Universities and growth: a model of human capital accumulation

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Universities and growth: a model of human capital accumulation

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Abstract

Introduction: Universities are a purely Western phenomenon. Their role in the systematization of knowledge has been central. They favoured UTHC[1] accumulation through the creation of a knowledgeable élite, who is suspected to have contributed to the outbreak of the so-called Great Divergence between the East and the West of the world. However, the Industrial Revolution originated as a geographically limited event and only thereafter its spillovers spread all over the world.

Research question: This research work aims to build a theory to read the interplay between UTHC and long-run economic growth. On top of this, the model serves as a way to assess the specific cross-country differences in pre-industrial times. Besides, it aims to shed light on the reasons that pushed some specific regions in Europe to become epicentres of the Industrial Revolutions.

Methodology: The model is composed of two overlapping generations. Agents must make an occupational choice between two sectors: the academic and the non-academic one. Depending on the sector they choose, agents undergo different human capital transmission mechanisms. Academic workers affect production using two channels. On the one hand, through their human capital supply and on the other through an externality on TFP. A quantitative implementation of the model is also included. To do it, I use country-level data for Italy, Spain, England (then Great Britain), France and the Netherlands, thereby adopting an intra-European comparative perspective.

Results: The theory is able to account for several fundamental features of both continental Europe (Italy, Spain, France and the Netherlands) and the UK. However, the model can only partially describe the turning point of the Industrial Revolution for the British economy.

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[1] Upper-tail human capital

Contents

1 Introduction

Universities are a purely Western phenomenon. We observe no such institutions in the country blocks that usually serve as a term of comparison for Europe, like India and China. As early as in the Middle Ages, an élite of scholars, most of whom was teaching in universities, started developing, thereby giving rise to what Mokyr (2007) calls the *market of ideas*. The continuous exchanges of this élite may have set the foundations for the outbreak of the so-called Great Divergence. Starting from the second half of the 18th century, the Great Divergence set the West apart from the rest of the world via massive increases in GDP, living standards and technological level. According to this view, which has been particularly emphasized by Joel Mokyr (e.g. Mokyr (2017)), the motive that led the West to be the stage of several Industrial Revolutions stems from knowledge. Indeed, Mokyr (2005b) stresses the importance of useful knowledge in generating economic growth as well as its interactions with technology. That of Mokyr is a particularly elitist and oligarchic narrative, in that he argues that it was not the diligence of the average individual who favoured the Western primacy. It was instead the dexterity of few knowledgeable and wise men whose interactions served as a necessary (perhaps not sufficient) condition for the Industrial Revolutions.

At the opposite, one may criticize Mokyr's argument by saying that this was not actually the case. In particular, that it was human capital as a whole, both lower and upper-tail, the cause of the Great Divergence. The literature has extensively tried to challenge this interpretation. Nonetheless, Romer (1989) finds that the growth in literacy rates exerts negligible effects on economic growth. Focusing on the Early Modern period, Allen (2003) reaches similar conclusions, saying that its contribution to growth was insignificant. Likewise, Squicciarini and Voigtländer (2015), in a study focusing on France, tried to disentangle lower and upper-tail human capital contribution to economic growth. They find that literacy rates were not associated with growth during the industrialization, even though they were correlated with the level of development. Cinnirella and Streb (2017) and Dittmar and Meisenzahl (2019) use data from ancient Prussia to enquire on the development of German cities. They reach similar conclusions as Squicciarini and Voigtländer (2015). The literature has therefore downplayed the importance of literacy rates and of mass education on economic growth. Scholars have attempted to explain the phenomenon by weighting more the role of UTHC. In this respect, universities enter the picture. In the beginning, universities originated as corporations of masters and students arising almost exclusively in a bottom-up fashion, even though there are few exceptions. Mokyr (2005a), Mokyr (2005b) and Mokyr (2017) argue on the central role of UTHC on the growth experienced in the aftermath of the Industrial Revolutions. Similarly, Carlsson et al. (2009) shed light on the role of the first engineering schools born in the 18th and 19th centuries. Their main contribution consisted in codifying the knowledge that had remained up to that moment a matter of apprenticeship and it was thus transmitted orally. Polytechnic universities brought together and codified practical knowledge by bringing scientific rigour and method in the industrial process, as remarked by Drucker (1998).

The unimportance of literacy rates in explaining the rise of the West is one of the reasons that explains the success of Mokyr's research (see Mokyr (2002)). Even though the first university was founded in Bologna in 1088

CE (see De la Croix and Vitale (2021)) and after that the phenomenon caught on, the Industrial Revolution mainly originated in Great Britain. Since long, the literature has tried to explain the reason for which Great Britain was the first country to experience an economic reorganization from the rural[2] scheme to the industrial one. Voigtländer and Voth (2006) adopt a probabilistic setting to estimate the odds of engaging in a wave of industrialization for some European and non-European regions. They find that fertility limitation in Great Britain massively contributed to increase the aforementioned probability. Instead, China had only minimal chances to set off a wave of industrialization. Besides, in the attempt to explain Britain's industrial advantage, it is worth reminding that, in the period preceding the Industrial Revolutions, the guild in Great Britain was already quite weak (Mokyr (2005a)). Indeed, some institutions of human capital transmission were judged by the literature to serve as a main brake to development. This point was made by several studies that adopt a comparative perspective in trying to explain the Great Divergence, e.g. Greif and Tabellini (2010) and Greif and Tabellini (2017). De la Croix, Doepke, and Mokyr (2018) develop a theoretical framework to explain the effect of different institutions of knowledge transmission on growth. They argue that better institutions, like the market, outperform the clan and the guild in terms of growth-creation capacity in a Malthusian setting.

Another well-established common wisdom shared by most scholars in the field is that the West started its socio-economic take-off with the Industrial Revolutions. However, some works have urged a revision of the concept of Industrial Revolution, thereby stressing the graduality of the process (see the discussion made by Voigtländer and Voth (2006) and Mokyr (2005b)). GDP per capita estimates by Fouquet and Broadberry (2015) show that Britain started growing, though at a very low pace, well before 1750 CE. Recently, Bouscasse, Nakamura, and Steinsson (2023) have argued that TFP in Great Britain started growing in 1600 CE. These findings should urge to think of the so-called Industrial Revolution as an inherently endogenous phenomenon that enabled the departure from the Malthusian trap, as in the tradition of models headed by Galor and Weil (2000) and Galor and Moav (2002).

Building on the aforementioned gradualist argument, I construct an overlapping generations model with endogenous growth. Its aim is to theorize the intricated relation between UTHC and growth. I want to theoretically and quantitatively challenge Mokyr's arguments concerning the effect of UTHC on long-term growth. Knowledge is mainly conceived as a cumulative phenomenon, as in most frameworks of this kind, even though Mokyr (2005a) highlights its not entirely cumulative nature. In fact, knowledge may be lost. According to the literature, the dynamic properties of the model and hence the long-run equilibrium are mainly determined by the upper-tail of the human capital distribution. Instead, the average individual is relatively unimportant. I then calibrate the model in order to match some target moments of 5 European countries, thereby adopting an intra-European comparative perspective. In my model, not only is knowledge transmitted across different generations, but also among members of the same generation. This will turn out to be a crucial assumption, which most works do not consider. On top of sharpening the debate around Mokyr's interpretation, my work also tests whether the UTHC argument can explain the different economic performances of these countries relative to Great Britain.

