,

(4) $\sum_{t=0}^{\infty} \beta^t U(c_{at}, c_{mt})$, where β is the degree of altruism.

Initial distribution of human capital

There are two types of agents in this economy: type 1 and type 2. Type 1 agents own $h_0^{(1)}$ units of human capital and 1 unit of land to start with, and Type 2 agents own $h_0^{(2)}$ units of human capital and one unit of land. We assume:

Assumption 1: $h_0^{(1)} < [\bar{a}/z]^{1/\alpha}$ and $h_0^{(1)} < h_{\min}$

Assumption 2: $h_0^{(2)} = h_{\min} > [\bar{a}/z]^{1/\alpha}$

The implications of these two assumptions are that the initial distributions of human capital are such that type 1 agents are poor and type 2 agents are rich in the following sense. Type I agents' initial human capital is not sufficient for them to produce the saturation quantity of food, which means they prefer not to trade with the rich[11]. Nor is it enough to meet the basic skill of operating an industrial technology.

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[9] We assume that $\bar{a}$ is less than the initial start up cost of launching a modern enterprise, $h_{\min}$.

[10]To avoid any discontinuity in the utility function, the logarithmic part of (4) should be written as $\ln(\varepsilon + c_m)$ where ε is very small number. This is equivalent to assuming that all agents have a small endowment of manufacturing goods. As in Gollin et. al. (2002), we avoid this complication since all the results in the paper would remain largely unaffected even if we introduced it. The decision rules (26) and (45) would only change by a constant term involving ε.

[11] If $h_0^{(1)} > [\bar{a}/z]^{1/\alpha}$, then the poor can trade their surplus food with the rich. The poor have then two options: trade with the rich for manufacturing goods or belt tighten and invest their surplus human capital, $h_0^{(1)} - [\bar{a}/z]^{1/\alpha}$, in the education of their children, sacrificing the consumption of manufacturing goods. Like in the model with no trade, an optimal belt-tightening time for the poor

On the other hand, type 2 agents have just enough human capital to launch both agricultural and industrial technologies. Following Assumption 2, h_{min} can be treated as an initial inequality parameter. A higher h_{min} is, therefore, associated with a greater initial inequality.

The population is constant and normalized in such a way that a fraction ϕ is made up of type 1 agents. It is assumed that credit markets are imperfect and that the poor can therefore not access the credit markets to finance schooling and reach h_{min} (see Appendix 2 for a justification of this issue).

Investment

There are two types of investment technologies for the creation of human capital. An agent can invest in the traditional sector or in the modern sector. Investment in the traditional sector can be thought of as educating one's child in a village primary school. Investment in the modern sector means sending one's child to a big city for secondary and more advanced education. Regardless of the form of schooling, the child can become an entrepreneur only if he/she acquires the minimum skill h_{min}.

We thus have the following technology for updating human capital over generations:

(5) $h_{jt+1} - (1-\delta)h_{jt} = I_{jt}$, where $j=a, m$.

I_{jt} is the investment in sector *j.* If the adult does not invest in schooling, the child only inherits a fraction (1-δ) of his/her parent's human capital. Benabou (1996), Mankiw et al. (1992), and Bandyopadhyay and Basu (2004) model the intergenerational knowledge transfer process in a similar way.

Resource constraints

Since their initial human capital stock is lower than the start-up level of running a modern enterprise, h_{min}, the poor produce food with the technology given by (1). Since the poor produce less than $\bar{a}$, they are not satiated with food, and therefore prefer not to engage in trade with the rich for manufacturing goods. The markets for agricultural and manufacturing goods thus fail to function due to the initial

exists for this scenario as well. All the quantitative implications reached in this paper change very little if we allow trade between rich and the poor. The details of the working of this model with trade are available upon request from the authors.

distribution of human capital. The poor invest $I_{at}^{(1)}$ in agriculture, and face the following resource constraints:

(6) $c_{at}^{(1)} + I_{at}^{(1)} = y_{at}^{(1)}$,

(7) $h_{at+1}^{(1)} - (1-\delta)h_{at}^{(1)} = I_{at}^{(1)}$.

Combining (1), (6), and (7), we get the sequential resource constraint for the poor:

(8) $c_{at}^{(1)} + h_{at+1}^{(1)} - (1-\delta)h_{at}^{(1)} = zh_{at}^{(1)\alpha}$

The rich, on the other hand, produce food and manufacturing goods as they can operate both technologies (1) and (2). Because of the utility function (3), the rich just consume $\bar{a}$ units of food. They will not produce food in excess of $\bar{a}$ because that would be wasteful, as they would neither want to consume that surplus food, nor be able to trade it with the poor for manufacturing goods, since the poor do not produce the latter.

