Innovation-Based Growth & Long-Run Economic Development[*]

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Abstract

Technological progress is unarguably instrumental in order for an economy to make the transition from primitive to advanced stages of economic development. Yet, what are the forces driving improvements in technology along this long transition? To address this question we propose a theory of technological progress in the long run based on small-scale innovations by individual agents. We study its implications in the context of a unified growth model and argue that our innovation-based theory implies that both the rate of technological progress and also the timing of the transition from stagnation to growth depend crucially on what incentives the economic environment provides to agents to engage in innovation activities. We also discuss how our theory compares with a theory of technological progress based on learning-by-doing and how it can help us account for the diverging paths of various regions of Europe in terms of economic development.

Keywords: Unified Growth Theory, Malthusian Stagnation, Micro-Incentives, Technological Innovation, Agricultural Productivity, Economic Development

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Technological progress is like a flower; unless the environment is "just right" technological progress will whither or yield weak flowers. (Mokyr, 2003, p. 41)

1 Introduction & Overview

During the last decade the field of economic growth has witnessed an important paradigm shift. The traditional focus on theoretical models aimed at capturing the stylized facts of growth in modern developed economies has gradually given way to theories which are consistent with the whole process of human economic development. This led to a new generation of models, which are typically referred to as unified growth models, characterized by the property that their equilibrium paths can encompass, apart from the relatively recent phenomenon of sustained increases in per capita income, also the long-period of economic stagnation that dominated most of recorded human history as well as the transition between the two aforementioned regimes.

One of the main reasons for the growing appeal of this new paradigm is the possibility that it provides to capture the entire historical process of economic development, from pre-industrial to modern times, within a single framework. To achieve this growth theorists had to intertwine key features of neoclassical growth theory -pioneered by Robert Solow- where increases in per capita income are driven by the accumulation of factors of production, with elements of Thomas R. Malthus' theory of population dynamics, where the expansion of resources in an economy leads to a larger but not richer population. Thus, this advancement eliminated the need to resort to different types of models in order to explain the current as well as the historic growth paths of various countries or regions across the globe.

Typical examples of unified growth models include those by Galor and Weil (2000), Hansen and Prescott (2002), Lucas (2002), Doepke (2004) and Voigtlaender and Voth (2006). Although these models ultimately highlight different mechanisms that can account for a more or less endogenous transition from the initial Malthusian environment of economic stagnation to an environment with sustained increases in per capita income, they all share a common theme. This common theme is associated with the presence of a slow-moving technological progress, which over time encourages the accumulation of one or more factors of production and eventually permits the shift from a labor-intensive mode of production to a capital intensive one[1].

Yet, despite the important role reserved for technological progress in this long transition, most unified growth models -including the ones mentioned above- do not deal explicitly with the actual determinants of technological progress. Instead, some authors resort to simple feedback rules such as Galor and Weil, who assume that the state of technology improves mechanically as a result of the economy growing in size and economic agents becoming better educated. Other authors, including Hansen and Prescott or Voigtlaender and Voth, abstract even more and treat technological progress as a process exogenous to their models. This approach, however, leaves open the following question. If technological progress is what in the end permits the transition from economic stagnation to sustained economic growth, where does this technological progress originate from?

This question, we believe, is an important one, given the fact that in the long run economic growth goes hand in hand with technological progress, and it will be exactly the one will try to address in this paper. Moreover, we think that treating technological progress as a black box –to use the metaphor of Joel Mokyr- is a methodological stance which is much harder to justify nowadays compared to the time when Solow made his contributions to the field. This is particularly true in light of all the attention that the relationship between the evolution of technology and the process of economic growth has received in the various strands of the literature on endogenous growth during the past twenty years.

In addition to the concerns raised above, several prominent economic historians have recently criticized the literature on unified growth particularly due to this abstraction from the determinants of technological progress. This is because, according to Mokyr (2007), any successful theory of the industrial revolution should first of all provide an explanation for

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[1] To be fair to all the authors mentioned above, the term capital here should be interpreted in its broad sense, incorporating the notions of physical, human as well knowledge capital.

the continuing improvements in the level of technology and this, as Allen (2006, 2007) has emphasized, requires more focus on the "sources of invention." Moreover, this explanation can not simply rely on a positive link between the state of technology and the level of population, given its inconsistency with the historical facts from Europe and other parts of the world (Crafts (1995), Crafts and Mills (2009)). Finally, as pointed out by Mokyr and Voth, it is exactly these first increases in the rate of technological progress that are the most puzzling: *"... while human-capital based approaches hold some attractions for the period after 1850,* [in the absence of a proper theory of long-run technological progress] *few growth models have much to say about the first escape from the low growth regime that survives contact with the basic facts in economic history."* (Mokyr and Voth (forthc.))

To address this shortcoming in the literature, in what follows, we will propose a theory of technological progress in the long run based on an explicit innovation process. We will specify exactly how innovation takes place in the economy and how it feeds back to the economy's growth rate. Hence, our theory will share many of the features of innovation-based growth models, like those of Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). Yet, given our focus which is on the whole process of human economic development, we are going to abstract from modern research and development activities and will instead think of innovations as coming from a primitive, although deliberate, experimentation process[2].

This primitive innovation model will then be embed within a larger unified growth model incorporating the typical features of long-run growth models. The economy will start off in a Malthusian state where the presence of a fixed factor of production will lead to decreasing returns to labor. The size of the population will be endogenously determined based on the fertility choices of individual agents. Parents will be facing the typical Beckerian trade-off between investing in the quantity or in the quality of their children. Finally, to account for the demographic transition, we will follow Galor and Weil (2000) and postulate rising returns

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[2] Since this will be an important assumption in our model we will return to it in Section 2 to assess its validity.

to human capital accumulation in an environment of accelerating technological process.

Hence, our main departure from the standard unified growth setup will come exactly in our assumption of technological progress stemming from the decisions of individual agents to engage in innovation activity in the form of simple experimentation. This experimentation process will carry benefits for the agents, as it can result in productivity enhancing innovations. However, these benefits will not come for free, but at the cost of foregone wages that agents could have earned, had they spend their time in production instead. Hence, retaining the main insights of innovation-based growth models, in our model the decision to engage in technological innovation will be made after a careful weighting of the resulting costs and benefits.

This last statement, though, has an immediate consequence. Each economic agent will only decide to engage in experimentation if and only if the benefits that he or she can reap from this activity exceed the resulting costs. On the other hand, if these costs are too high or the resulting benefits too low, nobody will choose to experiment and hence there will be no new innovations. This means that, under our assumption of all technological improvements having to come from individual innovations, our model will feature the possibility of a growth trap. This trap will arise in economies where the environment is not conducive to innovative activities and where, as a result, there will be no incentives for anyone to engage in experimentation that would improve the existing level of technology.

Aside from the possibility of a growth trap though, our model highlights an important link between the underlying institutional structure of the economy and its long-run growth potential. This is because economies where agents have stronger incentives to engage in the creation of new technologies will end up generating more productivity enhancing innovations. This will result in a faster pace of technological progress and an earlier onset of the transition out of Malthusian stagnation. On the other hand, in economies where the incentives for agents to engage in experimentation are weak, the pace of technological improvement will be slower and, as a result, Malthusian stagnation will persist for a longer time.

To make this point clearer, we perform a simple calibration exercise. We assign numerical values to the parameters of our theoretical model and simulate the time path of the economy to see how differences in institutional features can affect the timing of the demographic transition and the emergence of sustained economic growth. As our quantitative results demonstrate, this effect can be quite large. This is because, small changes affecting the decisions of individual agents to engage in experimentation can over time have a large impact on the growth rate of technology and hence lead to a much earlier or later advent of what Galor and Weil (1999) refer to as the modern growth regime.

Of course, in a given economy the incentives that individual agents face to engage in innovation activities may not necessarily be uniform across different sectors, but might vary from sector to sector. To account of that, a second step in our analysis is to look into the extent to which the emergence out of Malthusian stagnation can come from a dynamic sector of the economy, in which innovation activity is well rewarded compared to the remaining sectors of the economy.

To capture this possibility we extend our analysis to the case of an economy with two productive sectors, an agricultural one, operating under diminishing returns to scale, and a manufacturing one operating under constant returns. Moreover, to bring our model closer to the realities of economic development, we consider the output of the agricultural sector to be the basic subsistence good that the people need to consume.

Using this augmented setup, we investigate how differences in the underlying incentives to individual innovators can affect the timing of the demographic transition in the two-sector economy. Here, our main conclusion turns out to be that the transition out of Malthusian stagnation requires, first of all, strong incentives for innovation in the agricultural sector. This is because in a Malthusian environment the size of the manufacturing sector is typically constrained by the size of the agricultural sector and its expansion can only come from increases in the agricultural surplus channeled towards manufacturing.

This conclusion is also confirmed in the calibration of the two-sector variant of our model. Specifically we show that, institutional improvements affecting the incentives of agriculturalists to engage in innovation activities are, ceteris paribus, more important than similar improvements in the manufacturing sector. This last exercise is reminiscent of an old debate in development economics regarding the importance of agricultural productivity for the emergence of industrialization, with our results coming closer to the more integrated vision of agriculture's role first suggested by Johnston and Mellor (1961) and Schultz (1964).

Of course, there is an alternative view to our theory of technological progress in the long run. This view is associated with the notion of learning-by-doing, according to which the creation of technological improvements is simply a by-product of the production process. Hence, according to that view technological progress does not require taking time off from working, and thus, agents do not really need any particular incentives to engage in it. Instead of that, the learning-by-doing view emphasizes the importance of the economy's size for technological progress, as in larger economies the greater scale of production will lead to the creation of more technological improvements.

To contrast our innovation-based theory with the one based on learning-by-doing, we turn to historical evidence from development in pre-industrial Europe. Particularly, we focus on the rates of urbanization across several European countries, which provide a good proxy for the level of development prior to industrialization. Using these data, we find a positive and significant effect of particular institutional characteristics effecting incentives for individual innovation on the time path of urbanization. Moreover, we document that this effect survives, even when the differences in the size of individual economies are accounted for. Thus, we treat this finding as evidence supporting the link between innovation-promoting institutions and technological progress in the long run that our innovation-based theory emphasizes.

The remainder of this paper is organized as follows. In Section II we present evidence on the evolution of technology in industrial and pre-industrial societies, which we then use to motivate our description of the innovation process. The variant of our model with one productive sector is presented in Section III. We first analyze the model and then simulate its dynamic equilibrium path. Afterwards we turn in Section IV to the analysis of a variant with two productive sectors, which we also calibrate and simulate. Finally, the last section is devoted to a brief discussion of the historical evidence from Europe and the presentation of our empirical results. We close with a few concluding remarks.

2 Technological Progress in Pre-Industrial Times

In today's world, people tend to associate technological innovations with the notion of research and development activities. This is natural given that such activities, devoted to the solution of a particular technical problem, have in fact produced most of the major innovations of our times. Yet, this type of activities, typically undertaken by teams of scientists or researchers in universities, large corporations or government laboratories, is mainly a feature of modern developed economies, that can afford to allocate large amounts of resources for such purposes. It was definitely not the way in which technology was advancing for most of human history[3].

In pre-industrial, as well as early industrial societies, technological improvements were not the outcome of sophisticated research and development activities, but rather the results of a simple experimentation process undertaken independently by various individuals. As Allen simply put it: *"Invention occurred either inadvertently, or through low budget tinkering."* (Allen (2007)) The people involved into the process did not always have a clear goal in mind, nor the luxury of devoting themselves entirely to experimentation. Hence, most of the resulting innovations were of small scale and magnitude. Still, over time, these "microinventions", as they are often referred to[4] (Mokyr (1990)), resulted in large cumulative effects in productivity[5] (Mokyr (1993)).

One of the typical examples of an important technological advancement that emerged out of a series of simple experiments is the well-known Norfolk system of crop rotation. The

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[3] Edison's research lab in Menlo Park is generally considered the first modern "invention factory" and opened in 1876. Rosenberg and Birdzell (1986, ch.8) provide a brief overview of the rise of the modern R&D lab and note that it only began after 1875.

[4] Mokyr defines *"microinventions as the small, incremental steps that improve, adapt, and streamline existing techniques already in use, reducing cost, improving from a function, increasing durability, and reducing energy and raw material requirements. Macroinventions, on the other hand, are those inventions in which a radical new idea, without clear precedent, emerges more or less ab nihilo."* (p.13).

[5] As Mokyr notes on p. 33: *"The key to the British technological success was that it had a comparative advantage in microinventions."*

Norfolk system is a four-course crop system where wheat is grown in the first year, turnip in the second, barley in the third, and clover combined with ryegrass in the fourth[6]. The main advantage of this particular rotation system over alternative systems lies in the elimination of the unproductive fallow year, which was a common practice until the end of 18th century. In addition to that, clover and turnip have positive effects on the quality of the soil improving its structure as well as its nitrogen content. Moreover, they can both provide fodder for animals which allowed for more livestock to be kept on farms and additional manure that could be used as a fertilizer (Overton (1991), Allen (2004)).

Yet, the development of this particular system by farmers in the Norfolk County took at least 200 years. Most of its components were already known much earlier, but their successful combination involved a lot of trial and error. Clover came to Britain from Holland around 1650. Turnip had already been introduced from Flanders during the 16th century as a garden crop. However, it took British farmers almost 100 years to start growing it as a field crop and use it as fodder and another almost 100 years to integrate it in crop rotation. Even after the gradual spread of turnips and clover, there was a lot of variation among farmers in their husbandry methods, rotational and fallowing practices as well as in the fertilization techniques being used. A 1705-1711 crop-book from a village in Norfolk, for example, records 312 different cropping sequences on 493 separate plots (Campbell and Overton (1993)). This indicates that a common practice of farming had not yet developed, but farmers rather experimented with different methods and techniques. Moreover, it took many more years for the soil improving effects of the new crops to be realized, as farmers at that time had a very limited understanding of the chemical and biological processes involved.