[2]Pre-industrial and malthusian

2 Theory

Setup

Consider an overlapping generations framework with two generations: *i*) the young and *ii*) the old. Heterogeneity is given by differences in the human capital endowment. Population is normalized to 1 and constant over time. Time is discrete. When young, individuals accrue human capital, whereas when adult they inelastically supply it, get a remuneration and spend it. Also, when adult individuals procreate. Their children, will be uniformly distributed over the support $[0, \bar{h}_t]$, $\forall t \geq 0$.

$$h_t \sim U(0, \bar{h}_t), \text{ when young} \tag{1}$$

For $\bar{h}_t > 0$. $\bar{h}_t$ represents the human capital level of the most knowledgeable adult in society.

There are two sectors: the academic and the non-academic sector. The former is composed of a representative university, characterized by the presence of several masters working for it. The university is an institution and, as it grows, i.e. as it employs more masters, it becomes more formal, with standardized procedures and practices. On the other hand, there is a non-academic sector, in which human capital is transmitted via apprenticeship. The main decision of the young concerns which sector to join. If the young chooses to join the non-academic sector, it means she will be educated as an apprentice and, once grown older, she will keep working in the non-academic sector. Otherwise, she will be educated as an academic and she will keep working in academia as a master. The choice of the sector, which is made by the young, is determined by the discounted utilities that they would get as adults by joining each sector. We will end up with the lower tail of the human capital distribution, $[0, \hat{h}_t]$, working for the non-academic sector and the upper tail, $[\hat{h}_t, \bar{h}_t]$, working for academia (see the occupational choice section). Each sector has different human capital transmission capacity.

The rest of the chapter is organized as follows. In the following section, I illustrate how the human capital transmission works, which is a necessary condition to understand the occupational choice of the young, presented later. Then, I elucidate the evolution of the distributions and consequently I introduce production and conclude giving the definition of inter-temporal equilibrium.

Human capital transmission

In De la Croix, Doepke, and Mokyr (2018) and Blasutto and De la Croix (2023), the young learn exclusively from the old and new ideas spring up exogenously. My attempt, instead, consists of trying to isolate two different channels of knowledge transmission: *i*) the intra-generational transmission and *ii*) the inter-generational transmission. In each sector, only the first channel operates. Indeed, the university is conceived as a collective body, where students only learn from their peers. Similarly, apprenticeship is conceived as an institution that enables apprentices to gather and learn from each other. The second channel is only visible in procreation. As underlined at the start of our discussion, new generations will be uniformly distributed over their parent's support. This implies two main facts. On the one hand, human capital level at birth is purely random and there are no frictions that push children coming from a wealthier background to prefer the academic sector rather than the non-academic one. On the other hand, new generations inherit their parent's support. It follows that if the economy does well so that the maximum knowledge level, $\bar{h}_t$, increases, then the next generation will enjoy the same $\bar{h}_t$.

If the individual joins the non-academic sector and is educated through apprenticeship, her human capital will evolve according to:

$$h_{t+1}^{NA} = \mathbb{E}_t[h_t | h_t \in [0, \hat{h}_t]]\epsilon \tag{2}$$

For $\epsilon \sim U(0, \bar{\epsilon})$, where $\bar{\epsilon} > 0$. $\hat{h}_t \in [0, \bar{h}_t]$ is the marginal individual, who is indifferent between the two sectors (see the occupational choice section). It follows that after training via apprenticeship, the apprentice will have their human capital equal to that of the average (young) individual in the non-academic sector rescaled by a random component. Given that, when young, individuals are uniformly distributed, as expressed by eq. (1), one can say:

$$h_{t+1}^{NA} = \frac{\hat{h}_t}{2}\epsilon \tag{3}$$

The human capital of those who attend university, instead, evolves according to the following law of motion:

$$h_{t+1} = \mathbb{E}_t[h_t | h_t \in [\hat{h}_t, \bar{h}_t]]\epsilon \tag{4}$$

After attending university, the student will inherit the human capital level of her average peer rescaled by the same random component ϵ. For the same token, we can write:

$$h_{t+1}^{A} = \frac{\bar{h}_t + \hat{h}_t}{2}\epsilon \tag{5}$$

From eq. (3), it follows that an apprentice can reach at most:

$$\frac{\hat{h}_t}{2}\bar{\epsilon} \tag{6}$$

Instead, an academic will be allowed to attain at most:

$$\bar{h}_{t+1} = \frac{\bar{h}_t + \hat{h}_t}{2}\bar{\epsilon} \tag{7}$$

It should be noted that eq. (6) is systematically smaller than eq. (7).

$$\frac{\bar{h}_t + \hat{h}_t}{2}\bar{\epsilon} = \frac{\bar{h}_t\bar{\epsilon}}{2} + \frac{\hat{h}_t\bar{\epsilon}}{2} > \frac{\hat{h}_t\bar{\epsilon}}{2} \tag{8}$$

Indeed, as we remarked above $\bar{\epsilon}, \bar{h}_t > 0$. Consequently, the wisest adult in the following period will necessarily be an academic. In fact, $\bar{h}_{t+1}$, which is the largest attainable human capital level at $t+1$, cannot be reached by an apprentice. It must be highlighted that, in principle, the mechanism of human capital transmission is the same in each sector. However, there is a positive selection effect. Since the university attracts the upper-tail of the human capital distribution, its enhancement capacity is also greater with respect to the non-academic sector. This is what makes the two sectors different.

Occupational choice

We formerly said that during adulthood individuals inelastically supply human capital. They get a remuneration, which can only be spent on consumption goods. Therefore, when choosing which sector to join, preferences of the young will account for expected future consumption possibilities. If they choose to attend university, utilities will be impaired by the presence of many colleagues. This is to account for the fact that, as the university grows, it will also become more formal. This will impose stricter incentives and higher peer control on masters, which will make their utility decrease. At the margin, this effect impacts on the utility as a proportion of the wage in the following period. This fact is visible even today. Bigger universities tend to deploy more rigid administrative procedures, research incentives and academic requirements, which make them less attractive for certain types of individuals. There is no such effect in the non-academic sector. Thus, those who are young at time t foresee the following utilities:

$$\begin{cases} U_t^A = \beta \mathbb{E}_t[c_{t+1} - b w_{t+1} m_{t+1}] \\ U_t^{NA} = \beta \mathbb{E}_t[c_{t+1}] \end{cases} \tag{9}$$

$$\text{s.t. } c_{t+1} = w_{t+1} h_{t+1} \tag{10a}$$

$$m_{t+1} = \frac{\hat{h}_t - \bar{h}_t}{\bar{h}_t} \tag{10b}$$

These are forecasted utilities, so they are discounted using the discount factor $\beta \in [0, 1]$. Also, let $b > 0$ and m_{t+1} be the number of masters who will work at $t + 1$. The first constraint represents the fact that adults can spend their remuneration only on consumption goods. In defining m_{t+1}, we exploit the fact that the young are uniformly distributed (see eq. (1)). We need not make any assumption about the way expectations on w_{t+1} are formed. So long as agents have some finite expectations (whether they be perfect, myopic or, in general, absurd), w_{t+1} can be brought out of the expectation operator and then erased. For a moment, assume perfect foresight, so that expectations on future salary are on average correct. Final results would coincide with those obtained under purely random salary expectations. After making the appropriate substitutions, the problem reads as:

$$\begin{cases} U_t^A = \beta[w_{t+1} \frac{\hat{h}_t + \bar{h}_t}{2} \mathbb{E}_t[\epsilon] - b w_{t+1} \frac{\bar{h}_t - \hat{h}_t}{\bar{h}_t}] \\ U_t^{NA} = \beta[w_{t+1} \frac{\hat{h}_t}{2} \mathbb{E}_t[\epsilon]] \end{cases} \tag{11}$$