At any date *t*, the rich first allocate their human capital between the traditional and modern sectors. They produce $y_{at}^{(2)}$ units of food and $y_{mt}^{(2)}$ units of manufacturing goods. They then invest $I_{mt}^{(2)}$ of their human capital in the modern sector and $I_{at}^{(2)}$ in the traditional sector. The resource constraints facing the rich are as follows:

(9) $h_{at}^{(2)} + h_{mt}^{(2)} = h_t^{(2)}$,

(10) $\bar{a} + I_{at}^{(2)} = y_{at}^{(2)}$,

(11) $h_{at+1}^{(2)} - (1-\delta)h_{at}^{(2)} = I_{at}^{(2)}$,

(12) $c_{mt}^{(2)} + I_{mt}^{(2)} = y_{mt}^{(2)}$,

(13) $h_{mt+1}^{(2)} - (1-\delta)h_{mt}^{(2)} = I_{mt}^{(2)}$,

Using (2) and (9) through (13), one obtains the following sequential resource constraint of the rich:

(14) $\bar{a} + c_{mt}^{(2)} + h_{t+1}^{(2)} - (1-\delta)h_t^{(2)} = Ah_{mt}^{(2)} + zh_{at}^{(2)\alpha}$,

3.2. Growth of the rich

The rich cannot employ the poor in their manufacturing firms because the poor do not have the basic skill h_{min} to work there. They therefore invest in the traditional sector just enough to produce $\bar{a}$ units of food.[12] The rich will, therefore, allocate a constant amount $\tilde{h}_a^{(2)}$ of human capital to agriculture, which is sufficient for them to produce the saturation level of food and replacement investment of human capital. In other words,

$$(15) \qquad z\tilde{h}_a^{(2)\alpha} = \bar{a} + \delta \tilde{h}_a^{(2)} .$$

Using (2), (9), (12), and (15), one obtains:

$$(16) \qquad c_{mt}^{(2)} + h_{t+1}^{(2)} - (1-\delta)h_t^{(2)} = Ah_t^{(2)} - \bar{M} ,$$

where $\bar{M} = (A-\delta)\tilde{h}_a^{(2)}$.

The rich thus maximize (4) subject to (16). [13]

Given this structure, we have the following proposition:

Proposition 1: For a sufficiently large $h_{\min}$ *(meaning* $h_{\min} > \tilde{h}_a^{(2)}$ *), the human capital of the rich grows and reaches an asymptotic rate, β[1+A-δ].*

Proof: The intertemporal first-order condition of the rich is given by:

$$(17) \qquad \frac{c_{mt+1}^{(2)}}{c_{mt}^{(2)}} = \beta B ,$$

where $B = A + 1 - \delta$.

Plugging (16) into (17), we obtain the following second-order difference equation in $h_t^{(2)}$:

$$(18) \qquad h_{t+2}^{(2)} - B(1+\beta)h_{t+1}^{(2)} + \beta B^2 h_t^{(2)} = \bar{M}(\beta B - 1)$$

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[12] The rich can sustain this saturation level of food production in two alternative ways: by employing the poor, training them to acquire the skill level, $\tilde{h}_a^{(2)}$ so that they can produce $\bar{a}$ units of food for them; or by training their own offspring to acquire the same knowledge to be self-sufficient in the production of food in their backyards. (Once that basic skill of producing food is reached, the rich can then train their children to acquire the basic skill to be entrepreneurs, h_{min}.) We will see later that it will not be optimal for the poor to be employed by the rich to produce food in their backyard.

[13] One could ask why the rich do not incur the training cost λh_{min} and train the poor to be entrepreneurs. A quick look at the budget constraint (16) of the rich reveals that it is suboptimal to do so because the

The general solution to this difference equation is given by:

(19) $$h_t^{(2)} = A_1(B)^t + A_2(\beta B)^t + \tilde{h}_a^{(2)},$$

where A_1 and A_2 are determined by the initial and terminal conditions.[14] The initial condition is characterized by $h_{\min}$. The terminal condition is given by the transversality condition (TVC) as follows:

(20) $$\lim_{T\to\infty} \beta^T \frac{h_{T+1}^{(2)}}{c_{mT}^{(2)}} = 0.$$

We next show that the TVC requires that A_1 in (19) must equal to zero. We prove this by contradiction. If not, then $h_t^{(2)}$ grows at the rate B because $B>\beta B$. On the other hand, $c_{mt}^{(2)}$ grows at the rate βB as in (20). Thus the right hand side of (20) inside the limit operator reduces to:

(21) $$\begin{aligned}&\beta^T \frac{h_0^{(2)} B^{T+1}}{c_{m0}^{(2)}(\beta B)^T} \\ &= \frac{h_0^{(2)}}{c_{m0}^{(2)}} B\end{aligned},$$

which does not converge to zero as T approaches infinity. Consequently, the TVC is violated if $h_t^{(2)}$ grows at the rate B.