In spite of the slow development of whole system and its gradual spread across the English countryside during the 17th and 18th century, it ultimately led to large increases in agricultural productivity. This is demonstrated in Allen (1991) who simulates output per acre, labor per acre and output per worker between 1600 and 1800, using Turner's (1982) and

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[6] For more information on the Norfolk rotation, the reader is referred to Allen (2004), Campbell and Overton (1991, 1993), Jones (1965) and Overton (1985, 1991).

Young's (1768) estimates on grain yields. He shows that farmers had already accomplished 89-95% of the total advances in output per acre and 69-74% of output per worker by 1700. Moreover, about half of the growth in output per worker was also accomplished before 1700.

Another typical example of an important pre-industrial innovation is the development of the New Leicester sheep. This development began with Robert Bakewell (1725-1790) who, when taking over the family farm from his father, introduced the practice of separating male and female sheep. This allowed him to limit random mating among his livestock and to focus on selective inbreeding, which allowed him to exaggerate exactly the traits that were considered as desirable. The New Leicester breed of sheep was the first product based on that approach. Of course, the practice spread and was continued after Bakewell's death, resulting in better and better species of sheep, such as, the Border Leicester and Southdown, which gradually replaced the New Leicester. Yet, the impact was so immense that even the subsequent theories of Charles Darwin and Gregor Mendel seem to have drawn their influences from these types of experiments that began with Bakewell[7].

This view of small-scale experimentation as the driving force behind technological progress can also be seen in the works of Arthur Young (1741-1820). Young was an agricultural writer who, on his own farm in Suffolk, engaged in series of experiments in hope of improving his knowledge of agriculture. Though unsuccessful in most of his own experiments, he proceeded to describe his experiences in a handbook titled *"A Course in Experimental Agriculture"* (1770a). Additionally, he toured through England and Wales, visiting other farmers who had invited him to present their experiments to him, which he published in three other volumes with detailed descriptions on the actual resources used, the necessary expenses and the resulting profits. These projects were not revolutionary, but rather small-scale micro-inventions, such as the use of sea ooze as a fertilizer or the fattening of oxen with carrots and oil-cakes (Young, 1770b). The ultimate goal was no other than the dissemination of useful agricultural knowledge.

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[7] For a detailed discussion on Bakewell experiments, their subsequent diffusion across Europe and their connection to Mendel's theories an excellent reference is Roger Wood and Vitezslav Orel's *Genetic Prehistory in Selective Breeding: A Prelude to Mendel.*

To understand these historical facts better, we need a theory of technological progress that emphasizes the simple micro-motives of individual economic agents to engage in experimentation activities in pre-industrial times with the hope of producing useful technological innovations that would increase their productivity in the future. Thus, in our model we will treat all agents as being potential innovators and innovations being the outcome of simple experimentation process. Moreover, we will focus on simple "gap-filling" -as Mokyr calls them- micro-inventions which constituted the vast majority of innovations at that time and which despite their incremental nature contributed to large gains in productivity over time (McCloskey (1981), Mokyr 1993, MacLeod and Nuvolari (2006)). Finally, we will abstract from additional benefits that innovators could earn through a patent system, as in pre-industrial societies patents were generally quite costly and hard to obtain, while at the same time most of the micro-innovations were impossible to patent[8].

3 The One-Sector Model

Let us now begin our analysis with the construction of a simple one-sector unified growth model in which technological progress is the outcome of an explicit decentralized innovation process. The purpose of this simple model is to help us conceptualize better how the micro-motives that individual agents face can affect the technological innovativeness of a society and determine its long-run economic development path. Hence, in that aspect our model is going to be similar to the large class of innovation-based growth models. At the same time though, given the different scope of our analysis, which is to capture stylized facts of the whole process of human economic development, our model will have a basic structure that parallels those of unified growth models.

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[8] According to MacLeod (1988), obtaining a patent around 1660-1830 required expenses of approximately £100-130 as well as the completion of a cumbersome and costly bureaucratic procedure, which took about 1-2 months. At the same time the granted protection against infringements was rather imperfect. To give an idea of how expensive those patent expenses were, we should note that £100 of that period would be worth today around £120,000, using average earnings as the deflator (Officer (2009)).

3.1 Model Description

Our model economy consists of overlapping generations of households, who work, consume and raise children. These households constitute the basic unit of analysis and comprise one adult agent together with his or her offspring. Time -denoted by subscript t- is discrete, extending from an initial period 0 to infinity with each generation of agents living for just two periods. In their first period of life, childhood, we assume that agents do not engage in any economic decision-making and simply consume a fraction of parental time. In the second period of life though, adulthood, agents are active decision-makers who have to decide on the allocation of their time between working, child-rearing and experimenting[9].

Let L_t be the mass of agents entering adulthood in period t. This mass constitutes the labor force of the economy for that period. Yet, before engaging in production, each of these agents can decide independently to engage in some sort of primitive experimentation activity in the spirit of what we outlined in the previous section. The goal of this activity is to improve upon the current level of technology A_t, which the agents inherited from the previous generation.

This experimentation, though, is not costless, since the time that agents spent experimenting has to be taken off from working and child-rearing. Thus, agents can not devote themselves entirely to experimentation, as they also need to work in order to provide themselves and their families with at least the means for their subsistence. This means that each agent will devote to experimentation only some fraction ω_t of his or her total available time, which for simplicity we normalize to 1. The output of this experimentation process will be an innovation of magnitude ζ_t which depends on the fraction of time spent ω_t, the human capital h_t of the agent, and some fixed economy-wide factor B :

$$\zeta_t = B(h_t)^{\beta}\omega_t. \tag{1}$$

This is because the productivity of experimentation is affected by intrinsic characteristics

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[9] Given that in each household there is one active decision-maker, in what follows we will be often interchanging the terms household and agent.

of the agent, as well as overall socio-institutional characteristics of the economic environment in which the agents operate. The latter are captured in the factor B which accounts for both the formal institutional features that the Northian literature has emphasized (North (1981), North and Weingast (1989)) and for the relatively informal ones, in the spirit of Greif (1993, 2006), which can influence the decision of individual agents to engage in experimentation activities. For the exponent β we assume it to be strictly between 0 and 1, although this will be of limited importance for the agents' decisions, given that their level of human capital is based -as we will show later on- on decisions made by their parents[10].

Once the experimentation phase is over, agents split the rest of their time between productive and child-rearing activities. For the moment we will suppose that there is only one productive sector in the economy producing the unique final good Y_t with the technology,

$$Y_t = A_t H_t^{\alpha} X^{1-\alpha}, \tag{2}$$

where the two inputs correspond to land X and efficiency units of labor H_t. Hence, the production function is characteristic of a traditional agricultural sector. A_t denotes the current level of total factor productivity level, while $\alpha \in (0, 1)$ captures the relative importance of the fixed factor.

Rewriting the production function in per capita terms, we obtain the expression,

$$y_t = A_t h_t^{\alpha} x_t^{1-\alpha}, \tag{3}$$

where $y_t = \frac{Y_t}{L_t}$ corresponds to output per capita, $h_t = \frac{H_t}{L_t}$ to the average level of human capital and $x_t = \frac{X}{L_t}$ to the inverse of population density. To avoid dealing with the issue of property rights over land, we follow Galor and Weil (2000) and assume that the return to land is zero and hence workers earn their average rather than their marginal product. This

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[10] A natural element of any experimentation process that is missing from our treatment is, of course, uncertainty. This is an abstraction that we consciously made in order to simplify the exposition of the model, but which could be easily incorporated in the current setup, as we actually did in an earlier version of this paper. Given, though, that the introduction of uncertainty will have no effect on our main results, in what follows we will simply treat the experimentation process as being purely deterministic.

means that:

$$w_t = \frac{y_t}{h_t} = A_t(\frac{x_t}{h_t})^{1-\alpha}. \tag{4}$$

Technological progress is driven by individual innovations, which -as we discussed above- are the result of each agent's experimentation activities. Given the decentralized and uncoordinated nature of the experimentation process, though, these innovations could either be substitutes or complements. Thus, we take Z_t, the overall technological improvement in period t, to be the power mean of all individual innovations ζ_t, namely

$$Z_t = [\sum_{i=1}^{L_t}(\zeta_{i,t})^{\varepsilon}]^{\frac{1}{\varepsilon}}, \tag{5}$$

where ε is capturing the degree of complementarity or substitutability and can in principle take any value. This overall technological improvement determines the level of technology in the next period:

$$A_{t+1} = A_t + Z_t A_t. \tag{6}$$

Yet, the diffusion of technology within the economy is not instantaneous. Instead of that, we assume that all new innovations will be freely available to all agents only with one period delay. As a result, in the current period t, we suppose that each agent has access to just the level of technology inherited from the previous generation, A_t, with the addition of any new innovation, ζ_t, that he or she alone came up with. Let us define this particular level of technology as:

$$A'_t = (1 + \zeta_t)A_t. \tag{7}$$

This means that the wage earned by each individual agent will be given by:

$$w'_t = A'_t(\frac{x_t}{h_t})^{1-\alpha} = (1 + \zeta_t)A_t(\frac{x_t}{h_t})^{1-\alpha} = (1 + \zeta_t)w_t. \tag{8}$$

Regarding the evolution of human capital, we follow the approach of Galor and Weil (2000), who assume that the level of human capital of each adult agent depends on the amount of education received in the first period of life as well as the rate of technological progress between the two periods. Specifically, Galor and Weil treat the per capita level of human capital, h_t, as an increasing and concave function of its level of education, e_t, and as a decreasing and convex function of the economy's rate of technological progress, g_t[11]. Moreover, this adverse effect of technological progress is assumed to be the smaller, the higher is the level of education. Thus, for a human capital formation function,

$$h_t = h(e_t, g_t) > 0, \tag{9}$$

the described assumptions correspond to $h_e(\cdot) > 0, h_{ee}(\cdot) < 0, h_g(\cdot) < 0, h_{gg}(\cdot) > 0 \wedge h_{eg}(\cdot) > 0$[12].

Having described the production sector of the economy, we now turn to the problem of each individual household head, who is an adult agent with a unit time endowment at his or her disposal. This unit time endowment has to be divided between working time, child-rearing time as well as experimentation time, in such a way that would maximize the agent's utility function:

$$u_t = (c_t - \tilde{c})^{1-\gamma}(n_t h_{t+1})^{\gamma}. \tag{10}$$

Here, c_t denotes agent's current period consumption and n_t the chosen number of children[13]. The exponent $\gamma \in (0, 1)$ captures the relative importance of the two components for the agent's utility, while $\tilde{c} > 0$ corresponds to the level of subsistence below which an agent's consumption can not be reduced any further. This covers the amount of food that is ab-

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[11] The former assumption seems intuitive in the presence of decreasing returns to education. The latter is justified by the "erosion" effect which was first suggested by Schultz (1964). For more details on the reader is referred to the discussion in Galor and Weil (2000).

[12] The assumption that $h(\cdot) > 0$ can be justified with the existence of a basic level of cognitive skills that even an uneducated individual would possess. Particularly we will assume that $h(0, g_t) > 0$ and that $\lim_{g_t \to +\infty} h(0, g_t) \to 0$.

[13] Note that we are using the typical Beckerian utility function. According to Becker the second term captures either a notion of intergenerational altruism or implicit concerns for old age support. For more details on this type of utility functions, the reader is referred to Becker (1960), Becker and Lewis (1973), Becker, Murphy, and Tamura (1990) as well as the discussion in Galor (2005).

solutely necessary for the agent to avoid hunger, though, as Galor (2005) and Voigtlaender and Voth (2006) point out, this could be more than the amount he or she actually needs to survive.

To construct the corresponding budget constraint, let us begin by observing the household's potential income. This is the income that the household could earn if the adult agent devoted his whole unit time endowment to just work, in which case he or she would simply earn y_t. Let us then define the household's conditional potential income z_t as the potential income of a household whose adult agent has already spent a fraction ω_t of its unit time endowment experimenting:

$$z_t \equiv (1-\omega_t)w_t' h_t = (1-\omega_t)(1+\zeta_t)w_t h_t = (1-\omega_t)(1+\zeta_t)y_t. \tag{11}$$

From the above expression it is easy to see that agents will only engage in experimentation whenever:

$$(1-\omega_t)(1+\zeta_t) \geq 1 \Longleftrightarrow (1-\omega_t)[1+B(h_t)^{\beta}\omega_t] \geq 1. \tag{12}$$

If this is not the case, this means that the time cost of experimentation exceeds the benefit. Hence, no agent will devote any time to experimentation and as a result there will be no new innovations. This is an important observation to which we will return later in the section.