To define how many people will join each sector we wish to find $\hat{h}_t$, as in a standard Hotelling framework. This person is indifferent between joining university or go for apprenticeship. Indeed, it comes as the result of $U^{NA} = U^A$. It follows that all agents having $h_t > \hat{h}_t$ will join the academic sector, otherwise they will go for the non-academic sector. Such problem yields as a solution:

$$\hat{h}_t = \frac{\bar{h}_t(2b - \bar{h}_t \mathbb{E}_t[\epsilon])}{2b} = \frac{\bar{h}_t(2b - \bar{h}_t \frac{\bar{\epsilon}}{2})}{2b} \tag{12}$$

Which implies that:

$$m_{t+1} = \frac{\bar{h}_t \mathbb{E}_t[\epsilon]}{2b} = \frac{\bar{h}_t \frac{\bar{\epsilon}}{2}}{2b} \tag{13}$$

We assume the distribution of ϵ is common knowledge. Note that $\mathbb{E}_t[\epsilon] = \frac{\bar{\epsilon}}{2}$. The higher is $\bar{\epsilon}$, the more people will attend university and work as masters. Conversely, the higher is b, i.e. the coefficient affecting the disutility from university size, the smaller will be m_{t+1}. This is intuitive. As b increases, people belonging to the UTHC will be less inclined to choose the academic sector, even if this implies higher expected future wage. The occupational choice does not depend on expected future salary.

Evolution of the distributions

Since we have two different laws of motion of human capital, each period $t > 0$ will be characterised by the (endogenously determined) distribution of 3 types of individual:

1. The distribution of the adult non-academic workers

2. The distribution of the adult academic workers

3. The distribution of the young

Period $t = 0$, instead, will be only characterised by the (exogenously given) distribution of the young and the number of masters. Indeed, these are necessary initial conditions to define the intertemporal equilibrium (see final section). We begin by the first two categories, outlining how their distributions evolve. Eventually, we will clarify the last one. In light of eq. (3), it can be said that given an initial distribution of young individuals, human capital of non-academic workers will evolve as follows.

$$G_{t+1}^{NA}(h_{t+1}) = Pr(h_{t+1}^{NA} \leq l) = Pr\left(\frac{\hat{h}_t}{2}\epsilon \leq l\right) = Pr\left(\epsilon \leq \frac{4bl}{\bar{h}_t(2b - \bar{h}_t \mathbb{E}_t[\epsilon])}\right) \tag{14}$$

We call $G_{t+1}^{NA}(h_{t+1})$ the c.d.f. of human capital in the non-academic sector. Similarly, in light of eq. (5), it can be written that:

$$G_{t+1}^{A}(h_{t+1}) = Pr(h_{t+1}^{A} \leq l) = Pr\left(\frac{\bar{h}_t + \hat{h}_t}{2}\epsilon \leq l\right) = Pr\left(\epsilon \leq \frac{4bl}{\bar{h}_t(4b - \bar{h}_t \mathbb{E}_t[\epsilon])}\right) \tag{15}$$

Once individuals enter adulthood, they will procreate. Each agent will give birth to one child. After being trained in their respective sector, the adults will be jointly distributed (non-uniformly) over the support $[0, \bar{h}_{t+1}]$. As we remarked at the beginning of our discussion (see eq. (1)), their children's human capital will be an i.i.d. random draw from the following distribution:

$$h_{t+1} \sim U(0, \bar{h}_{t+1}), \text{ when young} \tag{16}$$

We will refer to this last distribution as $G_{t+1}^{Y}(h_{t+1})$. We assume no perfect inheritance of the human capital level from the parents. The draw that children get is independent of their parents' human capital. Hence, it might very well be that, in spite of her parental background, a poor individual ends up attending university and becomes a university professor. As we formerly said, education in this model, whether it take place in the non-academic or in the academic sector, does not allow for intergenerational transmission. However, this way of modelling procreation enables the parental generation, which is non-uniformly distributed over a given support, to bequeath the support to the following generation. Hence, if the good performance of the economy has led to a great increase in the maximum level of knowledge, $\bar{h}_t$, this will serve as a point of departure to future generations. Having clarified this point, the problem can start again and the young generation can decide which sector to join. $\bar{h}_t$ resembles what De la Croix, Doepke, and Mokyr (2018) call k_t. The analysis of the aforementioned k_t and that of $\bar{h}_t$, that follows, are indeed quite similar. Given the solution to the occupational choice problem, i.e. eq. (12), and the analysis summarized by eq. (7) we can derive how $\bar{h}_{t+1}$ evolves over time $\forall t \geq 0$:

$$\bar{h}_{t+1} = \frac{\bar{\epsilon}}{2}\left[\bar{h}_t + \frac{\bar{h}_t}{2b}[2b - \bar{h}_t \mathbb{E}_t[\epsilon]]\right] = \frac{\bar{h}_t \bar{\epsilon}}{2}\left[\frac{4b - \bar{h}_t \frac{\bar{\epsilon}}{2}}{2b}\right] \tag{17}$$

The above represents the evolution of the human capital level of the wisest individual in society. As we previously hinted at, this human capital level can be attained by only joining the academic sector. It may be of interest to determine under which conditions the human capital of the wisest individual grows over time. Using the previous result one can state:

$$\bar{h}_{t+1} \geq \bar{h}_t \iff \bar{h}_t \leq \frac{8b}{\bar{\epsilon}}\left[1 - \frac{1}{\bar{\epsilon}}\right] \tag{18}$$

The above relationship between parameters must hold in order for the support of human capital to grow over time. Similarly, we can conclude the analysis summarized by eq. (6) by claiming that the largest human capital level that an apprentice can attain is:

$$\frac{\hat{h}_t}{2}\bar{\epsilon} = \frac{\bar{h}_t(2b - \bar{h}_t\frac{\bar{\epsilon}}{2})}{4b}\bar{\epsilon} \tag{19}$$

Production

Production takes place in a representative firm that deploys standard Cobb-Douglas technology.

$$Y_t = F(H_t, X) = B_t {H_t}^{\alpha} X^{1-\alpha} \text{ for } \alpha \in [0, 1] \tag{20}$$