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

(22) $$h_t^{(2)} = A_2(\beta B)^t + \tilde{h}_a^{(2)},$$

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

(23) $$A_2 = h_{\min} - \tilde{h}_a^{(2)}$$

As long as $h_{\min} > \tilde{h}_a^{(2)}$, human capital in the modern sector will grow and eventually reach an asymptotic rate βB. Q.E.D.

right hand side would be reduced by this constant training cost thus resulting in a lower life time utility for the rich.

[14] See Appendix 3 for a derivation of Equation (19).

In order to grow, the rich must have initial human capital in excess of the amount necessary to sustain the agricultural production $\bar{a}$. This explains why $h_{\min}$ must exceed $\tilde{h}_a^{(2)}$.

3.3 A belt-tightening strategy for the poor

What conditions will ensure that the poor become entrepreneurs someday? In order to be entrepreneurs, the poor have to reach the minimum human capital, $h_{\min}$. They therefore have the option to follow a belt-tightening strategy of consuming just the subsistence level, ω, for several generations, and accumulate human capital until they reach the $h_{\min}$ units of human capital necessary for them to become entrepreneurs. We make two technological assumptions concerning $h_{\min}$:

Assumption 3: $h_{\min} > \tilde{h}_a^{(2)}$, where $z\tilde{h}_a^{(2)\alpha} = \bar{a} + \delta \tilde{h}_a^{(2)}$.

Assumption 4: $h_{\min} > \left[\dfrac{\alpha\beta z}{1-\beta(1-\delta)}\right]^{1/(1-\alpha)}$.

Assumption 3 specifies that h_{min} should be sufficiently large to preclude the possibility of the poor acquiring the basic skill of being entrepreneurs just by being employed by the rich for producing food in their backyard. Similarly, Assumption 4 stipulates that h_{min} should be sufficiently large to rule out the possibility of the poor becoming entrepreneurs simply by growing the optimal quantity of food in their own backyard.[15]

We now analyze what makes this belt-tightening strategy feasible. We have the following Lemma.

Lemma 1: Let the poor set the consumption plan: $c_{at}^{(1)} = \omega$. *For sufficiently large values of* $h_0^{(1)}$ *and/or z, or for a sufficiently small* h_{min}, *such a belt tightening strategy is feasible.*

Proof: For $c_{at}^{(1)} = \omega$, the time path of the human capital of the poor is given by the following difference equation:

$$(24) \qquad h_{at+1}^{(1)} = zh_{at}^{(1)^{\alpha}} + (1-\delta)h_{at}^{(1)} - \omega .$$

[15] This will be made clear in Lemma 2.

Figure 1 plots the phase diagram for (24). There are three steady-states at 0, $\bar{h}$, and $\tilde{h}$. If $h_0^{(1)} > \bar{h}$ and $h_{\min} < \tilde{h}$, the poor can become entrepreneurs[16]. Q.E.D.

We hereafter assume that the feasibility conditions set forth in Lemma 1 for the poor to become entrepreneurs hold. We next pose the question: given that the belt-tightening strategy is feasible, is it optimal for the poor to follow such a strategy? We answer this question in two steps. First, we determine the value function of the poor if they do not become entrepreneurs (V_{NE}). Next, we determine the corresponding value function if they do become entrepreneurs by following a belt-tightening strategy (V_E). Comparing V_{NE} with V_E, we determine an optimal belt tightening time for the poor to transform themselves.

The following lemma characterizes V_{NE}.

Lemma 2: The life-time utility of the poor for not being entrepreneurs (V_{NE}) is given by:

(25) $$V_{NE} = \frac{1}{1-\beta}[z h_a^{(1)*\alpha} - \delta h_a^{(1)*}], \text{ where } h_a^{(1)*} = \left[\frac{\alpha\beta z}{1-\beta(1-\delta)}\right]^{1/(1-\alpha)}.$$

Proof: If they cannot be entrepreneurs, the poor have two options:

(a) work for the rich in their backyard to produce food and acquire the human capital $\tilde{h}_a^{(2)}$ that satisfies (20);

(b) work in their own backyard and undertake an investment which maximizes (4) subject to (8).

Since the latter strategy maximizes their lifetime utility, (b) dominates (a). The first order condition for (b) is, therefore:

(26) $$1 = \beta[\alpha z {h_a^{(1)}}_{t+1}^{\alpha-1} + 1 - \delta].$$

In this case, the poor instantaneously reach a constant human capital $h_a^{(1)*} = \left[\frac{\alpha\beta z}{1-\beta(1-\delta)}\right]^{1/(1-\alpha)}$, which is the solution to (26).[17] This $h_a^{(1)*}$ does not make the poor entrepreneurs because of Assumption 3.