Yet, agents also devote time to child rearing. Suppose that the time cost for an adult agent of generation t of raising one child with educational level e_{t+1} is $\tau^q + \tau^e e_{t+1}$, where τ^q corresponds to the fixed time cost of rearing one child and τ^e to the unit cost of education. If the number of children raised is n_t, then the agents's consumption, c_t, is constrained by:

$$c_t \leq z_t[1-n_t(\tau^q+\tau^e e_{t+1})] \Longleftrightarrow c_t \leq (1-\omega_t)(1+\zeta_t)y_t[1-n_t(\tau^q+\tau^e e_{t+1})]. \tag{13}$$

Given the above constraints, each adult agent has to choose his or her optimal level of consumption, $\hat{c}_t$, determine the optimal number of children, $\hat{n}_t$, and decide on their level of education $\hat{e}_{t+1}$ such that his or her level of utility, conditional on having spent fraction ω_t of his or her time experimenting is maximized. Thus, each agent must solve the following optimization problem:

$$\max_{\{\omega_t, c_t, n_t, e_{t+1}\}} u_t = (c_t - \tilde{c})^{1-\gamma}[n_t h(e_{t+1}, g_{t+1})]^{\gamma}$$
$$s.t. \left\{ \begin{array}{c} (1-\omega_t)(1+\zeta_t)y_t[1 - n_t(\tau^q + \tau^e e_{t+1})] \geq c_t \\ (1-\omega_t)[1 + B(h_t)^{\beta}\omega_t] \geq 1 \\ (c_t, n_{i,t}, e_{t+1}) \geq 0 \wedge 1 \geq \omega_t \geq 0 \end{array} \right\} \tag{14}$$

Let us first consider the optimal choice for ω_t. From the first-order condition we obtain that:

$$\hat{\omega}_t = \frac{B(h_t)^{\beta} - 1}{2B(h_t)^{\beta}} = \frac{1}{2} - \frac{1}{2B}h_t^{-\beta}.$$

This is of course provided that the constraint $(1-\omega_t)[1 + B(h_t)^{\beta}\omega_t] \geq 1$ is not binding[14]. If this is not the case, though, the agent should simply choose $\hat{\omega}_t = 0$. Thus, the optimal fraction of time that each agent devotes to experimentation activities can be summarized as:

$$\hat{\omega}_t = \omega(h_t) = \left\{ \begin{array}{cc} 0 & \text{if } h_t < B^{-\frac{1}{\beta}} \\ \frac{1}{2} - \frac{1}{2B}h_t^{-\beta} & \text{if } h_t \geq B^{-\frac{1}{\beta}} \end{array} \right\}. \tag{15}$$

Substituting these values into (1) we obtain the corresponding magnitude of each individual innovation:

$$\hat{\zeta}_t = \zeta(h_t) = \left\{ \begin{array}{cc} 0 & \text{if } h_t < B^{-\frac{1}{\beta}} \\ \frac{1}{2}[B(h_t)^{\beta} - 1] & \text{if } h_t \geq B^{-\frac{1}{\beta}} \end{array} \right\}. \tag{16}$$

Turning now to the optimal solution for e_{t+1}, we have that this will be governed by the

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[14] Note that the above solution has the appealing properties of being an increasing and concave function of the agent's level of human capital: $\frac{d\omega_t^*}{dh_t} > 0 \wedge \frac{d^2\omega_t^*}{dh_t^2} < 0$.

first order condition,

$$G(e_{t+1}, g_{t+1}) \equiv [(\tau^q + \tau^e e_{t+1})h_e(e_{t+1}, g_{t+1}) - \tau^e h(e_{t+1}, g_{t+1})] \leq 0,$$

with the proviso that $e_{t+1} = 0$ if $G(e_{t+1}, g_{t+1}) < 0$. This is the same first-order condition as in Galor and Weil (2000). Hence, using the Implicit Function Theorem we can verify the existence of a strictly positive and monotonically increasing implicit function $e'(\cdot)$ such that:

$$\hat{e}_{t+1} = e(g_{t+1}) = \left\{ \begin{array}{cc} 0 & \text{if } g_{t+1} \leq g^* \\ e'(g_{t+1}) & \text{if } g_{t+1} > g^* \end{array} \right\} \tag{17}$$

where $g^* > 0$. Thus, the optimal choice of each adult agent regarding the education of his or her offspring is independent on the household's income and is only influenced by the pace of technological progress.

Finally, the optimal solutions for the number of children n_t and the agent's consumption c_t can be easily computed from the corresponding first-order conditions, which yield:

$$\hat{n}_t = \frac{\gamma}{\tau^q + \tau^e e(g_{t+1})}(1 - \frac{\tilde{c}}{[1 - \omega(h_t)][1 + \zeta(h_t)]y_t}), \tag{18}$$

$$\hat{c}_t = (1 - \gamma)[1 - \omega(h_t)][1 + \zeta(h_t)]y_t + \gamma\tilde{c}. \tag{19}$$

The former expression is particularly important as it governs the evolution of population in the economy given that $L_{t+1} = \hat{n}_t L_t$. Note that it incorporates the typical Malthusian feature that as the household's potential income z_t increases, so does the desired number of children. At the same time though, this number will also depend on the choice that the parent is going to make regarding the education of his or her offspring. Providing better education to each child can only come at the cost of decreasing the total number of children. Thus, the child-rearing decision encompasses a trade-off between offspring quantity and offspring quality as suggested by the Becker and Lewis (1973).

3.2 Model Implications

The important novelty of this simple one-sector model lies in the implications that it has for the economy's growth path. To understand these implications better, let us briefly compare it with the equilibrium path of the Galor-Weil model. In the latter one, the rate of technological progress is simply assumed to be an increasing and concave function of the size of the labor force L_t as well as of the overall level of education e_t, namely,

$$g_t^{GW} = g(e_t, L_t),$$

where $g_e(\cdot) > 0 \wedge g_L(\cdot) > 0$, while $g_{ee}(\cdot) < 0 \wedge g_{LL}(\cdot) < 0$. Hence, as the economy increases in size and its workforce becomes better educated, this will necessarily also lead to a speed up of technological progress.

Yet, in our model this may not necessarily be the case. The main reason has to do with the fact that technological improvements here require individual agents to come up with new innovations, which are the result of a deliberate experimentation process. Since this process implies a cost for the agents, associated with the time that these agents have to take off from their other activities, namely working and child-rearing, technological improvements are not automatic. If the time cost ends up exceeding the benefit that the agents incur from the resulting innovation, their rational response will be not to engage in any experimentation activities at all. As a result, in the current period there will not be any new innovations produced and consequently no technological progress. Thus, in our model the growth rate of technology is governed by the following expression:

$$\hat{g}_{t+1} = \left\{ \begin{array}{cc} 0 & \text{if } h_t < B^{-\frac{1}{\beta}} \\ \frac{1}{2}[B(h_t)^{\beta} - 1](L_t)^{\frac{1}{\varepsilon}} & \text{if } h_t \geq B^{-\frac{1}{\beta}} \end{array} \right\}. \tag{20}$$

Here, it is important to note that under the assumption that $\varepsilon \in (0,1)$ our growth rate expression has properties similar to the function assumed by Galor and Weil. It is an increasing and concave function of population and the per capita level of human capital, which is an increasing function of education. Nevertheless, this is all provided that the level of human capital in the economy is above the threshold $B^{-\frac{1}{\beta}}$, so that agents are willing to engage in innovation activities. If this is not the case, again, there will be not improvements to the current level of technology, and hence, $g_{t+1} = 0$.

This technological stagnation, though, in the context of the above model, will also have further adverse consequences as it will also diminish the incentives of adult agents to invest in the education of their offspring. As can be seen from (17), the absence of any technological improvements between periods t and $t+1$, will also result in no educational investment for the currently young generation that will constitute the economy's labor force in period $t+1$. This, according to (9), means that there will neither be any improvement in the per capita level of human capital h_{t+1}. Therefore, if h_t was below the threshold, this will also be the case for h_{t+1}. This precludes the presence of any technological progress also between the periods $t+1$ and $t+2$, as hence the economy will end up getting stuck in a growth trap.

This possibility of a growth trap with no technological progress and no investment in education from which the economy can not escape is a novel feature of our model which contrasts the predictions derived from most of the existing unified growth models. Particularly, one of the common themes in unified growth theory is that the transition from stagnation to growth is an inevitable outcome of the process of human economic development and will sooner or later be experienced by all economies. Yet, this prediction stems from models where technological progress is not the outcome of an explicit innovation process and as we have just observed this feature of an inevitable transition does not seem to survive in an innovation-based framework. For this reason, we believe that abstracting from the actual determinants of technological progress may lead to misleading predictions regarding nature of the transition from primitive to advanced stages of economic development.

Furthermore, it is important to point out the key role played by the institutional parameter B, a larger value of which is associated with an environment that is more favorable to individual innovators, as we discussed above. A careful observation of expression (20) reveals that higher values for B will not only have a positive effect on the growth rate of technology, in cases where it is positive, but will also lead to a reduction of the threshold value below which there is no growth. This means that, ceteris paribus, institutional arrangements that promote individual innovation can in the long-run not only speed up the growth process, but also diminish the possibility that the economy will end up in a growth trap. This is an important prediction of our simple theoretical model, which we will now attempt to assess quantitatively.

3.3 The Time Path of the Economy

To better understand the implications that our model has for the process of economic development, in what follows, we will make an attempt to simulate the model economy and discuss the properties of its dynamic equilibrium path.

3.3.1 Calibrating The Model Parameters

For our quantitative exercise we will rely on the existing body of literature that has focused on the calibration of the long-transition from Malthusian stagnation to sustained economic growth, such as Hansen and Prescott (2002), Lagerlof (2006), Voigtlaender and Voth (2006). Particularly the work of Lagerlof (2006), who provides a calibrated version of the Galor-Weil model, will provide a useful benchmark for our own exercise. Yet, before we embark on this quest, it is important to point out that given the absence of precise historical estimates for our main model parameters, we will need to be cautious regarding the scope of this exercise. Thus, we would like to emphasize that the purpose of the calibration is mostly to quantitatively assess the importance of the particular channels -in this case of the effect of the institutional parameter B- for the economy's development path, rather than to attempt a fit of historical data from particular countries or the world as a whole. With this caveat in mind, let us begin with the description of our parameter choices.

Following the calibration strategy of the aforementioned models, we first select the long-run equilibrium values for the main endogenous variables of the model. Specifically, given that the model economy should eventually converge to what Galor and Weil (1999) refer to as the modern growth regime, it must be that these values are consistent with the patterns observed in modern developed economies. For this reason we consider a long-run value for the optimal number of children $\bar{n}$ of 1, so that the population over time converges to a constant level. Regarding the long-run value of education $\bar{e}$, we take it to be equal to 0.075, which corresponds to the approximate share of education expenditure in the national accounts of most OECD countries. Moreover, we let the rate of technological progress be 2.5% in the long-run, so that it is consistent with modern growth accounting data.

Turning to the model parameters, we start by seeking values for the time costs of children, τ^q and τ^e, that do not make child-rearing too "expensive" during the early stages of development. With this in mind, we normalize the time cost of education τ^e to 1 as in Galor (2005), while for the fixed time cost τ^q, we follow Lagerlof's suggestion and set it equal to 0.15. Given that, we fix the value of the exponent of children in the utility function, γ, to 0.225, so that it is consistent with our steady state choices of $\bar{n} = 1$ and $\bar{e} = 0.075$.

For the exponent α of efficiency units of labor in the production function, we take a value of 0.4 following Hansen and Prescott (2002). For β, the exponent of human capital in the innovation function, we pick a value of 0.2 which lies at the lower bound of the estimates that Barro (2001) and Barro and Lee (2001) provide for the importance of human capital for economic growth. Regarding ε, the parameter that captures the degree of complementarity or substitutability of the different individual innovations, we choose a value of 2. This choice was made in order to balance out between two important considerations, the need for a declining role of the scale effect over the course of human economic development on the one hand, and a limited reliance on the assumption of substitutability of the individual innovations produced by different agents in each time period on the other.

In parametrizing the abstract human capital function $h(e_t, g_t)$, hypothesized by Galor and Weil (2000), we follow Lagerlof (2006), who recommends the choice of,

$$h(e_t, g_t) = \frac{e_t + \rho\tau^q}{e_t + \rho\tau^q + g_t}$$

and refer the reader to his article for more details on the virtues of this particular functional form. Also, as suggested by Lagerlof, we calibrate the parameter ρ based on our choice of steady state values for education $\bar{e}$ and the growth rate $\bar{g}$. Finally, we normalize the quantity of land to 1, as in Hansen and Prescott (2002), and do the same for the level of subsistence consumption $\tilde{c}$.

The last parameter of the model that needs to be calibrated is the institutional parameter B, which is our main parameter of interest. This is because we are interested in assessing how small changes in B can affect the time path of the economy, particularly the extent to which such changes can delay or even derail the transition to sustained economic growth. Thus, in what follows, we will slightly perturb the value for B around its chosen value. To begin with, though, we choose a benchmark value for B of 1.5, that together with the above set parameters allows us to match the stylized facts of total factor productivity growth summarized in Galor (2005).

Before presenting our baseline simulations results, we also need to set the initial conditions for our economy. In this we follow again the strategy of Lagerlof (2006) and Voigtlaender and Voth (2006) and let the economy begin at a "quasi steady state," i.e. in an equilibrium in which it would remain if there was no technological progress. This, given the nature of our model, should be a stagnant Malthusian equilibrium with low levels of per capita income. In such an environment, parents would rationally choose not to invest in the education of their children, as it is evident from (17). In the absence of any educational investment, we let the initial level of human capital capture a basic skill level, normalized to 1. We also take n_0 to be equal to 1, so that there is no population growth in the first period. Then, we choose z_0 based on (18), given our previous choices. The remaining initial values for L_0, A_0 and g_1 can be obtained simply by combining equations (11), (9) and (20).

3.3.2 Baseline Simulations

Let us now present our baseline simulation results. Figures 1a and 1b present the time path of the main endogenous variables under the parameter choices discussed above in linear as well as logarithmic scale. Note that the horizontal axis corresponds not to time periods but to generations, where each generation should roughly be thought as corresponding to 20 years. Hence, the simulated path for our model economy features a long-period of Malthusian stagnation, of approximately 250 generations, where small increases in the level of technology are followed by similar increases in the level of the population and almost no change in the level of per capita income.

[Insert Figures 1a & 1b here]

In spite of this stagnant economic environment, increases in the size of the population and the fraction of time spent on experimentation will gradually lead to increases in the pace of technological progress. This means that, over time, the growth rate of technological progress will accelerate and at some point it will eventually reach the threshold of g^* above which parents find it optimal to invest in the education of their children. This is shown in Figure 2, where the eventual "take-off" of per capita income is shown to be associated with a sudden rise in the fraction of time devoted by parents to educate each child as well as a decline in the actual number of children.