Where B_t is a TFP component, H_t is aggregate human capital and X is the economy's land endowment, which we shall normalize to 1, $X = 1$. Even though the standard Cobb-Douglas has constant returns to scale, since now land is in fixed supply, this implies decreasing returns to scale for human capital. This means that if H_t suddenly doubles, Y_t will react with a less than proportional increase. The production function then becomes:

$$Y_t = F(H_t) = B_t {H_t}^{\alpha} \tag{21}$$

Each adult, whether she be an academic or not, inelastically supplies her human capital endowment and gets remunerated. Individuals supply human capital only when adult. It follows that both non-academic and academic workers work for the representative firm, which produces final goods. However, academic workers also give classes at the representative university. Hence, they are part-time workers for both the representative firm and the academic sector. Recalling that $G_t^i(h_t)$ for $i \in \{A, NA\}$ is the distribution of the human capital of the adults in each sector, it can be said that $\forall t \geq 0$ we have that:

$$H_{t+1} = \frac{\hat{h}_t}{\bar{h}_t} \int_0^{\frac{\bar{h}_t(2b - \bar{h}_t \mathbb{E}_t[\epsilon])}{4b}\bar{\epsilon}} h_{t+1} dG_{t+1}^{NA}(h_{t+1}) + \left(1 - \frac{\hat{h}_t}{\bar{h}_t}\right) \int_0^{\bar{h}_{t+1}} h_{t+1} dG_{t+1}^{A}(h_{t+1}) \tag{22}$$

The upper limit of the first integral in the RHS is the result obtained in eq. (19). That in the second integral is equivalent to eq. (17). Therefore, $\forall t > 0$ we have that the adults in each sector supply their human capital level. At the individual level, some masters will probably supply higher levels of human capital. However, the human capital supplied by the academic sector may end up weighing less on Y_t than that of the non-academic sector. This is the case in which the academic sector is small relative to the non-academic sector.

Academic workers, however, can contribute to the production of the final good via an additional channel, i.e. the TFP component. Indeed:

$$B_t = B(1 + \gamma m_t) \text{ for } \gamma \geq 0 \text{ and } B > 0 \tag{23}$$

This means that the higher is the number of masters, the larger will be the aggregate productivity component. γ represents the capability of the upper-tail of the human capital distribution to affect Y_t. In light of Mokyr's arguments, I argue that it would be reasonable to expect γ to be significantly different from 0. Otherwise, if it were equal to 0, the upper-tail would affect production only through their human capital endowment, i.e. through H_t. Therefore, there would be no alternative channel through which the élites could cause an Industrial Revolution, which manifests through a remarkable boom in GDP.

Bearing in mind that we normalize selling price to 1, the representative firm solves the following simple optimization problem, from which we can determine the size of the remuneration.

$$\max_{H_t} \Pi_t = Y_t - w_t H_t \tag{24}$$

It follows that the wage level (expressed in efficiency units) is:

$$w_t = F'_{H_t}(H_t) = \alpha B_t H_t^{\alpha-1} \tag{25}$$

Workers will then be remunerated on the basis of the wage in efficiency units rescaled by the individual human capital endowment. There is only one type of good on which the available remuneration can be spent on consumption goods. This has already been expressed by eq. (10a). The adult's budget constraint therefore reads:

$$w_t h_t = c_t \tag{26}$$

We assume that the young are not able to spend any remuneration whatsoever (since they do not have any) and they are bred by part of their parents' consumption expenditure, on whose size we do not enquire. From this, one can compute aggregate consumption, which at time $t \geq 0$ equals:

$$C_{t+1} = \frac{\hat{h}_t}{\bar{h}_t} \int_0^{\frac{\bar{h}_t(2b-\hat{h}_t\mathbb{E}_t[\epsilon])}{4b}\bar{\epsilon}} c_{t+1} dG_{t+1}^{NA}(h_{t+1}) + \left(1 - \frac{\hat{h}_t}{\bar{h}_t}\right) \int_0^{\bar{h}_{t+1}} c_{t+1} dG_{t+1}^{A}(h_{t+1}) \tag{27}$$

As well as the feasibility constraint of our economy:

$$Y_t = C_t \tag{28}$$

Whereby C_t stands for aggregate consumption. We now have all the elements to define the intertemporal equilibrium.

Definition 1 (Intertemporal equilibrium) *Let human capital of the young generation at period $t = 0$ be uniformly distributed over the support $[0, \bar{h}_0]$, such that $\bar{h}_0$ be the maximum human capital level. Let m_0 be the number of masters at $t = 0$. Given these initial conditions, the intertemporal equilibrium is composed of i) a sequence of prices $\{w_{t+1}\}_{t\geq 0}$, ii) a sequence of individual decision rules $\{c_{t+1}\}_{t\geq 0}$, iii) a sequence of aggregate variables $\{m_{t+1}, Y_{t+1}, B_{t+1}, H_{t+1}, C_{t+1}, X\}_{t\geq 0}$ and iv) a human capital distribution such that:*

- *$\{w_{t+1}\}_{t\geq 0}$ is such that, $\forall t \geq 0$, w_t is determined by eq. (25) so that firms maximize their profits by solving eq. (24) and the human capital market clears;*

- $\{c_{t+1}\}_{t\geq 0}$ *is such that,* $\forall t \geq 0$, c_t *is determined by eq. (27) so that the b.c. is balanced for every individual;*
- m_{t+1} *is determined by eq. (13) and it results from individual preferences in eq. (9);*
- Y_t *represents aggregate production and it is determined by eq. (20),* B_t *represents the TFP component and it is determined by eq. (23),* H_t *represents aggregate human capital and it is determined by eq. (22),* C_t *represents aggregate consumption and it is determined by eq. (28),* X *represents the economy's land endowment and it is* $X = 1$, $\forall t \geq 0$*;*
- *The economy is such that the feasibility constraint of eq. (29) holds* $\forall t \geq 0$*, hence the goods market clears;*
- *The human capital distribution of non-academic workers,* $G_t^{NA}(h_t)$ *evolves according to eq. (14), that of academic workers,* $G_t^A(h_t)$*, evolves according to eq. (15), whereas that of the young,* $G_t^Y(h_t)$*, results from eq. (16).*

3 Dynamic properties

In this chapter, I study the dynamic behaviour of the model. To do so, I use m_t as the main variable. Consider a backward transposition by one period of eq. (17):

$$\bar{h}_t = \frac{\bar{h}_{t-1}\bar{\epsilon}}{2}\left[\frac{4b - \bar{h}_{t-1}\mathbb{E}_{t-1}[\epsilon]}{2b}\right] \tag{29}$$

Also, consider the result of the occupational choice problem represented in eq. (13). Rearranging terms and carrying out a backward transposition we obtain:

$$\bar{h}_{t-1} = \frac{2bm_t}{\mathbb{E}_{t-1}[\epsilon]} \tag{30}$$

We assume the distribution of ϵ is common knowledge in every period, so that $\mathbb{E}_{t+1}[\epsilon] = \mathbb{E}_t[\epsilon] = \frac{\bar{\epsilon}}{2}$, $\forall t \geq 0$. Putting eq. (31) into eq. (30) we get:

$$\bar{h}_t = \frac{\bar{\epsilon}b}{\mathbb{E}_{t-1}[\epsilon]} m_t(2 - m_t) \tag{31}$$