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[16] We assume that $h_0^{(1)} > \bar{h}$. Otherwise, the poor would reach the 0 steady-state (see Figure 1), violating Equation (3).

Using the budget constraint (8), it is easy to verify that the optimal consumption of the poor is: $zh_a^{(1)*\alpha} - \delta h_a^{(1)*}$, which upon substitution into the utility function (4) yields the value function (25). Q.E.D.

We are now ready to state a proposition for the optimal belt-tightening rule for the poor:

Proposition 3: There exists a date T until which it is optimal for the poor to follow the belt-tightening strategy.*

Proof: If the poor follow such a strategy, a time *T* comes when their offspring attain the human capital h_{min} necessary for them to become entrepreneurs. Until date *T*, the poor just consume the subsistence level ω. Beyond *T,* they consume the saturation level $\bar{a}$ of food and make a transition to the growing manufacturing sector. The value function associated with such a belt-tightening strategy which makes the poor entrepreneurs at date *T* is given by[18]:

(27) $$V_E = \left[\frac{1-\beta^T}{1-\beta}\right]\omega + \sum_{s=T}^{\infty} \beta^s [\bar{a} + \ln c_{ms}^{(2)}]$$

From date *T* onwards, the manufacturing consumption grows at the rate βB, as per (17). Using (17), (27) can be rewritten as:

(28) $$V_E = \frac{1}{1-\beta}.\omega + \frac{\beta^T}{1-\beta}\left\{[\bar{a} - \omega] + [\ln c_{mT}^{(2)} + \frac{\beta}{(1-\beta)}\ln \beta B]\right\},$$

where, using the budget constraint (16) and the decision rule (22), the manufacturing consumption $c_{mT}^{(2)}$ is given by:

(29) $$c_{mT}^{(2)} = (A + 1 - \delta)h_{\min} - \tilde{h}_a^{(2)} - [h_{\min} - \tilde{h}_a^{(2)}](\beta B).$$

It is straightforward to verify that V_E is monotonically decreasing in *T*.

On the basis of Lemma 2, we observe that the poor will follow the belt-tightening strategy if $V_E \geq V_{NE}$. Since V_E is monotonically decreasing in *T*, and V_{NE} is independent of *T*, there exists a *T**, at which $V_E = V_{NE}$. It is therefore optimal for the poor to belt-tighten until *T**. Q.E.D.

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[17] To ensure an interior solution, we that assume $\bar{a} > zh_a^{(1)*\alpha} - \delta h_a^{(1)*}$.

[18] Because after time *T* the poor become entrepreneurs, the c_m term in equation (34) has a superscript (2).

Figure 2 characterizes T^* as the point where the downward sloping V_E schedule intersects V_{NE}. If T exceeds T^*, the belt-tightening strategy is no longer optimal for the poor.

4. Quantitative analysis

In this section we report some quantitative implications of the model and discuss how they match the data. Our purpose in this exercise is to gain some insights about the evolution of the distribution of human capital and the path of industrialization of a representative country based on empirically plausible model parameter values.

We set the parameters A, β, and δ in such a way that a world average annual growth rate of 3.76% is reproduced (as in our sample of countries)[19]. We then calibrate the initial distribution $\frac{h_{\min}}{h_0^{(1)}}$ as follows. Based on our dataset, 12% of the world population had secondary education in the period 1960-65: we therefore set ϕ, the initial proportion of poor in the population, at 0.88. In the next step, using the formula for the Gini coefficient derived in Appendix 4, we figure out that $\frac{h_{\min}}{h_0^{(1)}}$ is equal to 11. We then choose a value of $h_0^{(1)}$ equal to 0.4 with the objective to replicate the actual time path of the Gini coefficient in Table 1, and to ensure that the restrictions set forth in Assumption 1 are not violated.

The other parameter values are fixed as follows: $\alpha = 0.3$, ω =0.01 and $\bar{a}$ =0.1, These parameter values are chosen so that the simulated human capital stocks do not become negative, and Assumptions 1 through 4 are not violated. We calculate the long run Gini coefficient, and the time to industrialize (i.e. T, which is the time at which the poor acquire h_{min}) for various values of z around 0.10[20]. This is accomplished by simulating the time path of the human capital of the poor using equation (24).[21] As soon as the poor acquire h_{min}, a regime change occurs and from that time onwards the time path of capital is computed by using (22).

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[19] More specifically, we set A=0.1; β=0.95; and δ=0.08.

[20] This range of values of z is chosen with the objective to replicate the cross-country average Gini coefficient for our sample.

[21] We also make sure that $h_0^{(1)}$ and h_{min} satisfy the restrictions set forth in Assumptions 1 through 4.