[Insert Figure 2 here]

The above figures depict graphically the main mechanism that drives the transition from economic stagnation to sustained economic growth in the Galor-Weil model. That is a slow-moving, yet accelerating, technological progress eventually generating a rise in the returns to human capital, which induces parents to invest in their offspring's education and, given their limited resources, to substitute child quality for child quantity. However, as we argued in the previous section, the pace of technological progress in our model depends crucially on the decision of individual agents to engage in innovation activities, a decision which is also influenced by institutional features of the economic environment, captured in our simple setup by the parameter B. Thus, changes in B will be reflected on the growth rate of technology, since they alter the incentives that each agent as a potential innovator faces. Yet, the question is, how large can this effect quantitatively be?

To answer this question we slightly perturb B from its baseline value of 1.5 and observe the impact of this perturbation on the time path of the economy. Particularly, we focus how changes in B are reflected in the number of generations, denoted by t^*, that elapse before the growth rate of technology reaches the crucial threshold g^*, above which parents start investing in the education of their children. The results are displayed in the following table:

B	*1.3*	*1.4*	*1.5*	*1.6*	*1.7*
$\mathbf{t}^*$	*381*	*306*	*252*	*212*	*181*

Note that the magnitude of the effect is quite large, with an adjustment of B from a value of 1.3 to a value of 1.7 leading to an earlier advent of the transition by 200 generations and vice versa. This is because even small improvements in the institutional environment can alter the behavior of individual agents, who will then be more inclined to engage in experimentation. More importantly though, when aggregated at an economy-wide level, this adjustment can contribute to a substantially faster overall pace of technological progress. Furthermore, the resulting gains in productivity at early stages of development, despite the fact that they may not raise directly the level of output per capita, will generate increases in the size of the economy, which will also feed back to the growth rate through the scale effect of population. Thus, the cumulative effect over time of an otherwise small-scale institutional improvement can be prove to be quite large.

4 The Two-Sector Model

One of the main drawbacks of the one-sector model presented above, as well as any unified growth model that includes only one productive sector, is that it can not account for the structural transformation that takes place as an economy makes the transition from primitive to advanced stages of economic development. Particularly, from the historical experience of development in various regions of the globe, we are well aware that development is typically associated with a gradual shift of economic activity from agricultural to manufacturing, rather than simply with the modernization of a backward agricultural sector, as the above model would predict. Yet, this shift is important for an additional reason. The reason is that, as the size of the agricultural sector declines, also the constraints imposed on the economy by the presence of a fixed factor of production, namely land, become less and less binding.

The above observation has lead several economists to the claim that the whole process of human economic development can be understood as the result of this shift from an agrarian to a manufacturing-based economy and the associated diminishing role of land for aggregate production. This view has most recently been emphasized in Hansen and Prescott (2002) who claim that, *"the transition from stagnant to growing living standards occurs when profit-maximizing firms, in response to technological progress, begin employing a less land-intensive production process that, although available throughout history, was not previously profitable to operate."*

However, as we mentioned above, Hansen and Prescott in their analysis treat technological progress as exogenous to the economy, an assumption which obscures the interactions between the structural transformation and the nature of technological progress. Moreover, as we argued in the previous section, once the link between technological progress and individual innovations has been established, it becomes evident that different institutional arrangements may hasten or hamper the pace of technological improvement. For this reason, in this section we proceed to augment our simple unified growth model with an additional sector, where land will not be necessary for production. Using this model, we will make an attempt to better understand how the changing role of land in the economy interacts with the incentives of agents to engage in technological innovation and the extent to which the latter can influence the observed transition away from agriculture and into manufacturing over the course of human economic development.

4.1 Model Description

The basic structure of the economy in our two-sector model remains identical to that of the one-sector version. The economy still consists of overlapping generations of households, who work, consume, raise children and engage in experimentation as before. However, in this case we allow for two separate productive sectors, an agricultural one operating under decreasing returns to scale and a manufacturing one operating under constant returns. Moreover, we let the two sectors also produce two distinct final goods which we denote by Y_t^A and Y_t^M. The production technologies for these two goods are given by,

$$Y_t^A = A_t^A (H_t^A)^\alpha X^{1-\alpha}, \tag{21}$$

$$Y_t^M = A_t^M H_t^M, \tag{22}$$

where X corresponds to amount of available land, as before, H_t^j to the amount efficiency units of labor employed by sector j, and A_t^j to the current state of technology in sector j.

Maintaining our assumption of a zero return to land, we have the wage rate in both sector being given by the average product of efficiency units of labor, namely

$$w_t^A = A_t^A (\frac{X}{h_t L_t^A})^{1-\alpha}, \tag{23}$$

$$w_t^M = p_t^M A_t^M, \tag{24}$$

with L_t^j denoting the amount of labor employed in sector j[15]. Note also that the wage rates are denominated by the price of the agricultural good, $w_t^j \equiv \frac{W_t^j}{P_t^A}$ and so $p_t^M \equiv \frac{P_t^M}{P_t^A}$ represents the price of the manufacturing good relative to that of the agricultural good.

Technological progress in the two sectors is assumed to evolve in a fashion similar to the one-sector case. Agents employed in each sector can decide to take some fraction ω_t^j

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[15] The absence of a superscript in the per capita level of human capital is not a typo. The reason why h_t does not vary between the two sectors will be clarified once we return to discuss the household's objective problem.

of their unit time endowment in order to experiment with the existing level of technology in their corresponding sectors. This experimentation results in innovations of magnitude $\zeta_t^j = B^j(h_t)^\beta \omega_t^j$[16], which individual agents can then utilize to increase their wage per amount of time to $(1+\zeta_t^A)w_t^A$ and $(1+\zeta_t^M)w_t^M$ in the two sectors. As in the one-sector case, we maintain the assumption that the complete diffusion of all these new innovations only occurs with one period delay.

Furthermore, to incorporate interaction between the two sectors, we also entertain the possibility of positive technological spillovers. Particularly, we assume that technological improvements in the relatively more advanced sector partially spill over to the less advanced one in each period at a rate σ. Thus, the evolution of technology in sector j is governed by the expression,

$$A_{t+1}^j = (1+g_{t+1}^j)A_t^j + \sigma \max\{0, A_t^i - A_t^j\}, \tag{25}$$

with g_{t+1}^j corresponding to the rate of technological progress from innovation in sector j[17].

Given the above description, we have that the conditional potential income of a household whose adult agent works in the agricultural sector and spends fraction ω_t^A of his or her time experimenting should be,

$$z_t^A \equiv (1-\omega_t^A)(1+\zeta_t^A)w_t^A h_t, \tag{26}$$

while that of a household whose adult agent is employed in the manufacturing sector and spends fraction ω_t^M on experimentation should be:

$$z_t^M \equiv (1-\omega_t^M)(1+\zeta_t^M)w_t^M h_t. \tag{27}$$

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[16] The superscript on the parameter B is added to allow for potential institutional differences between the two sectors to affect the incentives of agent to engage in experimentation activities. We will comment more extensively on the importance of such differences in the following section when we are going to simulate the time path of the economy.

[17] We would like to emphasize here that the assumption of positive technological spillovers is not essential for the results of the paper and its purpose is mostly to add realism in the dynamics implied by the model.

Assuming a competitive economy-wide labor market, we have that the total labor force of the economy L_t will move between the two sectors to equate the income earned in the agriculture and manufacturing, i.e.: $z_t^A = z_t^M = z_t$. Hence, combing the above two equations with the identity $L_t^A + L_t^M = L_t$ as well as equations (23) and (24), we can solve for the labor market clearing condition,

$$L_t^A = (\frac{1-\omega_t^A}{1-\omega_t^M}\frac{1+\zeta_t^A}{1+\zeta_t^M})^{\frac{1}{1-\alpha}}(\frac{A_t^A}{p_t^M A_t^M})^{\frac{1}{1-\alpha}}\frac{X}{h_t}, \tag{28}$$

as well as the common level of conditional potential income:

$$z_t = (1-\omega_t^M)(1+\zeta_t^M)p_t^M A_t^M h_t.$$

This assumption of perfect labor mobility means that children of agricultural workers may end up working in the manufacturing sector in their second period of life and vice versa. For this reason, we will also not distinguish between the human capital of children raised in agricultural households and that of children raised in manufacturing ones. More concretely, as the offspring of each individual agent may end up working in either sector of the economy, we will consider the dynamics of human capital accumulation as being dictated by the average rate of technological progress in the economy:

$$\bar{g}_{t+1} = g_{t+1}^A \frac{L_t^A}{L_t} + g_{t+1}^M \frac{L_t^M}{L_t}. \tag{29}$$

Having described the production side of our two-sector economy, let us now turn to the discussion of the objective problem that each individual household faces. This problem is slightly more complicated than in the previous case as now households have two final goods to choose from. Specifically, given the imperfect substitutability of the agricultural and the manufacturing good, the relevant variable entering the household's utility is not the total amount consumed, but a composite index of the form,

$$\{[\chi(c_t^A - \tilde{c})]^\eta + [(1-\chi)c_t^M]^\eta\}^{\frac{1}{\eta}},$$

where c_t^j denotes the household's consumption level of the final good produced in sector j. The parameter η captures the degree of substitutability between the two goods, while χ denotes the weight that each type of good carries in the agent's utility. Note also that the subsistence requirement $\tilde{c}$ is reflected in terms of the agricultural good only.

Combined with this choice between the two goods, the head of each household has to decide, as before, on how to allocate his or her time endowment among the three possible activities of working, child-rearing and experimenting. Thus, for households working in the agricultural their objective problem reads,

$$\max_{\{\omega_t^A, c_t^{AA}, c_t^{MA}, n_t^A, e_{t+1}^A\}} u_t^A = \{[\chi(c_t^{AA} - \tilde{c})]^\eta + [(1-\chi)c_t^{MA}]^\eta\}^{\frac{1-\gamma}{\eta}}[n_t^A h(e_{t+1}^A, \bar{g}_{t+1})]^\gamma,$$
$$s.t. \left\{ \begin{array}{c} (1-\omega_t^A)(1+\zeta_t^A)^{1-\alpha} w_t^A h_t [1 - n_t^A(\tau^q + \tau^e e_{t+1}^A)] \geq c_t^{AA} + p_t^M c_t^{MA} \\ (1-\omega_t^A)[1 + B^A (h_t)^\beta \omega_t^A] \geq 1 \\ (c_t^{AA}, c_t^{MA}, n_t^A, e_{t+1}^A) \geq 0 \wedge 1 \geq \omega_t^A \geq 0 \end{array} \right\}, \tag{30}$$

while for households working in manufacturing we have:

$$\max_{\{\omega_t^M, c_t^{AM}, c_t^{MM}, n_t^M, e_{t+1}^M\}} u_t^M = \{[\chi(c_t^{AM} - \tilde{c})]^\eta + [(1-\chi)c_t^{MM}]^\eta\}^{\frac{1-\gamma}{\eta}}[n_t^M h(e_{t+1}^M, \bar{g}_{t+1})]^\gamma,$$
$$s.t. \left\{ \begin{array}{c} (1-\omega_t^M)(1+\zeta_t^M)^{1-\alpha} w_t^M h_t [1 - n_t^M(\tau^q + \tau^e e_{t+1}^M)] \geq c_t^{AM} + p_t^M c_t^{MM} \\ (1-\omega_t^M)[1 + B^M (h_t)^\beta \omega_t^M] \geq 1 \\ (c_t^{AM}, c_t^{MM}, n_t^M, e_{t+1}^M) \geq 0 \wedge 1 \geq \omega_t^M \geq 0 \end{array} \right\}. \tag{31}$$

Let us begin the analysis of the household's objective problem with the optimal choice between the two goods[18]. Under our assumption of perfect labor mobility, we argued that the

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[18] To clarify the notation used in the above expressions, let us mention that the variable c_t^{jk} denotes the amount of the final good of sector j consuamed by households employed in sector k, $j, k \in \{A, M\}$.

conditional potential income should be the same in both sectors of the economy. This means that both types of households end up demanding the same amount from the two goods, since they earn the same income. Thus, the corresponding demands for the two goods are as follows,

$$\hat{c}_t^{AA} = \hat{c}_t^{AM} = \hat{c}_t^{A} = \frac{1-\gamma}{1+(\frac{\chi}{1-\chi}p_t^M)^{\frac{\eta}{\eta-1}}} z_t + \frac{\gamma}{1+(\frac{\chi}{1-\chi}p_t^M)^{\frac{\eta}{\eta-1}}} \tilde{c} + \frac{1}{1+(\frac{\chi}{1-\chi}p_t^M)^{-\frac{\eta}{\eta-1}}} \tilde{c}, \tag{32}$$

$$\hat{c}_t^{MA} = \hat{c}_t^{MM} = \hat{c}_t^{M} = \frac{1-\gamma}{1+(\frac{\chi}{1-\chi}p_t^M)^{-\frac{\eta}{\eta-1}}} \frac{z_t - \tilde{c}}{p_t^M}. \tag{33}$$

Similarly, the decisions regarding the optimal number of children as well as their education are also identical for the two types of households who both choose,

$$\hat{n}_t^A = \hat{n}_t^M = \hat{n}_t = \frac{\gamma}{\tau^q + \tau^e e(\bar{g}_{t+1})}(1 - \frac{\tilde{c}}{z_t}), \tag{34}$$

$$\hat{e}_t^A = \hat{e}_t^M = \hat{e}_{t+1} = e(\bar{g}_{t+1}) = \left\{ \begin{array}{cc} 0 & \text{if } \bar{g}_{t+1} \leq g^* \\ e'(\bar{g}_{t+1}) & \text{if } \bar{g}_{t+1} > g^* \end{array} \right\}^{19}. \tag{35}$$