Eventually, putting eq. (32) into eq. (13) we get:

$$m_{t+1} = g(m_t) = \frac{\bar{\epsilon}}{2} m_t(2 - m_t) \tag{32}$$

It follows that the lower bound of the distribution of the r.v. ϵ does not affect the dynamic properties of the model. For the sake of simplicity, we set this lower bound to 0, but one could have set it to a positive value and still the dynamics would remain unchanged. For instance, let the support of ϵ change into $[\underline{\epsilon}, \bar{\epsilon}]$, for $\underline{\epsilon} > 0$. It goes without saying that, both the average and the lowest skilled workers in each sector would change with respect to the case we considered. Nevertheless, the dynamic would remain unchanged. Conversely, if the most knowledgeable individual sees her human capital enhanced, i.e. if $\bar{\epsilon}$ increased, the dynamics would mutate. In this respect, we can say that the dynamics of the model is consistent with the literature[3].

Eq. (33) can be represented as follows.

[3] See the introduction

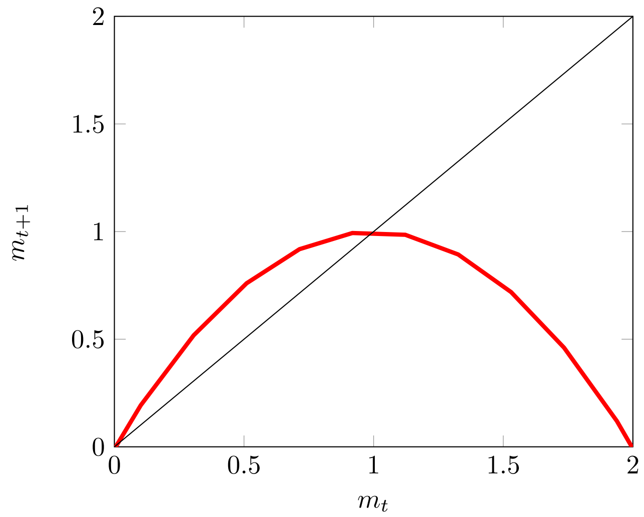

Figure 1: System's dynamic behaviour in m_t (e.g. $\bar{\epsilon} = 2$)

To determine the long-run equilibrium we need to study eq. (33). It must be acknowledged that m_t is not defined over the entire set $\mathbb{R}$, but only on $[0, 1]$. Indeed, it cannot be that more than the available population works for the academic setor. Similarly, it cannot be that the economy enjoys a negative number of masters. It can easily be noted that the dynamic presents no discontinuity point and is differentiable on the aforementioned interval. By taking the first derivative of the function $g(\cdot)$ we get:

$$g'(m_t) = \bar{\epsilon}(1 - m_t) \geq 0 \iff m_t \leq 1 \tag{33}$$

Therefore, this is sufficient for us to claim that, on the interval of interest, the dynamic is increasing. This is also enough to rule out oscillatory convergence to the equilibria. The second derivative, instead, reads as follows.

$$g''(m_t) = -\bar{\epsilon} < 0, \forall m_t \tag{34}$$

Thus, the dynamic is concave over the entire domain.

To solve for the equilibria, we need to solve:

$$m = g(m) = \frac{\bar{\epsilon}}{2} m(2 - m) \tag{35}$$

Recalling that by assumption $\bar{\epsilon} > 0$, we can state what follows.

Proposition 1 *Let $m_0 \in [0, 1]$ and $G_0^Y(h_0)$ be given as initial conditions. Considering only the cases in which $m_t \in [0, 1]$, the long-run number of masters working in the academic sector $m = \lim_{t\to\infty} m_t$ is:*

1. $m_1 = 0$
2. $m_2 = \frac{2(\bar{\epsilon}-1)}{\bar{\epsilon}}$

If $\bar{\epsilon} < 1$, m_1 is stable and m_2 is not a steady state. If $\bar{\epsilon} > 1$, m_1 is unstable and m_2 is stable.

Proof 1 *To determine* m_1 *one needs to acknowledge that:*

$$g(0) = 0$$

This implies that 0 *is a fixed point.* m_2 *is determined by solving eq. (36). Considering eq. (34), one gets that:*

$$g'(m_1 = 0) = \bar{\epsilon}$$

So, m_1 *is stable iff* $\bar{\epsilon} < 1$*, otherwise it is not. Similarly:*

$$g'\left(m_2 = \frac{2(\bar{\epsilon} - 1)}{\epsilon}\right) = -\bar{\epsilon} + 2$$

So, m_2 *is stable iff* $\bar{\epsilon} > 1$*, otherwise it does not exist as a separate steady state equilibrium.*

■

It follows that in order to have two distinct and significant, i.e. in $[0, 1]$, steady states, $\bar{\epsilon} \in [1, 2]$. This means that, in period t, students in the academic sector must be able to get as $\bar{h}_{t+1}$ a value which is at least slightly above their average human capital level during youth. Namely:

$$\bar{h}_{t+1} > \mathbb{E}_t[h_t | h_t \in [\hat{h}_t, \bar{h}_t]] \tag{36}$$

Otherwise, the system will have a single and stable steady state equilibrium $m_1 = 0$. In proposition (1) I have completely disregarded the case $\bar{\epsilon} = 1$. It must be acknowledged that $\lim_{\bar{\epsilon}\to 1} m_2 = m_1$, so $\bar{\epsilon} = 1$ may represent a bifurcation point. This case is addressed by proposition (2).

Proposition 2 *In the point:*

$$\bar{\epsilon} = 1$$

the dynamics of the share of masters over the entire population described by:

$$\Psi(m; \bar{\epsilon}) = \frac{\bar{\epsilon}}{2} m(2 - m) - m$$

for $\Psi : [0, 1] \to \mathbb{R}$*, undergoes a transcritical bifurcation.*

Proof 2 *To prove this, we must check that 5 conditions stated by Wiggins (2003) hold.*

1. $\Psi(m_1 = m_2 = 0; \bar{\epsilon} = 1) = 0$;
2. $\Psi'_m(m_1 = m_2 = 0; \bar{\epsilon} = 1) = 0$;
3. $\Psi'_{\bar{\epsilon}}(m_1 = m_2 = 0; \bar{\epsilon} = 1) = 0$;
4. $\Psi''_{mm}(m_1 = m_2 = 0; \bar{\epsilon} = 1) = -\bar{\epsilon} = -1 \neq 0$;
5. $\Psi''_{m\bar{\epsilon}}(m_1 = m_2 = 0; \bar{\epsilon} = 1) = 1 \neq 0$

■

The following graph represents the steady state equilibria as a function of $\bar{\epsilon}$.