The results are summarized in Table 4[22], which reports the long run (i.e. terminal) Gini coefficient and the time to industrialize for the poor (i.e. *T*). Both time to industrialize and inequality are lower for economies with higher agricultural productivity, *z*, and very sensitive to the *z* values. For instance, a change in *z* from 0.09 to 0.12 makes the Gini coefficient drop from 0.32 to 0.19, and the time to industrialize decrease from 48 to 33 years. Countries with higher agricultural productivity industrialize therefore faster and have lower inequality. This is consistent with the negative cross-country correlations between agricultural productivity and the terminal Gini coefficient, and between agricultural productivity and the share of agriculture shown in Table 3.[23]

Table 5 repeats the same computational experiment when h_{min} is higher. A higher h_{min} means a higher initial inequality (see Assumption 2). We can see that both the long run Gini coefficient and the time to industrialize are higher when the initial distribution of human capital is less favorable to the poor. Furthermore, as in Table 4, both time to industrialize and inequality are lower for economies with higher agricultural productivity. These findings suggest that countries with a higher initial inequality end up having a higher long run inequality: inequality is therefore a persistent process and the persistence is higher for low agricultural productive countries, as shown in Tables 2 and 3.

Figure 3 plots the transitional paths of the Gini coefficient for z=0.1 and h_{min}=11. Staring from 0.41, there is a sharp decline in the Gini coefficient to a level around 0.22 during a fifty year course of industrialization. This decline in inequality over time is consistent with the stylized facts reported in Table 1.[24]

The overall picture that emerges from the quantitative analysis of the model agrees with the data. Countries generally show a decrease in inequality. However,

[22] The issue arises whether it is always optimal for the poor to belt-tighten for these calibrated range of parameters. To answer this question, we have also calculated the optimal belt-tightening period T^* as shown in Figure 2. We found that T^* is always higher than the time to industrialize (*T*) reported in Tables 4 and 5. This means that the belt-tightening strategy is indeed optimal for the poor.

[23] This relationship between agricultural productivity and industrialization is also very consistent with Gollin et. al. (2002) and Hansen and Prescott (1999).

[24] During the intermediate phase (from year 25 onward), we observe a slight increase in the Gini coefficient until it stabilizes at its long run level. This can be explained as follows. Due to diminishing returns to agriculture, initially, the poor grow significantly faster than the rich and that is why the Gini coefficient shows a decline over time. As the knowledge gap between the rich and poor narrows, the poor grow at a slower rate, and this explains why the Gini coefficient shows a slight increase as the time to industrialize approaches. This slight reversal in the Gini coefficient is also consistent with the data: countries with low initial inequality generally show a very small increase in inequality over time. We do not report these results for brevity.

countries setting off with a higher initial inequality experience a higher long run inequality, and take longer to industrialize. In addition, for countries with low agricultural productivity, this phenomenon of higher long run inequality and slower pace of industrialization becomes more pronounced. A combination of initial inequality and low productivity of agriculture thus explains why some countries industrialize late and why their within-country inequality persists in the long run.

5. Conclusion

This paper has attempted to analyze the relationship between industrialization and within country inequality. In addition to agricultural productivity, we have highlighted the role of the initial distribution of human capital as a critical determinant of the time path of industrialization of a country and of the resulting evolution of within country inequality. Countries starting off the process of industrialization with an uneven distribution of human capital, and low agricultural productivity industrialize late. However, in those countries, the poor grow rapidly because they find it optimal to tighten their belts in order to augment their human capital and become entrepreneurs in the future. In the process, the knowledge inequality declines. However, despite this reduction in inequality, the latter continues to persist in the long run because of initial conditions. Such a persistent knowledge inequality can be seen as a consequence of failing credit markets. A public policy implication is that in the presence of such market failures, the government may provide corrective educational subsidies to the poor to narrow the knowledge gap.

Appendix 1: List of countries used in Section 2

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, Islamic Rep.
38. Ireland
39. Israel
40. Italy
41. Jamaica
42. Japan
43. Jordan
44. Kenya
45. Korea, Rep.
46. Kuwait
47. Lesotho
48. Malawi
49. Malaysia
50. Mali
51. Mauritius
52. Mexico
53. Mozambique
54. Nepal
55. 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. Syrian Arab Republic
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: Credit markets

We outline here a simple model of imperfect credit markets, which deter the poor from obtaining finance. The model draws on Galore and Zeira (1993). International creditors are unable to distinguish between bad and good borrowers, and therefore, incur a fixed monitoring cost M. Let r_b denote the borrowing rate for the poor who borrow b, and r^* denote the world interest rate. The zero profit condition of the creditors implies:

(A.1) $r_b b = r^* b + M$.

If the borrower runs away with the loan, the cost of evasion is κM (where κ>1), which is proportional to the monitoring cost. Banks set the borrowing level and the borrowing rate in such a way that this evasion is not incentive compatible, which yields:

(A.2) $b(1+r_b) = \kappa M$.