The only differences will be in terms of the time devoted to experimentation where -in the presence of variations in the institutional environment in the two sectors- agricultural households will choose,

$$\hat{\omega}_t^A = \omega^A(h_t) = \left\{ \begin{array}{cc} 0 & \text{if } h_t < (B^A)^{-\frac{1}{\beta}} \\ \frac{1}{2} - \frac{1}{2B^A} h_t^{-\beta} & \text{if } h_t \geq (B^A)^{-\frac{1}{\beta}} \end{array} \right\}, \tag{36}$$

while manufacturing households will choose,

$$\hat{\omega}_t^M = \omega^M(h_t) = \left\{ \begin{array}{cc} 0 & \text{if } h_t < (B^M)^{-\frac{1}{\beta}} \\ \frac{1}{2} - \frac{1}{2B^M} h_t^{-\beta} & \text{if } h_t \geq (B^M)^{-\frac{1}{\beta}} \end{array} \right\}. \tag{37}$$

For the market of both goods to clear, though, it has to be that the demand coming from the two types of households is met by the actual production in both sectors. This requires that,

$$\begin{aligned} L_t \hat{c}_t^A &= Y_t^A[1 - \hat{n}_t(\tau^q + \tau^e \hat{e}_{t+1})], \\ L_t \hat{c}_t^M &= Y_t^M[1 - \hat{n}_t(\tau^q + \tau^e \hat{e}_{t+1})], \end{aligned}$$

which can be simplified to:

$$p_t^M c_t^M L_t^A = c_t^A L_t^M. \tag{38}$$

This last expression can be understood simply as a requirement that the total value of the manufacturing goods consumed by agricultural households being equal to the value of agricultural goods consumed by manufacturing households. Substituting in the demands for both goods we obtain that,

$$[\frac{1-\gamma}{1+(\frac{\chi}{1-\chi}p_t^M)^{\frac{\eta}{\eta-1}}}z_t + \frac{\gamma}{1+(\frac{\chi}{1-\chi}p_t^M)^{\frac{\eta}{\eta-1}}}\tilde{c} + \frac{1}{(\frac{\chi}{1-\chi}p_t^M)^{-\frac{\eta}{\eta-1}}+1}\tilde{c}]L_t = [(1-\gamma)z_t + \gamma\tilde{c}]L_t^A. \tag{39}$$

Combining this last expression with the labor marker clearing equation (28) and using the solution for the households' conditional potential income we obtain a non-linear system of two equations, which can be solved for the relative price $\hat{p}_t^M$ that clears the market as well as the corresponding amount of labor $\hat{L}_t^A$ that needs to be devoted to agriculture,

$$\begin{aligned} \hat{p}_t^M &= p^M(h_t, A_t^A, A_t^M, L_t), \\ \hat{L}_t^A &= L^A(h_t, A_t^A, A_t^M, L_t). \end{aligned} \tag{40}$$

Note that both depend on the current state of technology in both sectors (A_t^A, A_t^M), the total size of the economy's labor force L_t, as well as the per capita level of human capital h_t.

The above solution, though, may not necessarily be interior. Particularly, given the size of the economy's labor force, the state of technology, and the level of human capital, the economy might not be able to support a manufacturing sector. This is because in order for labor to move into manufacturing, the agricultural sector has to be sufficiently productive in order to provide manufacturing workers with the necessary means for their subsistence. This is a requirement which is independent of the level of per capita income since,

$$\hat{c}_t^A \geq \frac{\gamma}{1+(\frac{\chi}{1-\chi}\hat{p}_t^M)^{\frac{\eta}{\eta-1}}}\tilde{c} + \frac{1}{1+(\frac{\chi}{1-\chi}\hat{p}_t^M)^{-\frac{\eta}{\eta-1}}}\tilde{c},$$

given the market clearing price. Hence, unless $0 \leq L^A(h_t, A_t^A, A_t^M, L_t) \leq L_t$, the manufacturing sector will not be operated and the agricultural sector will absorb the entire labor force of the economy. Thus, we have that the allocation of labor within the economy can be described with the following expression:

$$\hat{L}_t^A = \left\{ \begin{array}{cc} L_t & L^A(h_t, A_t^A, A_t^M, L_t) > L_t \\ L^A(h_t, A_t^A, A_t^M, L_t) & otherwise \end{array} \right\}, \tag{41}$$

$$L_t^{*M} = \left\{ \begin{array}{cc} 0 & L^A(h_t, A_t^A, A_t^M, L_t) > L_t \\ L_t - L^A(h_t, A_t^A, A_t^M, L_t) & otherwise \end{array} \right\}. \tag{42}$$

4.2 Model Implications

Although the above described model is too complicated to allow for the presentation of explicit comparative statics results, it nevertheless allows us to make some concrete inference. First of all, given the nature of agricultural output as the basic subsistence good, it is clear that the amount of labor allocated to manufacturing in each period is in fact constrained by the level of productivity in the agricultural sector. This is because an economy with a relatively unproductive agricultural sector will need to allocate a larger fraction of its labor force to that sector in order to cover the needs of its population in the basic subsistence good. Moreover, the imperfect substitutability of the two goods means that even if manufacturing was highly productive, this could only partially compensate for the low agricultural productivity.

Over time, though, technological improvements will ease this constraint, as gains in agricultural productivity will liberate resources that can be channeled toward manufacturing. Moreover, given our assumption regarding the nature of technological progress, the pace of such improvements will depend crucially on the institutional environment in the two sectors. Particularly, it is the institutional characteristics of the agricultural sector that matter the most for the long-run development path of the economy. This is because, given that the economy will start off in a predominantly agricultural state, for technological progress to take place, it is important that the agents employed in agriculture have the right incentives to engage in experimentation and produce new innovations.

This provides an alternative view of the structural transformation taking place over the course of economic development compared to that of Hansen and Prescott (2002). Our view suggests that the absence of manufacturing in the early stages of development is not due to the fact the manufacturing technology was unprofitable to operate, as emphasized by Hansen and Prescott, but due to the low level of agricultural productivity. Hence, even if the manufacturing sector was highly productive and thus profitable enough to be operated, a backward agricultural sector could still keep the economy in a low state of development.

Moreover, our theory suggests that a modernization of the agricultural sector should predate any structural transformation from agriculture to manufacturing. In the Hansen-Prescott model this is not necessary, as the two sectors are assumed to produce the same good. Thus, the whole transition is simply a matter of when the manufacturing sector will become productive enough, regardless of the state of technology in agriculture. Once this occurs, the whole labor force will gradually switch to that sector and the agricultural sector will seize to exist. Yet, Hansen and Prescott do not deal explicitly with the actual determinants of technological progress in the two sectors and how the on-going structural transformation feeds back to technological progress. This can be captured, though, in our model; so let us redo our calibration exercise using this time the two-sector model that we just outlined.

4.3 The Time Path of the Economy

Given the similarities of the one-sector and the two-sector models, the additional work needed to calibrate the latter is rather limited. We retain the same long-run equilibrium values for the main endogenous variables as well as the same initial conditions. Hence, we only have to choose numerical values for the additional parameters that we introduced with the manufacturing sector. These are the utility parameters η and χ, plus the spillover rate σ. For the latter, given the absence of any historical estimates, we resort to a contemporary value of 0.3 from Bottazzi and Peri (2002) estimated from European patent data. Regarding the utility parameters, η and χ, we can rely on historical evidence from Clark (2005, 2007) who analyzes the consumption patterns of the working class in England over the long period from 1209 to 1914. Based on this evidence, we set the parameter η to be equal to 0.8 and the value of χ to be 0.75.

Turning to our institutional parameter B, we maintain our previous benchmark value of 1.5 and assume initially that this value applies to both sectors. Later on, we will allow this value to differ between the two sectors and see how small changes in B^A and B^M can affect the time path of the economy. Particularly, as before, we focus on the extent to which such changes can delay or speed up the demographic transition and the emergence of sustained economic growth in an economy that starts off in a stagnant Malthusian equilibrium. Yet, let us begin with our baseline simulation results.

Figure 3 presents the time paths for the main endogenous variables. The simulated path is qualitatively similar to that of the one-sector economy, although it incorporates a substantially shorter period of Malthusian stagnation of about 160 generations.

[Insert Figure 3 here]

Figure 4 displays also the time paths of fertility and the share of labor force employed in the manufacturing sector. There, it can be seen that the accelerating phase of technological progress is associated with a rise in the level of income per capita, an increase in the number of children per household and a structural transformation of the economy with labor moving from agriculture to manufacturing.

[Insert Figure 4 here]

However, which factor is really driving this transition? Is it technological progress in manufacturing "pulling" labor from agriculture or technological progress in agricultural generating a surplus, part of which is channeled into manufacturing? To investigate these possibilities, we perform a simple test. We perturb slightly the values for B^A and B^M around the benchmark of 1.5 and observe, as in the previous section, how these changes are reflected in the number of generations elapsing before parents start investing in the education of their children. The results are displayed in the following two tables:

$\mathbf{B}^A$	*1.3*	*1.4*	*1.5*	*1.6*	*1.7*
$\mathbf{t}^*$	*227*	*193*	*165*	*137*	*109*

$\mathbf{B}^M$	*1.3*	*1.4*	*1.5*	*1.6*	*1.7*
$\mathbf{t}^*$	*178*	*171*	*165*	*157*	*149*

Note that the picture in the two tables is quite different. While small changes in B^A can, on the one hand, influence to a large degree the advent of the demographic transition, this does not seem to be true for changes of similar magnitude in B^M, on the other. Specifically, an adjustment of B^A from a value of 1.3 to a value of 1.7 leads to an earlier advent of the transition by exactly 118 generations, while at the same time a similar adjustment of B^M can only speed up the transition by 29 generations.

This highlights the central role that the agricultural sector plays in the long transition from primitive to advanced stages of economic development. Despite the presence of other -more dynamic- sectors in the economy, which are not subject to diminishing returns, the emergence from Malthusian stagnation, in the context of a closed economy, has to start from agriculture. For this reason, it is important that there are strong incentives to individual agents employed in agriculture to engage in technological innovation and to that extent the institutional environment in the agricultural sector can be instrumental in providing such incentives.

5 Empirical Evidence from Europe's Development History

In the previous sections we have attempted to argue that particular institutional characteristics of an economy, influencing the decisions of individual agents to engage in technological innovation, can have a large impact on its long-run development path. A question, though, that comes naturally here is whether there is also empirical evidence in support of this view. Specifically, to what extent have the actual development paths of particular economies been influenced by the prevalence or the absence of innovation-promoting institutions. After all, if technological progress was the result of a simple learning-by-doing process, then the effect of such institutional characteristics on long-run economic development would be limited. The pace of technological improvement would solely be driven by the size of the economy as the effect of learning-by-doing would be stronger in larger economies.

In what follows, we will make an attempt to assess the importance of innovation-promoting institutions for long-run economic development looking across the European continent. We focus on Europe, because the historical development in this continent is relatively better documented compared to other parts of the world. Also, given the long-run focus of our theory, we will concentrate our analysis on pre-industrial times, during which European countries can be safely treated as closed economies[20].

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[20] By this last sentence we don't mean that trade was generally nonexistent, but that its effect on specialization in production was rather limited. After all, it is a well documented historical fact that international trade up until the end of the19th century was mainly concentrated on luxury goods such as gold, silk and various spices, while the share of basic agricultural goods was neligible. Also, as documented in Bairoch (1988), 19th century European countries produced about 94-97% of the food suppy consumed by their pop-

Ideally, the hypothesis that we would like to test is the positive effect of innovation-promoting institutions on the rate of technological progress as reflected in equation (20). Yet, given the difficulty of measuring technological progress explicitly, in what follows we will turn to the indirect effect of such kind of institutions on other economy-wide variables. These variables are going to be measures of per capita GDP and urbanization, which -as we have shown in our simulations above- over the course of development follow the time path of technological progress. Particularly, as we have argued in the previous section, faster technological progress will speed up the pace of economic development and lead to higher levels of per capita GDP and higher urbanization rates. Thus, we can infer that the effect of a better institutional environment over long periods of time which will be reflected on a higher level of per capita GDP as well as a greater level of urbanization.

Of course, this is not to say that scale does not matter for technological progress. Yet, if technological improvements are the results of a costly innovation process and not just the result of simple learning-by-doing, as our theory has emphasized, we would expect to see that differences in innovation-promoting institutions should be reflected on measures of historical development, even when we account for differences in the relative sizes of the economies.

5.1 Data

To perform this empirical exercise we will use historical development data from pre-industrial Europe. Our main variable of interest is going to be the rate of urbanization across European countries during the late medieval and early modern times. This is based on the work of Bairoch, Batou, and Chevre (1988) who have collected data on the total number of people living in cities with more than 5000 inhabitants and which are available for the period from 800 AD to 1700 for every 100 years, and for the period 1750 to 1850 for every 50 years.

Particularly, we are going to focus on the period from 1300 to 1850 AD given that the earlier data are less reliable, as Bairoch, Batou, and Chevre (1988) themselves point out.

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ulation, and the large-scale imports of wheat from Northern America only started after the 1870s. Similar arguments have also been made by Jackson (1985) and Wrigley (1991).

These city-level data are then aggregated at the level of the country and combined with the historical population estimates of McEvedy and Jones (1978) to construct a panel of urbanization rates over the period 1300-1850 for 24 European countries[21].

This provides us with a good proxy for the relative size of the labor force employed outside of agriculture and the relative share of the non-agricultural sector in each country's output, as several economic historians including Wrigley (1985) and Bairoch (1988) have suggested. Moreover, this approach is in line with the recent literature in economics studying the determinants of the "Rise of Europe" that includes Acemoglu, Johnson, and Robinson (2005), Nunn and Qian (2009) and Voigtlaender and Voth 2009[22].