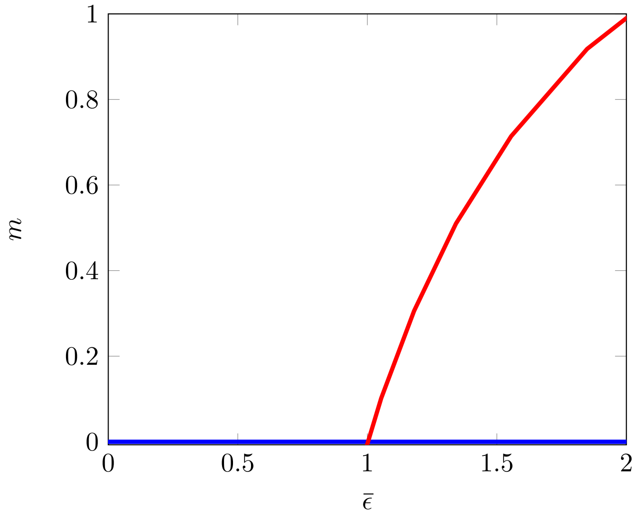

Figure 2: Transcritical bifurcation

As I proved in proposition (1), the blue line represents the locus of steady states which are stable in $\bar{\epsilon} < 1$ and unstable in $\bar{\epsilon} \geq 1$. The red line, instead, is the locus of steady states which are stable in $\bar{\epsilon} > 1$ and unstable in the bifurcation point.

4 Parameter estimation and simulation

The quantitative exercise that I conduct can be divided into two fundamental steps. Firstly, I calibrate the parameters using observational data, in the attempt to pin the model to real-world facts. Secondly, I simulate the model. For the calibration part, I use data from 5 major European economies. These are England (Great Britain after the Glorious Revolution), the Netherlands, Italy, Spain and France. The choice of these countries is mainly justified by two reasons. On the one hand, these countries serve as a good comparison group for the UK. Indeed, I want to assess whether the model manages to explain the so-called British advantage, that pushed the UK to become the epicentre of the First Industrial Revolution. On the other hand, there is a data availability concern. For example, for Scandinavia, we have reliable historical GDP estimates starting from very late in time. This would make it impossible to fit the model predictions on a sufficiently long time span. In conducting the analysis, I concentrate on the period between 1300 CE and 1800 CE.

In this chapter, I present the highlights of the quantitative exercise. In the following section, I present the data used for fitting GDP and those used for calibrating the model. Then, I illustrate the identification strategy. In particular, I concentrate on the techniques that I deploy to face identification while estimating the parameters. Eventually, I present and discuss the results of the model simulation.

Data

To estimate part of the parameters, I use the human capital series from Curtis and De la Croix (2023)[4]. A common feature of the series is that all the countries considered, but the UK, knew a period of sharp rise in aggregate human capital around 1600 CE. In this respect, the series for Italy, Spain and France are rather similar. All the three economies have stagnant, if not decreasing, human capital supply from 1200 CE to 1400 CE. Consequently, they all knew a marked increase, which was then followed by a plunge and again a rise during the 18th century. The Dutch economy shares the increase of 1600 CE. However, before then, the series appears to be stagnant to the 0 level. The fall known by all other continental economies after 1600 CE seems to be less accentuated for the Netherlands. The British series, instead, shows sustained growth rates all the way through 1800 CE. There are two major peaks. One is in 1650 CE, and it seems to be correlated with the aforementioned continental trend. The other is in 1750 CE, in conjunction with the outbreak of the First Industrial Revolution.

Once the model is calibrated, I fit predicted GDP to the series from the Bolt and Van Zanden (2020)[5]. The Italian economy seems to have lived a flourishing period during the Renaissance. After then, the Italian series shows a substantially stagnant trend. Likewise, the Spanish series does not bear significant growth in GDP per capita over the considered time span. The overall production of the Spanish economy, though, staggers around lower levels than Italy. The Dutch economy, instead, is increasing. It reached its peak in 1600 CE when GDP per capita was around 5,000 2011 US $ per individual. France has a much volatile series. GDP boomed in the years before 1400 CE and then plunged during the 16th century. Again, the British series shows a pattern which is more similar to the Netherlands than to its continental counterparts. The trend is undoubtedly increasing, reaching its historical maximum in 1800 CE.

Identification strategy and estimates

The model is characterised by 6 parameters. These are:

$$\varphi \equiv \{\beta, \alpha, B, \bar{\epsilon}, b, \gamma\}$$

β does not show up in any analytical solution. Given its irrelevance, we can exclude it from the list of the meaningful parameters. We remain with 5 parameters in total. The set then becomes:

$$\varphi \equiv \{\alpha, B, \bar{\epsilon}, b, \gamma\}$$

For the sake of completeness, one should know the disaggregation level at which each parameter is calibrated. In fact, 3 parameters are country-specific, these are B, $\bar{\epsilon}$ and b and they are calibrated using country-level data.

[4]See the appendix for the plotted series

[5]Maddison project database (2020). Data sources for:

- Spain: Scheidel and Friesen (2009), Álvarez-Nogal and Escosura (2013) and De la Escosura (2017).
- France: Scheidel and Friesen (2009) and Ridolfi (2017).
- UK: Scheidel and Friesen (2009) and Broadberry et al. (2012).
- Italy: Malanima (2011) and Baffigi (2011).
- Netherlands: Van Zanden and Leeuwen (2012) and Smits, Horlings, and Van Zanden (2000).

Instead, α and γ bear the same value for all countries. The method to determine the value of φ is manyfold. Namely, 1 parameter is set in accordance with the literature, 1 parameter is set to match a pre-specified target, 2 parameters are obtained by fitting, through a minimum distance estimation (MDE) procedure, the human capital series of Curtis and De la Croix (2023) and 1 parameter is set arbitrarily.

Parameter taken from the literature The value of α is calibrated taking account of Clark (2007). He estimates that, from 1200 CE to 1800 CE, the share of land on total income remained approximately constant around the 0.2 level. Therefore, I calibrate $1-\alpha = 0.2$. Consequently, $\alpha = 0.8$.

Parameter set with moment matching The value of country-specific B is determined so as to match the value of each country's GDP in 1760 CE. The choice of this year is motivated by two reasons. In the time span going from 1300 CE to 1800 CE we assume that GDP in 1800 CE is close enough to the steady state. However, the French GDP series lacks observations for the period going from the French Revolution until after the Congress of Vienna. Hence, I chose 1760 CE as a proxy for GDP in 1800 CE.

Parameter set arbitrarily The value of γ is calibrated by arbitrarily assuming $\gamma = 1$. Consequently, I perform a sensitivity analysis [6], where I study the sensitivity of the model predictions to arbitrary increases in the value of γ. A discussion follows below.