Using (A.1) and (A.2), one can easily determine the borrowing rate and the optimal loan size as follows:

(A.3) $r_b = \dfrac{(1+\kappa r^*)}{\kappa - 1} > r^*$,

(A.4) $b^* = \dfrac{(\kappa - 1)M}{1+r^*}$.

In other words, the borrowing rate exceeds the world interest rate, r^*. As κ approaches infinity, the borrowing rate approaches r^* and the loan size approaches infinity.

To become an entrepreneur, one needs the basic skill h_{min}. Let the schooling cost necessary to attain this basic skill be $\lambda.h_{min}$, where λ>1. If $b^* < \lambda.h_{min}$, borrowers do not obtain financing. We assume that our model is characterized by such a scenario of imperfect credit markets.

Appendix 3: Derivation of Equation (19)

The solution of Equation (18) consists of two parts: the solution for the non-homogenous part (particular integral); and the solution for the homogenous part (complementary solution).

We initially conjecture a solution:

(A.5) $h_t^{(2)} = Q$ for all t .

We then plug (A.5) into (18) and solve for Q to obtain

(A.6) $Q = \dfrac{\bar{M}}{B-1}$,

which solves the particular integral part.

The homogenous part of (19) is given by:

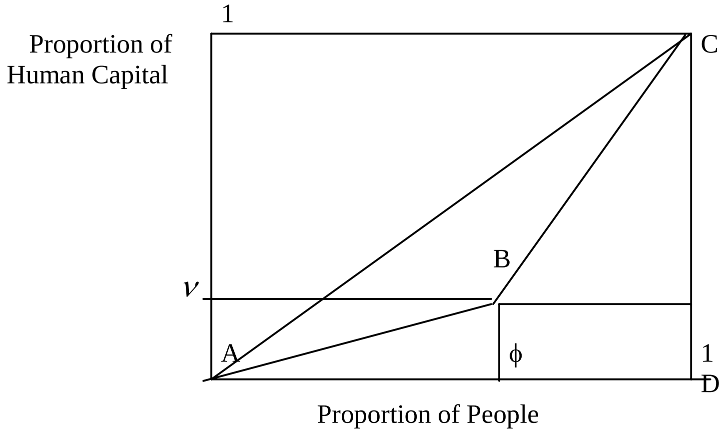
(A.7) $h_{t+2}^{(2)} - B(1+\beta)h_{t+1}^{(2)} + \beta B^2 h_t^{(2)} = 0$.

The two characteristic roots of (A.7) are given by:

(A.8) $$\lambda_1, \lambda_2 = \frac{B(1+\beta) \pm \sqrt{B^2\{(1+\beta)^2 - 4\beta\}}}{2} = B, \beta B.$$

The general solution, which is the sum of the solutions for the non-homogenous and homogenous parts, is thus given by (19). Q.E.D.

Appendix 4: Derivation of the Gini coefficient



In the diagram above, the Gini coefficient, also known as the Lorenz ratio, is given by the area ABC/ACD. It is straightforward to verify that the Lorenz ratio is ϕ-v, where

(A.9) $$v = \frac{\phi h_0^{(1)}}{\phi h_0^{(1)} + (1-\phi) h_0^{(2)}}.$$

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Table 1: Time paths of knowledge inequality and the share of agriculture

Year	1960-65	1965-70	1970-75	1976-80	1981-85	1986-90	1991-95	1996-99
Average human capital Gini coefficient	0.48	0.48	0.46	0.46	0.43	0.41	0.39	0.36
Average share of agriculture	0.32	0.27	0.25	0.23	0.20	0.19	0.18	0.17

Note: The human capital Gini coefficient represents the human capital inequality in the population aged 15 and over. The average share of agriculture represents the share of the value added coming from agriculture to GDP, and is taken from the World Bank Development Indicators (2002).

Table 2: Persistence of inequality

Dep. Var.: *Gini15*	*First-diff. GMM*
$Gini15_{i(t-1)}$	0.85 (0.07)
$Gini15_{i(t-1)}*LOWAGRPROD_i$	0.13 (0.06)
Sargan (p-value)	0.12
m2	-0.61
Observations	419
Countries	81

Notes: Gini15 represents the human capital Gini coefficient in the population aged 15 and over. $LOWAGRPROD_i$ is a dummy variable equal to one for those countries with average agricultural productivity in the bottom quartile of the distribution. Time dummies were included in all the specifications. Standard errors are reported in parentheses. Standard errors and test statistics are asymptotically robust to heteroskedasticity. All left-hand side variables were instrumented using two and three lags of those same variables together with time dummies. The Sargan statistic is a test of the overidentifying restrictions, distributed as chi-square under the null of instrument validity. *m2* is a test for second-order serial correlation in the first-differenced residuals, asymptotically distributed as N(0,1) under the null of no serial correlation.