The population estimates of McEvedy and Jones (1978) will also provide us with a measure of the absolute size each country's economy. Yet, given the fact that our observations correspond to countries of very unequal land areas, ranging from the roughly 5,000,000 square kilometers of the European part of the former Soviet Union to the 30,000 square kilometers of Belgium, we will divide the population figures for each country by land area to derive the corresponding population densities. This will be our main scale parameter based on which we will be assessing the urbanization rate data.

To capture historical differences in the institutional environment across countries, influencing the decisions of individual agents to engage in technological innovation, we consider several of the proxies that have been suggested in the literature given the absence of a definitive measure of historical institutional quality available across a wider range of countries in the historical period of interest. The first proxy that we employ is a measure constructed by Acemoglu, Johnson, and Robinson (2005) capturing the historical constraints placed on the executives across Europe and spanning the whole period from 1000 to 1750 AD. The

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[21] These countries are Albania, Austria, Belgium, Bulgaria, Czechslovakia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Romania, Russia, Yugoslavia, Spain, Sweden, Switzerland and the U.K. delineated by their borders in 1978.

[22] Actually Acemoglu, Johnson, and Robinson (2005), Nunn and Qian (2009) and Voigtlaender and Voth 2009 have gone one step further, treating a country's rate of urbanization as a proxy for its level of per capita GDP. As we have shown in our simulation exercise, these variables do seem to move in the same direction of the course of the transition from stagnation to growth. Yet, the simpler interpretation of urbanization rates as the share of labor employed in manufacturing is sufficient for our current empirical exercise.

measure is based on research by Langer (1972) and Stearns (2001) on historical political institutions and follows the coding methodology applied in the POLITY IV index[23]. This together with the original data in POLITY IV gives us a measure of institutional quality for the entire period until 1850 that we are interested in.

Our second measure is based on the state history index of Putterman and Bockstette. This index captures the presence of an early and durable history of political organization above the tribal level for most present-day countries and is available over fifty years period starting from 1 A.D. and ending in 1950. Our rational for employing such an index lies on the fact that longer state history fosters governmental effectiveness, bureaucratic discipline and efficiency in public administration, as argued in Bockstette, Chanda, and Putterman (2002), which are factors that should also promote individual innovation both directly as well indirectly. To construct measures of each country's state history for the years of interest (1300, 1400, 1500, 1600, 1700, 1750, 1800, 1850), we follow Chanda and Putterman (2007) and calculate a weighted average of the current and previous values of the state history index giving full weight to the most recent half century and discounting earlier periods progressively with a 5% discount rate.

As a last proxy capturing institutional features affecting the incentives for innovation in the agricultural sector face, we use enclosure rates, namely the proportion of arable land enclosed, which we take from Allen (2003). This is because, as argued by O'Brien (1977), Campbell and Overton (1991) and Overton (1996), the traditional open-field farming system was not conducive to the introduction of new crops, new techniques and new husbandry methods. This is because such decisions had to be made at the community level and the potential benefits were, of course, shared[24]. Thus, the enclosure of open fields allowed individual farmers to reap a larger share of the benefits from improvements in agricultural

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[23] For more details on the POLITY IV project the reader is refered to Marshall and Jaggers (2006).

[24] As Simpson (2004) observes in early modern times French farmers made little attempts to increase output, because they feared that a greater surplus would only be appropriated by the seigneurs or the state. According to Overton and Campbell (1991), tenurial reforms in Ireland 1870 that transformed the land from tenant-farms to owner occupied farms also brought considerable gains in land, labor and total factor productivity in Ireland after 1870.

productivity. The actual enclosure data are based on information by Wordie (1983) and Pounds (1990) and span 9 European countries[25].

5.2 Regression Results

Having described the data, in what follows, we are going to present empirical evidence highlighting the indirect effect of innovation promoting-institutions on urbanization rates across European countries. Specifically, we estimate the following pooled OLS model:

$$urbanization_{i,t} = \alpha_0 + \alpha_1 \cdot Institutions_{i,t-1} + \alpha_2 \cdot Population\_Density_{i,t-1} + \alpha_3 \cdot urbanization_{i,t-1} + \varepsilon_{i,t}$$

where i indicates the country and t denotes the year. Note that we are backdating our main explanatory variables of institutions and population density as we expect their effect on urbanization via technological progress to set in over time. We also include the lagged value of the urbanization rate on the right hand side, recognizing the persistence of urbanization. This allows us to focus on the change in urbanization rates taking place between the years $t-1$ and t and avoid the potential endogeneity bias.

Moreover, following Acemoglu, Johnson, and Robinson (2005), we weight each observation by the population of each country in the corresponding year. This will help us mitigate the problem of measurement error in the urbanization rates. This is most likely higher in small countries for which the urban population estimates are just based on the information from a small number of cities[26].

Table 1 shows our baseline estimation results where each alternative explanatory variable is introduced separately first, and then. in column (5), the variables capturing the institutional environment are entered together with population density. The results of Table 1 confirm that all four types of variables have a positive and significant effect on urbanization

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[25] These countries are Austria, Belgium, England, France, Germany, Italy, Netherlands, Poland and Spain.

[26] For example, in the case of Albania or Ireland we only have information on 4 cities. The urban population of Germany on the other hand is derived by adding the population of 125 cities.

rates. Yet, it is interesting to note that the effect of population density becomes insignificant, once the effect of the institutional environment is taken into account.

[Insert Table 1 here]

Table 2 presents the same regressions with the additions of time fixed effects, which should take into account general time trends in the dependent variable. Note that the inclusion of fixed effects doesn't seem to affect the patterns observed in Table 1.

[Insert Table 2 here]

Furthermore, to account for the potential serial correlation in the urbanization rates within in each country, in Table 3 we repeat the estimation of Table 1 using this time the Huber/White/Sandwich estimator of variance and clustering observations by country. As it can be see, applying this technique also doesn't see to change the baseline results of Table 1.

[Insert Table 3 here]

Moreover, as a robustness exercise, we also estimate our model adding controls for other factors that could also influence the pattern of urbanization across Europe. These controls include geographic characteristics such as latitude, the average suitability of each country's land for agriculture and the degree of access to waterways, as well as the degree to which a country was involved in Atlantic trade, which according to Acemoglu, Johnson, and Robinson (2005) was important factor that influenced the rise of several western European nations. Again though, the inclusion of the above variables does not seem to affect our baseline results.

[Insert Table 4 here]

Finally, we would like to mention, although we do not report any results for the sake of brevity, that even if we redo the above exercise using historical per capita GDP data from Maddison (2001) instead of urbanization rates, we obtain results similar to the ones presented above. However, given that Maddison's data are only available for a smaller number of countries before 1800, our preferred specification is based on the urbanization data which are more comprehensive and detailed.

6 Concluding Remarks

The purpose of this research is to shed light on the determinants of technological progress in the long run, as an economy transitions from primitive to advanced stages of economic development. Our analysis emphasizes the deliberate efforts of individual agents to improve upon the existing level of technology and underscores the importance of the institutional environment in which the economy operates in providing incentives and influencing innovativeness of economic agents. Hence, our approach shares many of the aspects with the large body of literature on innovation-based growth. At the same though, our work on this topic, given its long-run focus, compliments important contributions in the recent literature on unified growth theory that aims at provides a unified framework for the study of the whole process of human economic development.

Starting from a simple theoretical model, we demonstrate how, once the link between technological progress and individual innovation is established, particular institutional characteristics of the economy can influence the pace of technological progress. Also, using a small-scale calibration exercise, we show that the effect of institutions on innovation and technological progress can be quite substantial in the long-run and influence to a large extent the timing of the transition from economic stagnation to sustained economic growth. Furthermore, extending our analysis to an economy with two productive sectors, agriculture and manufacturing, we show that innovation-promoting institutions in the former sector, given the special nature of the agricultural sector in producing the economy's basic subsistence good, are more important than in the latter one for the economy's long run economic development.

Finally, in a small scale empirical exercise using historical data from Europe, we are also able to provide empirical support for the above theoretical predictions. Particularly, using the rate of urbanization across countries as a proxy for the degree of economic development, we document an important positive effect of innovation-promoting institutions on economic development. Furthermore, we show that this effect survives even when differences in the scale of these economies are controlled for. Hence, these results support our view of technological progress stemming from individual innovation and not just simple learning by doing.

Still, we would like to point out, this paper is only a first step in direction of providing a theory of technological progress in the long run as well as of understanding the interaction between technological progress and the process of economic development. Much more work has to be done before the influence of particular institutional characteristics on technological innovation and the creation of new ideas is fully uncovered. Also more attention needs to be concentrated on the effect that particular aspects of economic development such as the shift from agriculture to manufacturing and the expansion of international trade have on the transfer of technology and the spread of new ideas across nation and continents.

References

Acemoglu, D., S. Johnson, and J. A. Robinson (2005): "The Rise of Europe: Atlantic Trade, Institutional Change and Economic Growth," *American Economic Review*, 95(3), 546–579.

Aghion, P., and P. W. Howitt (1992): "A Model of Growth Through Creative Destruction," *Econometrica*, 60, 323–351.

Allen, R. C. (1991): "The Two English Agricultural Revolutions, 1450-1850," in *Land, Labour and Livestock: Historical Studies in European Agricultural Productivity.* Manchester University Press, Manchester and New York.

——— (2004): "The Nitrogen Hypothesis and the English Agricultural Revolution: A Biological Analysis," Ph.D. thesis, Nuffield College.

——— (2006): "A PessimistŠs Guide to the British Industrial Revolution," Working paper no. 315, University of Oxford, Department of Economics.

——— (2007): "The British Industrial Revolution in Global Perspective: How Commerce Created The Industrial Revolution and Modern Economic Growth," Mimeo, University of Oxford.

Bairoch, P., J. Batou, and P. Chevre (1988): *The Population of European Cities, 800-1850.* Droz, Geneva.

Barro, R., and J.-W. Lee (2001): "International Data on Educational Attainment: Updates and Implications," *Oxford Economic Papers*, 3, 541–563.

Becker, G. S. (1960): "An Economic Analysis of Fertility," in *Demographic and Economic Change in Developed Countries*, ed. by A. J. Coale. Princeton University Press.

Becker, G. S., and H. G. Lewis (1973): "On the Interaction between the Quantity and Quality of Children," *Journal of Political Economy*, 81, 279–288.

Becker, G. S., K. V. Murphy, and R. Tamura (1990): "Human Capita, Fertility and Economic Growth," *Journal of Political Economy*, 98(5), 12–37.

Bockstette, V., R. Chanda, and L. Putterman (2002): "States and Markets: The Advantage of an Early Start," *Journal of Economic Growth*, 7, 347–369.

Campbell, B. M. S., and M. Overton (1991): "Productivity Change in European Agricultural Development," in *Land, Labour and Livestock: Historical Studies in European Agricultural Productivity.* Manchester University Press, Manchester and New York.

——— (1993): "Agricultural Progress in Medieval England: Some Evidence from Eastern Norfolk," *Economic History Review*, 36(1), 26–46.

Chanda, R., and L. Putterman (2007): "Early Starts, Reversal, and Catch-up in the Process of Economic Development," *Scandinavian Journal of Economics*, 109(2), 387–413.

Clark, G. (2005): "The Suprising Dynamism of the Malthusian Workld: Institutions, Preferences and Modern Growth," Meeting paper, 187, Society of Economic Dynamics.

Crafts, N. (1995): "Exogenous or Endogenous Growth? The Industrial Revolution Reconsidered," *Journal of Economic History*, 55(4), 745–772.

Crafts, N., and T. C. Mills (2009): "From Malthus to Solow: How Did the Malthusian Economy Really Evolve?," *Journal of Macroeconomics*, 31(1), 68–93.

Doepke, M. (2004): "Accounting for the Fertility Decline During the Transition to Growth," *Journal of Economic Growth*, 9(3), 347–383.

Galor, O. (2005): "From Stagnation to Growth: Unified Growth Theory," in *Handbook of Economic Growth*, ed. by P. Aghion, and S. Durlauf, pp. 171–293. North Holland.

Galor, O., and D. Weil (1999): "From Malthusian Stagnation to Modern Growth," *American Economic Review*, 89(2), 150–154.

——— (2000): "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90(4), 806–828.

Greif, A. (1993): "Contract Enforceability and Economic Institutions in Early Trade: The Maghribi Traders' Coalition," *American Economic Review*, 83(3), 525–549.

——— (2006): *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade*. Cambridge University Press.

Grossman, G., and E. Helpman (1991): "Quality Ladders in the Theory of Economic Growth," *Review of Economic Studies*, 58, 41–63.

Hansen, G. D., and E. C. Prescott (2002): "From Malthus to Solow," *American Economic Review*, 92(4), 1205–1217.

Johnston, B., and J. Mellor (1961): "The Role of Agriculture in Economic Development," *American Economic Review*, 51(4), 566–593.

Jones, E. L. (1965): "Agriculture and Economic Growth in England, 1660-1750," *Journal of Economic History*, 25(1), 1–18.

Lagerlof, N.-P. (2006): "The Galor-Weil Model Revisited: A Quantitative Excercise," *Review of Economic Dynamics*, 9(1), 116–142.

Langer, W. L. (1972): *An Encyclopedia of World History, 5th ed.* Houghton Mifflin Company, Boston.

Lucas, R. L. (2002): *Lectures on Economic Growth.* Harvard University Press, Cambridge, MA.

MacLeod, C. (1988): *Inventing the Industrial Revolution: The English Patent System.* Cambridge University Press, Cambridge.

MacLeod, C., and A. Nuvolari (2006): "Inventive Activities, Patents and Early Industrialization: A Synthesis of Research Issues," Druid working paper 06-08, Danish Research Unit for Industrial Dynamics.

Malthus, T. R. (1798): *An Essay on the Principles of Population, as it Affects the Future Improvement of Society with Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers.*

Marshall, M. G., and K. Jaggers (2006): *Polity IV Project: Political Regime Characteristics and Transitions, 1800-2006.*

McCloskey, D. (1981): "The Industrial Revolution 1780-1860: A Survey," in *History of Britain Since 1700*, ed. by R. Floud, and D. McCloskey. Cambridge University Press.