Parameter set using minimum distance estimation The value of b and $\bar{\epsilon}$ is identified using MDE. Firstly, I compute the dynamics using H_t as a reference variable[7]. The first-order difference equation resulting from the aforementioned derivation, which depends on b and $\bar{\epsilon}$, is then implemented for simulation. As far as the data are concerned, I use the human capital series from Curtis and De la Croix (2023). They serve as the data counterpart of the model predictions. I set the parameters' values so as to minimise the sum squared relative deviation between the model predictions and the data. For a given time $t > 0$, country i and the parameters $b, \bar{\epsilon} \in \varphi$, call $H^f_{i,t}$ the value of human capital predicted by the model. Also, call $H^o_{i,t}$ the observed level of human capital. The objective to minimize reads as follows.

$$\Omega(H^f_{i,t}, H^o_{i,t}; b, \bar{\epsilon}) = \sum_{t=1300 \text{ CE}}^{1800 \text{ CE}} \left(\frac{H^f_{i,t} - H^o_{i,t}}{H^o_{i,t}} \right)^2$$

For the Netherlands, t goes from 1560 CE to 1800 CE. The necessary conditions for a well-defined intertemporal equilibrium in H_t are i) the parameter specification and ii) the initial condition for $H^p_{i,t}$. Thus, I perform the minimization on a 3-dimensional domain[8]. In the end, I obtain 3 minimizers of the objective defined above, 2 of which refer to the parameters and 1 to the necessary initial condition. The domain over which I perform the optimization is constrained. In particular, every estimate must be positive. Then, I arbitrarily impose an upper bound on b equal to $2,500$. This value must be large enough in relationship with the initial conditions. This is to allow the predicted series to grow, thereby mimicking the increasing pattern of the data shared by all the countries considered. Also, I set the maximum value for $\bar{\epsilon}$ to 1.03 and for H_1 (the initial condition) to the observed value in the year where the simulation starts. The

[6]See the appendix for the results

[7]See the appendix for computational details

[8]To perform the minimization programme, I use the R package for the genetic algorithm by Scrucca (2013), which allows for global minimization

second condition is of paramount importance. Indeed, it implies that in the steady state no country can have more than 5.8% of its population working for the representative university. These upper bounds must be set so as to avoid ending up in unrealistic situations. Since the human capital historical series for the Netherlands shows stagnation around the 0 level from 1200 CE to 1560 CE, the simulation for the Netherlands is assumed to start in 1560 CE. All the others are assumed to begin in 1300 CE[9].

An alternative approach could be to fit eq. (32) with a MDE procedure using the series of the share of masters over total population provided by the database of the project RETE from De la Croix, Docquier, et al. (2019). This procedure could have been used to calibrate $\bar{\epsilon}$, as the dynamics of the share of masters does not depend on b. However, this approach conceals a fundamental drawback which is ultimately, once again, a data availability concern. Indeed, European countries are very heterogeneous in terms of data coverage. Some countries display very detailed descriptions of scholars, like Italy, which has very wide coverage. However, most scholars appear to have no publication record. Curtis and De la Croix (2023) attempt to address this problem when constructing their human capital series. They weigh each scholar by the number of publications. Overall, this should reduce, if not totally eradicate, the bias due to heterogenous coverage across countries. Let a country have a large number of scholars, 50 % of which with void publication record and let another country have far smaller number of scholars, all of which with a track of at least a few publications. Despite their noticeable differences, the two countries could end up with equal estimated human capital index.

Results for the calibration part are hereunder summarized[10].

	b	$\bar{\epsilon}$	B	α	γ
Netherlands	2379.259	1.029910	0.64305135		
Spain	2017.012	1.029922	1.00841316		
England (then Great Britain)	2475.217	1.029745	1.00841316	0.80	1
Italy	2486.678	1.029785	0.05545828		
France	2491.846	1.029748	0.03373485		

Table 1: Results of the parameter estimation

As far as b is concerned, France bears the highest estimates. It should be recalled that b is a central parameter. Eq. (18) suggests that it affects whether $\bar{h}_t$ grows over time or decays. Moreover, the dynamics of H_t[11] suggests that the value of b, in conjunction with the initial condition H_1, determine whether the aggregate human capital series increases or decreases over time.

[9]See the appendix for the plots of fitted human capital
[10]See the appendix for the estimated initial conditions
[11]See the appendix

Italy enjoys the highest estimate for $\bar{\epsilon}$. All countries show very little differences in $\bar{\epsilon}$ between each other. Instead, the value of B is much higher in the UK and Spain relative to all other countries. In our setting, B represents the component of TFP which cannot be explained with an UTHC argument.

Simulation

I perform a 25-period simulation. Each period corresponds to 20 years. In fact, the period must equate a sufficient number of years in order for the predictions not to be too exposed to idiosyncratic fluctuations in the observed data. Such fluctuations may undermine the model's predictions. The simulation of the Dutch economy, instead, only lasts for 12 periods. To assess the plausibility of the theory I compare the GDP series predicted by the model with the historical series of GDP per capita from Bolt and Van Zanden (2020). I focus on the period ranging from 1300 CE to 1800 CE. It is important to remark that these historical data have not been used to calibrate any parameter, but B. The fact of using the GDP series to estimate B does not significantly impair the interpretation of the findings. Indeed, B serves as a rescaling factor of the TFP component (and therefore of the whole GDP). It follows that what is at stake are only the absolute levels of predicted GDP and not the shape, even though misspecification of B may still affect the trend. For example, the overestimation of B has the power to induce an upward (non-parallel) shift of the fitted curve relative to its optimal counterfactual. However, it does not significantly modify its shape. When interpreting the results one should bear in mind that predictions for a given year only make sense if compared with that of other years, i.e. only looking at the trend. For this reason, in the comments that follow I only focus on the pattern of the fitted curve and disregard the absolute values that it actually predicts. When simulating the model, I initialize the master share to 0.0001 at $t = 0$.

Fig. (3) shows the simulation results. The theory mimics a series of observed facts. As far as Italy is concerned, we witness good fit of the model. Indeed, since Italy has remained rather stagnant during the considered period, the model performs very modest slope. The trend is only slightly increasing at a low rate.

The same good fit cannot be found when considering the Spanish economy. The model materially underestimates Spanish GDP until the 17th century. The predicted growth rate of GDP seems to be overestimated. After the 17th century, the model appears to be able to perform slightly better. However, overall, when it comes to Spain, it seems not to be capable of describing the Spanish long run trend, at least for the period under enquiry.

The Dutch economy was simulated for a smaller number of periods. The model appears to describe quite well the observed increasing pattern. One should acknowledge that since the simulation is run over a smaller number of periods, there might be other periods before 1500 CE where the observed vagaries of the Dutch economy cannot be read through the lenses of the model.