Table 3: Cross-country correlations between inequality, agricultural productivity and the rate of industrialization

	Share of agriculture in GDP	Agricultural productivity	Initial human capital Gini coefficient	Terminal human capital Gini coefficient
Share of agriculture in GDP	1.00			
Agricultural productivity	-0.583	1.00		
Initial human capital Gini coefficient	0.654	-0.626	1.00	
Terminal human capital Gini coefficient	0.761	-0.539	0.883	1.00

Note: The human capital Gini coefficient represents the human capital inequality in the population aged 15 and over. 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).

Table 4: Agricultural productivity, inequality, and time to industrialize when $h_{\min} / h_0^{(1)}$ = 11

z	0.09	0.10	0.11	0.12
Gini coefficient	0.32	0.26	0.23	0.19
Time to industrialize (*T*)	48	42	37	33

Source: authors' calculations.

Table 5: Agricultural productivity, inequality, and time to industrialize when $h_{\min} / h_0^{(1)}$ = 13

z	0.09	0.10	0.11	0.12
Gini coefficient	0.39	0.33	0.27	0.24
Time to industrialize (*T*)	56	49	43	39

Source: authors' calculations.

Figure 1: Time path of human capital for the poor if they just consume the subsistence level

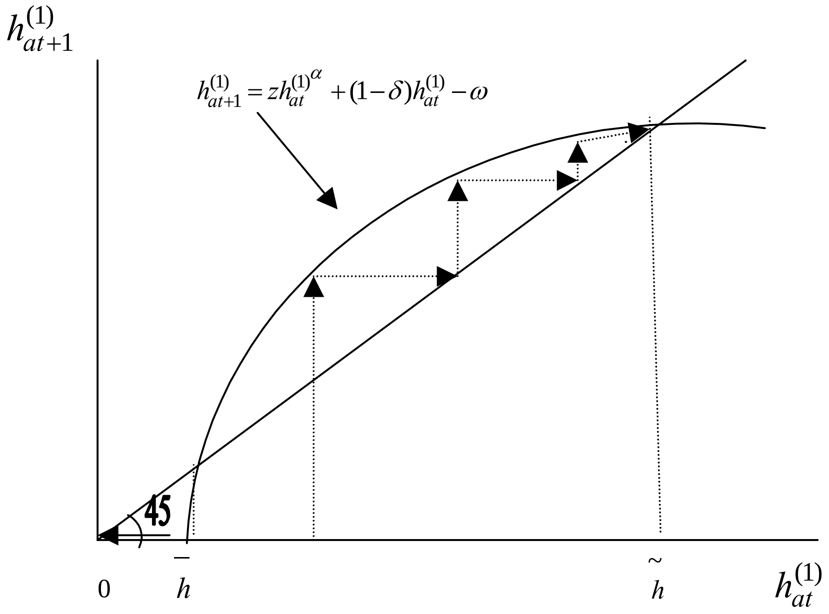


Figure 2: The optimal time to become entrepreneurs

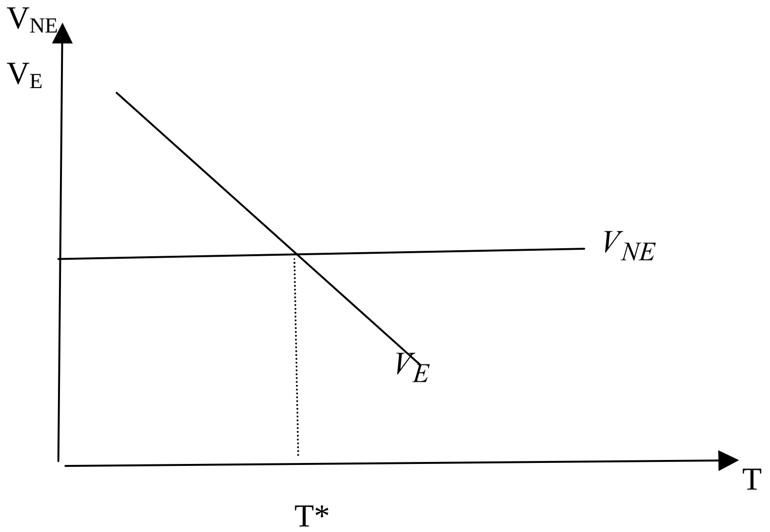
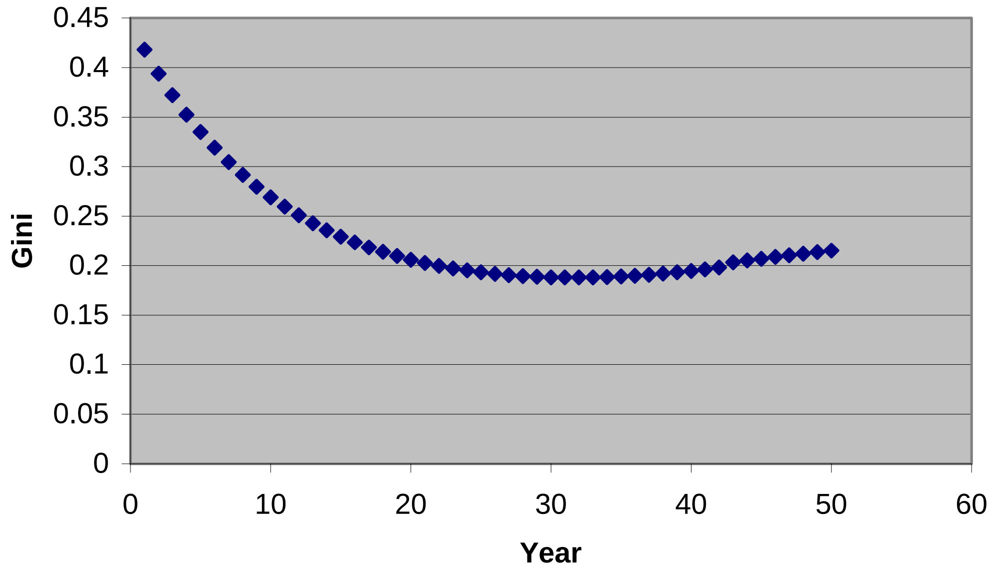


Figure 3: Time plot of the Gini coefficient



ABOUT THE CDMA

The **Centre for Dynamic Macroeconomic Analysis** was established by a direct grant from the University of St Andrews in 2003. The Centre funds PhD students and a programme of research centred on macroeconomic theory and policy. Specifically, the Centre is interested in the broad area of dynamic macroeconomics but has a particular interest in a number of specific areas such as: characterising the key stylised facts of the business cycle; constructing theoretical models that can match these actual business cycles; using these models to understand the normative and positive aspects of the macroeconomic policymakers' stabilisation problem; the problem of financial constraints and their impact on short and long run economic outcomes. The Centre is also interested in developing numerical tools for