McEvedy, C., and R. Jones (1978): *Atlas of World Population History.* Facts on File, New York.

Mokyr, J. (1990): *The Level of Riches: Technological Creativity and Economic Progress.* Oxford University Press, Oxford and New York.

——— (2003a): *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press.

——— (2003b): "Institutions, Technological Creativity, and Economic History," in *Innovation, Resources and Economic Growth*, ed. by A. Q. Curzio, M. Fortis, and Z. R. Springer.

——— (2007): "The Institutional Origins of the Industrial Revolution," in *Institutions and Economic Performance*, ed. by E. Helpman. Harvard University Press.

Mokyr, J., and J. Voth (forthc.): "Understanding Growth in Europe, 1700-1870: Theory and Evidence," in *The Cambridge Economic History of Europe, 1700-1870*, ed. by S. Broadberry, and K. O'Rourke. Cambridge University Press.

Mokyr, J. E. (1993): *The British Industrial Revolution: An Economic Perspective.* Westview Press, Boulder.

North, D. C. (1981): *Structural Change in Economic History.* Norton Press, New York.

North, D. C., and B. Weingast (1989): "Constitutions and Commitment: Evolution of Institutions Governing Public Choice," *Journal of Economic History*, 49, 803–832.

Nunn, N., and N. Qian (2009): "The Potato's Contribution to Population and Urbanization: Evidence from an Historical Experiment," *NBER Working Paper*, w15157.

O'Brien, P. (1977): "Agriculture and the Industrial Revolution," *Economic History Review*, 30(1), 166–181.

Officer, L. H. (2009): "Purchasing Power of British Pounds from 1264 to Present," Ph.D. thesis, MeasuringWorth.

OVERTON, M. (1985): "The Diffusions of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk," *Transactions of the Institute of British Geographers*, 10(2), 205–221.

——— (1991): "The Determinants of Crop Yields in Early Modern England," in *Land, Labour and Livestock: Historical Studies in European Agricultural Productivity.* Manchester University Press, Manchester and New York.

——— (1996): *Agricultural Revolution in England: The Transformation of the Agrarian Economy 1500-1850.* Cambridge University Press, Cambridge.

POUNDS, N. J. G. (1990): *An Historical Geography of Europe.* Cambridge University Press.

ROMER, P. (1990): "Endogenous Technical Change," *Journal of Political Economy*, 98, 71–102.

ROSENBERG, N., AND L. E. BIRDZELL JR (1986): *How the West Grew Rich: The Economic Transformation of the Industrial World.* Basic Books.

SCHULTZ, T. W. (1964): *Transforming Traditional Agriculture.* Yale University Press, New Haven.

SOLOW, R. (1956): "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economic*, 70(1), 65–94.

STEARNS, P. N. (2001): *The Encylopedia of World History, 6th ed.* Houghton Mifflin Company, Boston.

TURNER, M. E. (1982): "Open Fields and Enclosures: Retardation or Productivity Improvements," *Journal of Economic History*, 46(3), 669–692.

VOIGTLAENDER, N., AND J. VOTH (2006): "Why England? Demographic Factors, Structural Change and Physical Capital Accumulation During the Industrial Revolution," *Journal of Economic Growth*, 11(4), 319–361.

WORDIE, J. R. (1983): "The Chronology of English Enclosure, 1500-1914," *The Economic History Review*, 36(.), 482–505.

WRIGLEY, E. A. (1985): "Urban Growth and Agricultural Change: England and the Continent in the Early Modern Period," *Journal of Interdisciplinary History*, 15(4), 683–728.

YOUNG, A. (1770a): *A Course in Experimental Agriculture.*

——— (1770b): *The Farmer's Tour Through the East of England.* London.

Figure 1a

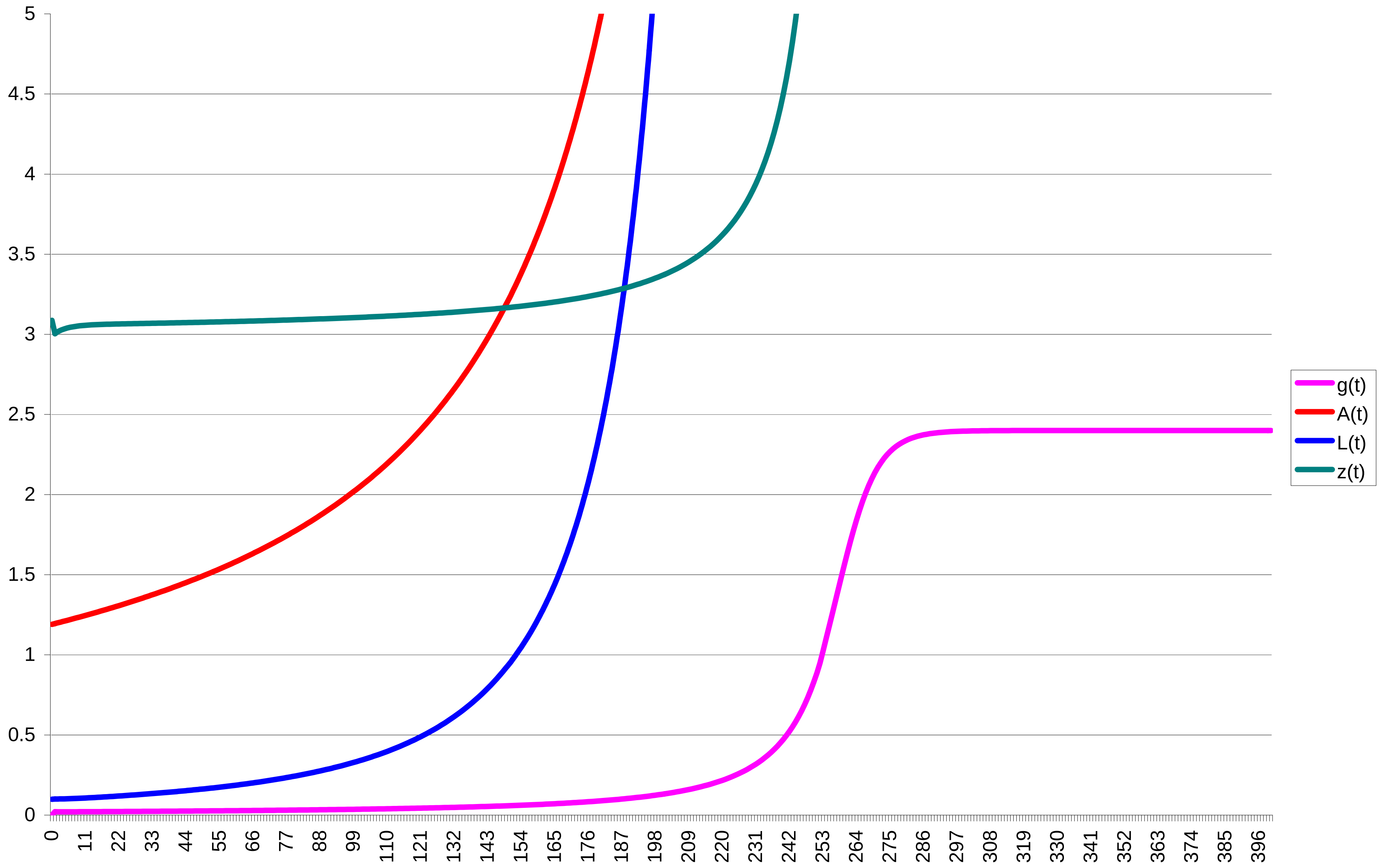
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Figure 1b

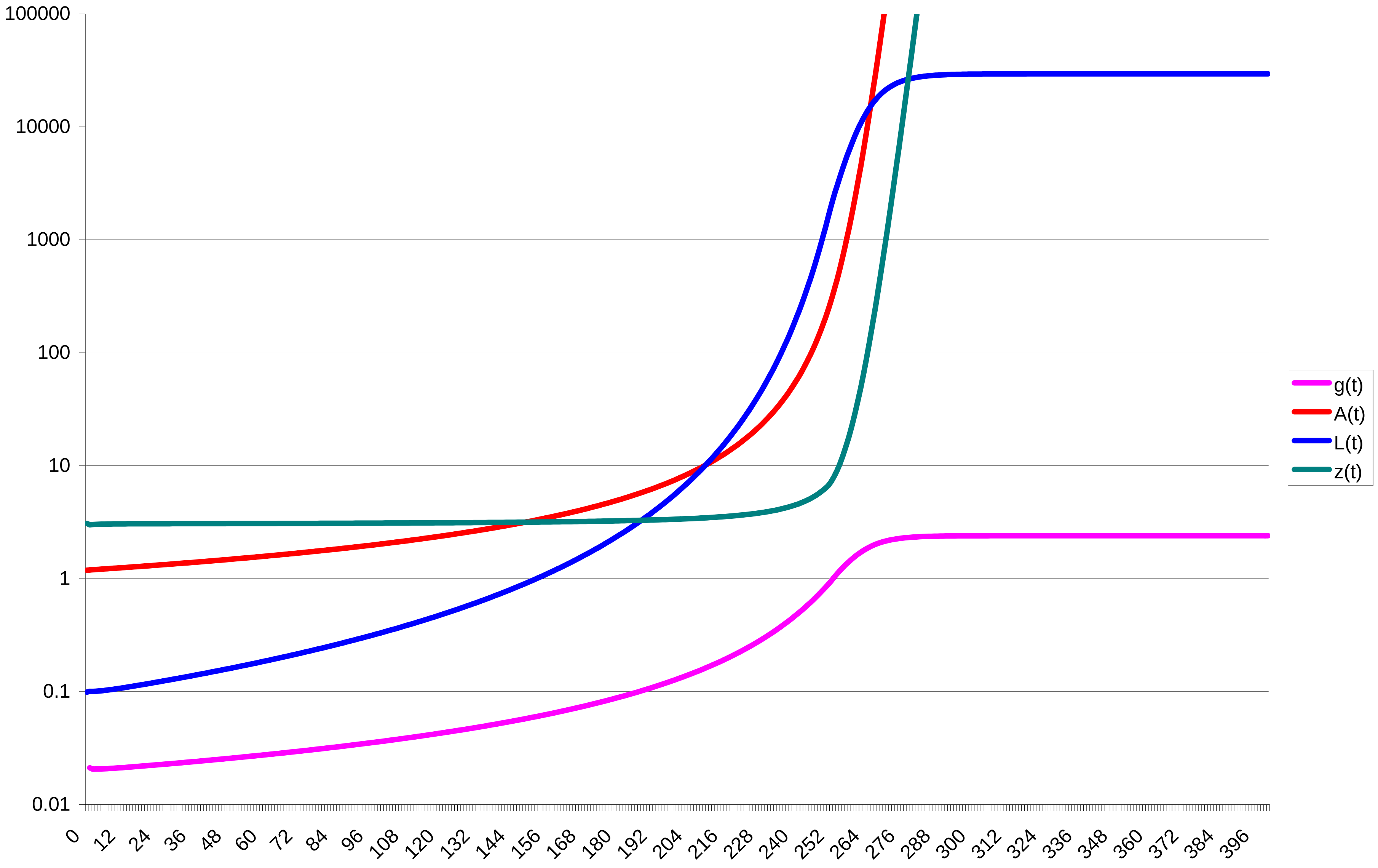
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Figure 2

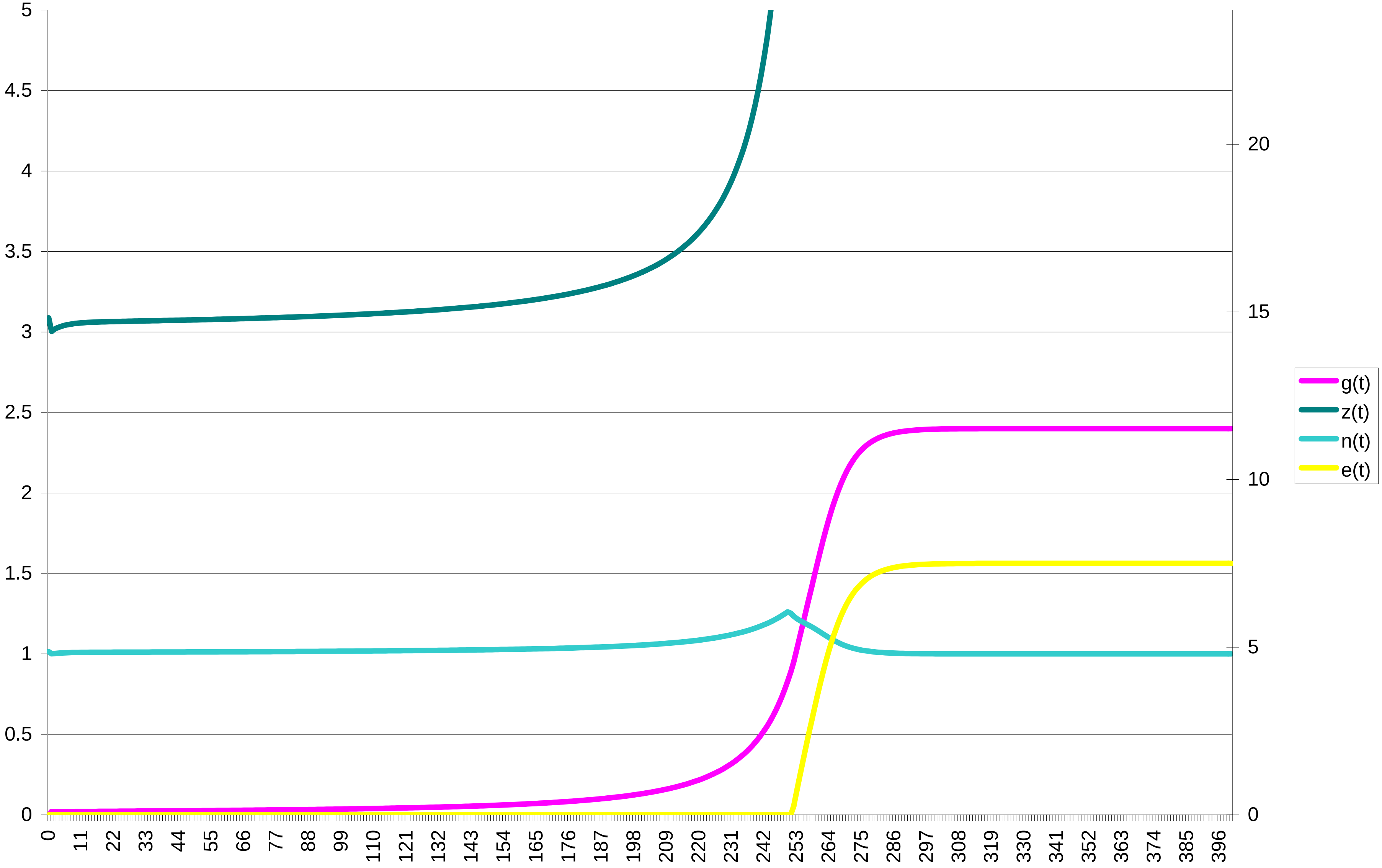
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Figure 3