When simulating the French economy, the model predicts an upward sloping productive trend. The French series stops in the period between the French Revolution and a few years after the Congress of Vienna. For this period, the model predicts a GDP which is in line with that of 1780 CE. This estimate is far from being

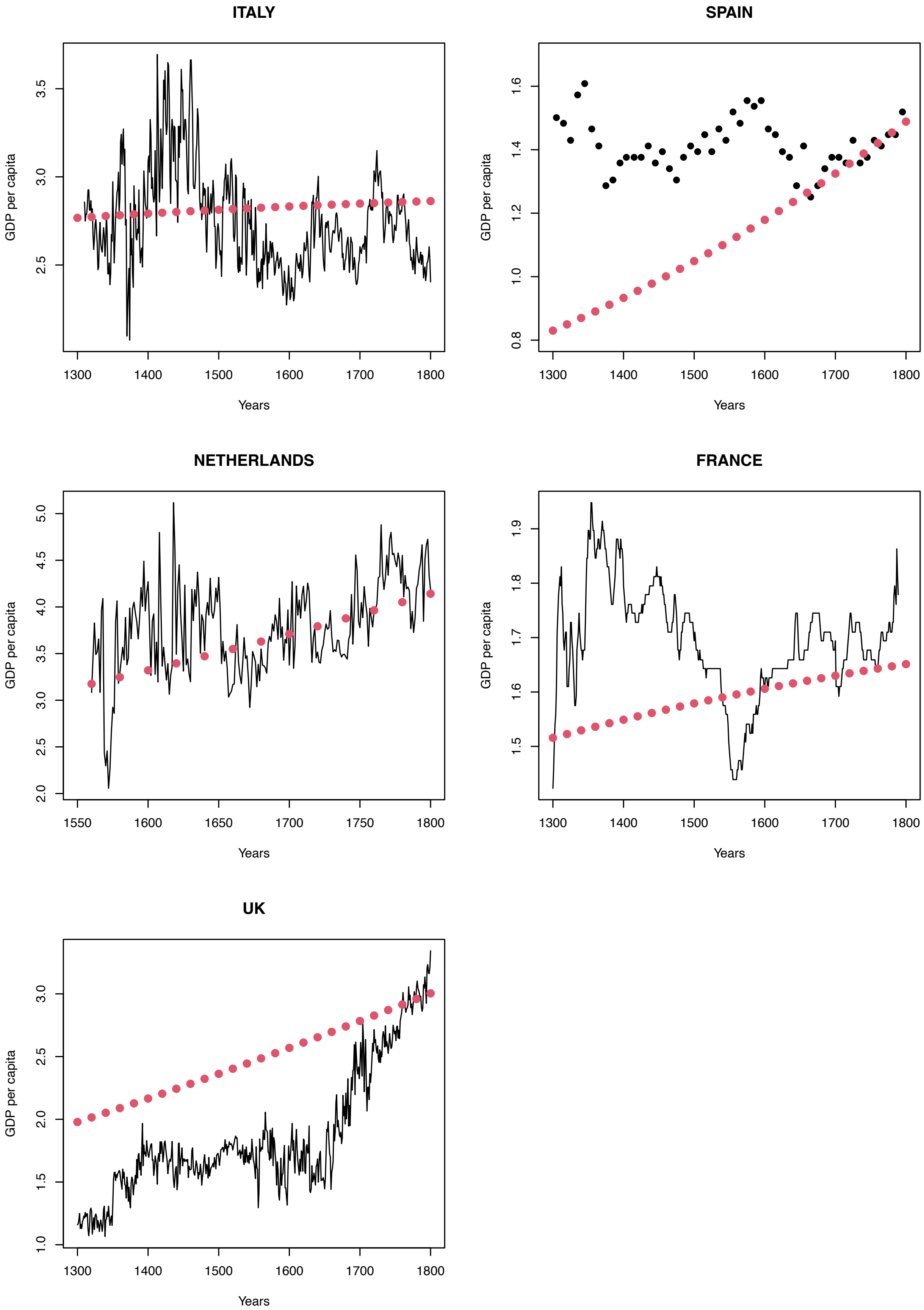

Figure 3: Simulation results. Data (black line) and predicted values (red). Data in thousands of 2011 US $.

credible due to the unprecedented events[12] that affected France in that period.

The results obtained in the simulation of the British economy are interesting. On the one hand, the series seems to be predicted quite well by the model from 1750 CE onward. Before that period, however, the model has a hard time keeping up with the pace of the data. Indeed, the slope of the growth path does not seem to be in line with reality. The model falls behind expectations with respect to the pre-1750 period. Hence, the breakout of the First Industrial Revolution represents a turning point. For this reason, it can be said that the Industrial Revolution is perhaps an even more complex phenomenon than just a human capital affaire. The model tries to explain bursts in GDP focusing on a human capital/knowledge transmission mechanism. In particular, the novel channel through which UTHC is assumed to affect production is TFP. Maintaining that $\gamma = 1$, it can be noticed that the model cannot perfectly describe the transition period that the British economy lived during the Industrial Revolution. The slope of the fitted line is too low with respect to the data. This shortfall of the developed theory underlines the urgency of an explanation. To my knowledge, there can be two explanations at play, one doubts the empirics and the other the theory. On the one hand, this may be a result of an imperfect calibration of the parameter γ, which indeed affects the slope of the fitted curve. If $\gamma > 1$ it means the academic sector has the power to affect TFP by a larger amount, thereby resulting in a steeper fitted curve, which could in turn keep up with the post-1750 trend. Ceteris paribus, it is certain that γ be no smaller than 1, as otherwise predictions would go further out of fit. On the other hand, this problem might ring a bell on the mechanisms of knowledge transmission and on the interconnection of UTHC with TFP and production. Namely, it can suggest that the there may be other major channels that I might have downplayed, if not disregarded.

In the attempt to bust the first criticism concerning the calibration of γ, I perform a simple sensitivity analysis. Keeping everything else unchanged[13], I set the following values to the parameter γ: $\gamma = 1,000$ and $\gamma = 1,000,000$. Results are exhibited in the appendix. The findings are striking. Indeed, the model with $\gamma = 1,000,000$ seems to perform much better in predicting the English GDP trend but, when it comes to all other nations, the model underperforms, thereby producing worse goodness of fit. This enlighten our exegetic analysis with few additional facts. Following the insights of the model, it could be said that the British economy must have had structural characteristics that, at a certain point, boosted to an unprecedented level the effect of the UTHC on TFP. As remarked in the introduction, a necessary condition for this structural change could lie in the institutional framework. This is the argument of Mokyr (2005a) and De la Croix, Doepke, and Mokyr (2018).

5 Conclusions

The British economy has marked distinguishing features that set it apart from its continental counterparts. By concentrating on a human capital argument, I developed a theory of endogenous growth aimed to explain the complex interplay between UTHC and the Industrial Revolution that ignited the Great Divergence. The model

[12]The French Revolution first (including the Reign of Terror, during Robespierre's dictatorship) and then the Napoleonic era

[13]Clearly, to keep the match with GDP in 1760 CE, I have to recalibrate B. Indeed, its estimated values in the original simulation hinged on the assumption that $\gamma = 1$.

interprets this interplay allowing UTHC to affect production through the two channels described in the theory chapter. We have seen that the setup is quite versatile and enables to describe several fundamental features of continental Europe in the years preceding the Industrial Revolution. However, the theory is able to only partially describe the British extrication from the Malthusian trap, that characterised the pre-industrial times. In this respect, it cannot be said to be a model of the Industrial Revolution.

As a consequence, the sensitivity analysis turns out to be a fundamental step for our enquiry. It is through a sensitivity assessment of the model to the parameter γ that we witness how the model goes out of fit for all countries but the UK. Hence, the UK appears to have much higher γ with respect to its continental peers. This finding further corroborates the fact that the British economy might have had a socio-economic advantage over other nations in continental Europe. This advantage produced the inception of the Industrial Revolution. Future research should pave the way to explore alternative elements that contributed to UK's economic primacy, like the Financial Revolution of the Bank of England in 1694 CE and the demise of obsolete institutions for knowledge transmission.

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