analysing quantitative general equilibrium macroeconomic models (such as developing efficient algorithms for handling large sparse matrices). Its affiliated members are Faculty members at St Andrews and elsewhere with interests in the broad area of dynamic macroeconomics. Its international Advisory Board comprises a group of leading macroeconomists and, ex officio, the University's Principal.

The CDMA Inaugural Conference 2004

The Inaugural CDMA Conference was held in St. Andrews on the 17th and 18th of September 2004. The list of delegates attending, and the group photo, can be found here.

Papers presented at the conference, in order of presentation:

Title	Author(s) (presenter in bold)
A Critique of rule-of-thumb/indexing Microfoundations for inflation persistence	**Richard Mash (Oxford)**
Fiscal and Monetary Policy Interactios in a New Keynesian Model with Liquidity Constraints	**V. Anton Muscatelli (Glasgow)**, Patrizio Tirelli (Milano-Bicocca) and Carmine Trecroci (Brescia)
Inflation Persistence as Regime Change in a Classical Macro Model	**Patrick Minford (Cardiff and CEPR)**, Eric Nowell (Liverpool), Prakriti Sofat (Cardiff) and Naveen Srinivasan (Cardiff)
Habit Formation and Interest Rate Smoothing	**Luisa Corrado (Rome 'Tor Vergata')** and Sean Holly (Cambridge)
A Model of Job and Worker Flow	**Nobuhiro Kiyotaki (LSE)** and Richard Lagos (FRB of Minneapolis and New York)
The Specification of Monetary Policy Inertia in Empirical Taylor Rules	**John Driffill (Birkbeck, London)** and Zeno Rotondi (Ferrera and Capitalia)
Inequality and Industrialization	**Parantap Basu (Durham)** and Alessandra Guariglia (Nottingham)
Public Expenditures, Bureaucratic Corruption and Economic Development	**Keith Blackburn (Manchester)**, Niloy Bose (Wisconsin) and M. Emanrul Haque (Nottingham)
On the Consumption-Real Exchange Rate Anomaly	Gianluca Benigno (LSE and CEPR) and **Christoph Thoenissen (St Andrews)**
The Issue of Persistence in DGE Models with Heterogeneous Taylor Contracts	**Huw Dixon (York)** and Engin Kara (York
Performance of Inflation Targeting Based on Constant Interest Rate Projections	**Seppo Honkapohja (Cambridge)** and Kaushik Mitra (Royal Holloway, London)

See also the CDMA Working Paper series.