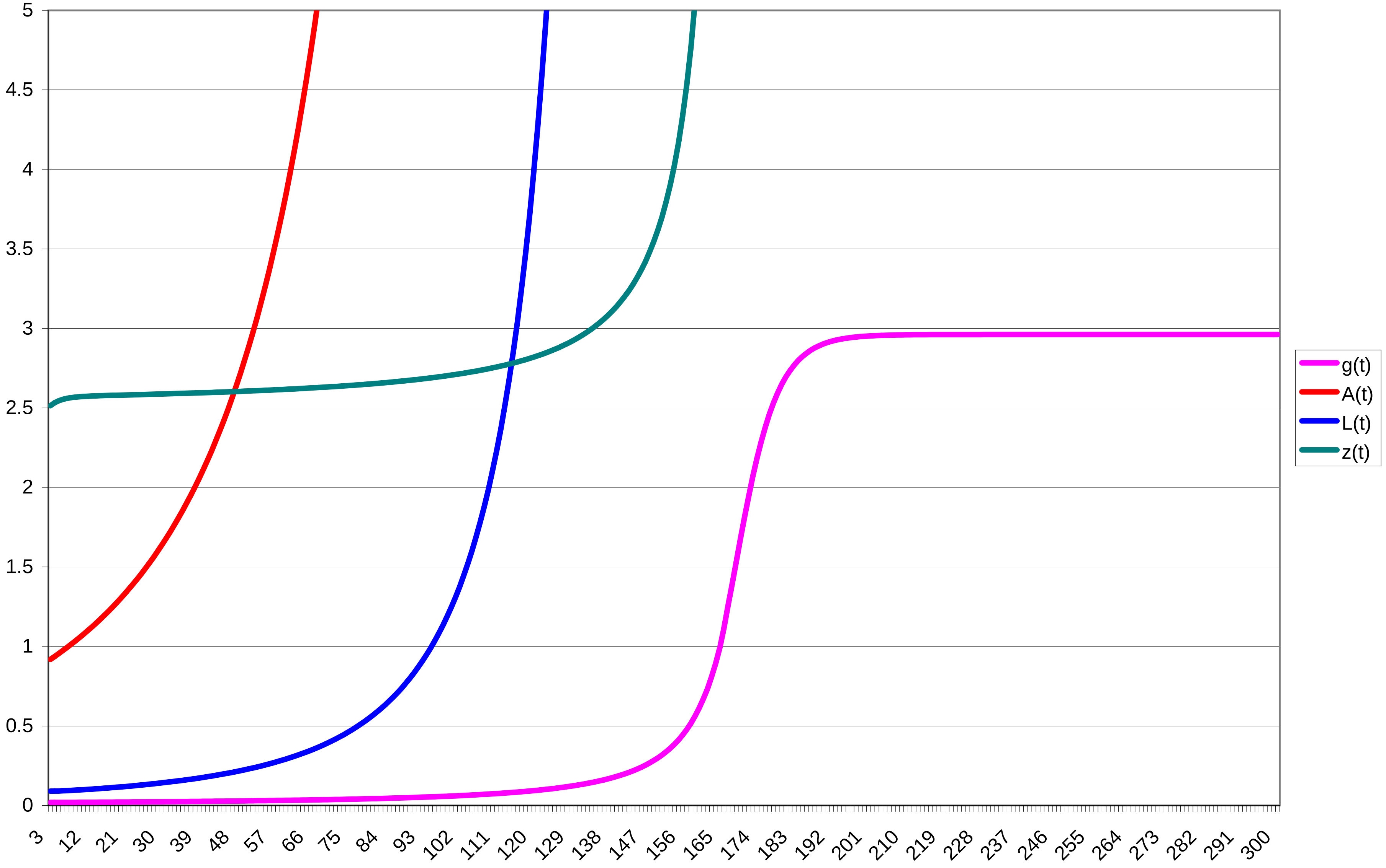
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Figure 4

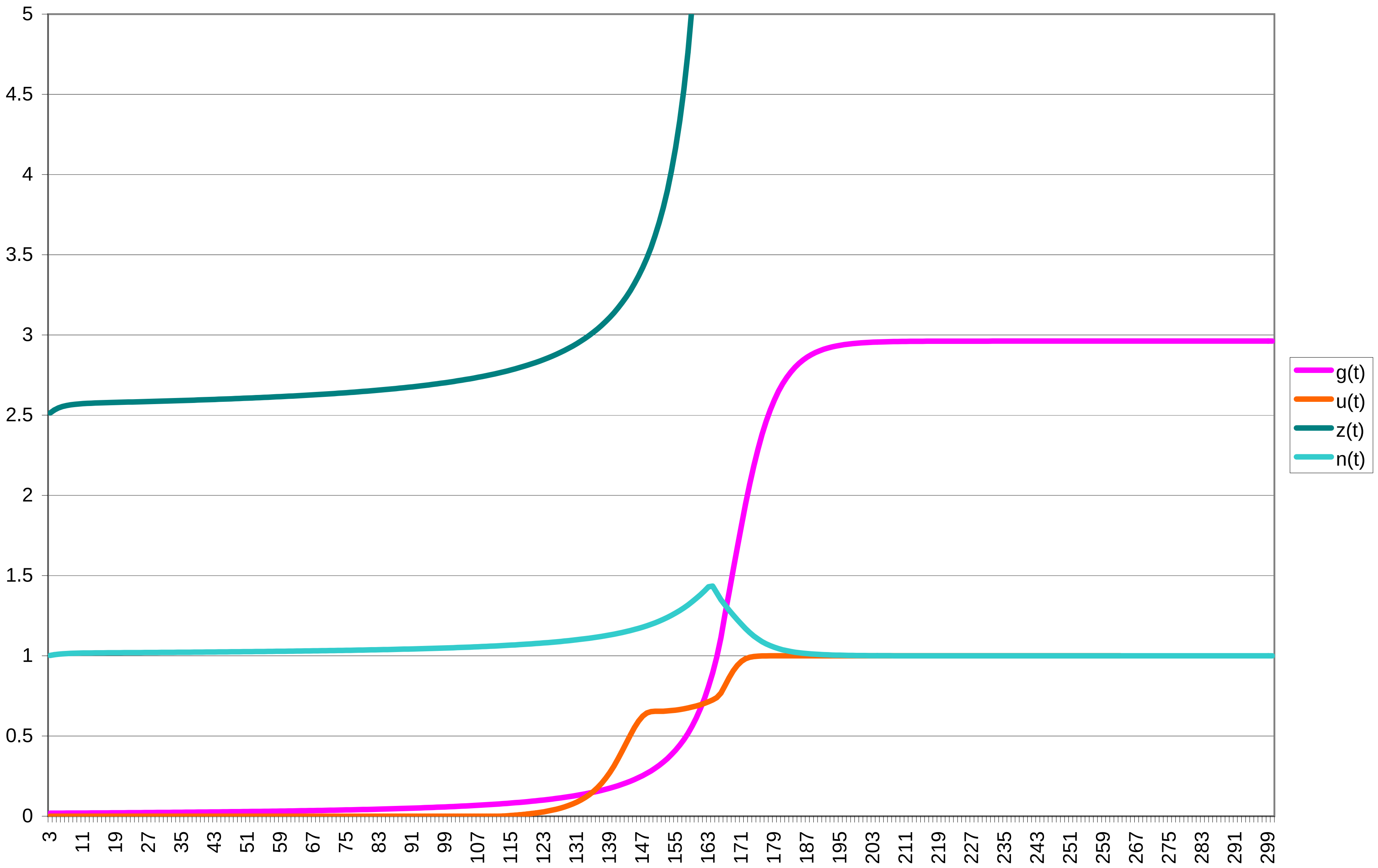

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Table 1: Baseline Results

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is Urbanization Rate, 1300-1850					
Population Density, lagged	0.000313*				-0.000109	0.000106
	[0.000166]				[0.000191]	[0.000334]
Institutions, lagged		0.00934***			0.00916***	
		[0.00182]			[0.00186]	
State History, lagged			0.0000461***		0.0000445**	
			[1.75e-05]		[1.99e-05]	
Enclosure Rate, lagged				0.0442**		0.0432**
				[0.0181]		[0.0185]
Lagged Value of Urbanization	0.972***	0.958***	0.970***	0.961***	0.925***	0.950***
	[0.0426]	[0.0330]	[0.0381]	[0.0607]	[0.0406]	[0.0719]
Weighted by Population	YES	YES	YES	YES	YES	YES
Clustering by Country	NO	NO	NO	NO	NO	NO
Year Fixed Effects	NO	NO	NO	NO	NO	NO
Observations	168	168	168	55	168	55
R-squared	0.858	0.875	0.861	0.842	0.877	0.833

*** p<0.01, ** p<0.05, * p<0.1; if there is more than one control variable, the adjusted R-squared is reported

Table 2: Panel Results

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is Urbanization Rate, 1300-1850					
Population Density, lagged	0.000252[a]				-0.000227	-0.0003
	[0.000172]				[0.000197]	[0.000413]
Institutions, lagged		0.00995***			0.0100***	
		[0.00178]			[0.00182]	
State History, lagged			0.000042**		0.0000445**	
			[1.73e-05]		[1.96e-05]	
Enclosure Rate, lagged				0.0438**		0.0460**
				[0.0177]		[0.0180]
Lagged Value of Urbanization	0.979***	0.948***	0.968***	0.942***	0.930***	0.963***
	[0.0420]	[0.0329]	[0.0384]	[0.0634]	[0.0393]	[0.0699]
Weighted by Population	YES	YES	YES	YES	YES	YES
Clustering by Country	NO	NO	NO	NO	NO	NO
Year Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	168	168	168	55	168	55
R-squared	0.862	0.883	0.865	0.846	0.885	0.844

[a] marginally significant at 14%

*** p<0.01, ** p<0.05, * p<0.1; if there is more than once control variable, the adjusted R-squared is reported

Table 3: Clustering By Country

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is Urbanization Rate, 1300-1850					
Population Density, lagged	0.000313**				-0.000109	0.000106
	[0.000150]				[0.000199]	[0.000246]
Institutions, lagged		0.00934**			0.00916**	
		[0.00395]			[0.00400]	
State History, lagged			0.0000461***		0.0000445***	
			[1.49e-05]		[1.44e-05]	
Enclosure Rate, lagged				0.0442		0.0432
				[0.0291]		[0.0295]
Lagged Value of Urbanization	0.972***	0.958***	0.970***	0.961***	0.925***	0.950***
	[0.0843]	[0.0454]	[0.0859]	[0.0867]	[0.0605]	[0.0995]
Weighted by Population	YES	YES	YES	YES	YES	YES
Clustering by Country	YES	YES	YES	YES	YES	YES
Year Fixed Effects	NO	NO	NO	NO	NO	NO
Observations	168	168	168	55	168	55
R-squared	0.858	0.875	0.861	0.842	0.879	0.842

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Robustness

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable is Urbanization Rate, 1300-1850					
Population Density, lagged	0.000187				-0.0000138	0.000473
	[0.000213]				[0.000210]	[0.000340]
Institutions, lagged		0.00937**			0.00965**	
		[0.00388]			[0.00384]	
State History, lagged			0.0000713***		0.0000777***	
			[1.75e-05]		[2.07e-05]	
Enclosure Rate, lagged				0.0437*		0.0476*
				[0.0231]		[0.0274]
Latitude	0.0419	-0.0139	0.072	0.089	0.00999	0.095
	[0.0839]	[0.0416]	[0.0776]	[0.235]	[0.0421]	[0.255]
Access to Waterways	0.0113	0.00275	-0.00509	-0.0403	-0.0217*	-0.0642
	[0.0154]	[0.00691]	[0.0121]	[0.0401]	[0.0122]	[0.0500]
Lagged Value of Urbanization	0.989***	0.946***	0.984***	0.978***	0.917***	0.923***
	[0.108]	[0.0587]	[0.0905]	[0.129]	[0.0681]	[0.157]
Weighted by Population	YES	YES	YES	YES	YES	YES
Clustering by Country	YES	YES	YES	YES	YES	YES
Year Fixed Effects	NO	NO	NO	NO	NO	NO
Observations	168	168	168	55	168	55
R-squared	0.86	0.876	0.865	0.844	0.882	0.847

*** p<0.01, ** p<0.05, * p<0.1; if there is more than once control variable, the adjusted R-squared is reported