The English Skill Premium Puzzle, 1750 - 1913*

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Abstract

The paper proposes a theory of demography that helps chart the evolution of skill premia in England during its first and second Industrial Revolutions. Skilled labor in England earned roughly 60% more than their unskilled counterparts during the first half of the 18th century. Skill-premia did however fall during the first Industrial Revolution to below 50% and remained below 50% through the entire 19th century. This fact is at odds with most theories of the Industrial Revolution, which tend to imply rising premia as natural concomitants to economic growth. I develop a simple model of economic demography to help solve this puzzle. Conjecturing that English households wished to maximize both their levels of income and the levels of education of their children, I demonstrate how rising education levels, non-monotonic fertility rates, and falling skill premia of England's 19th century economy can all be explained within one theory.

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1 Introduction

Growth economists have made great strides in opening up the 'black box' of innovation. By endogenizing the evolution of technology through mathematical modeling and economic reasoning, growth theorist have gained a deeper sense of how progress occurs. But with these strides have come new challenges, namely adequately capturing the qualitative *effects* of these technological changes. In particular, the accessories of today's technological advances are in many ways completely different from those at the dawn of technological growth. Today progress is associated with a stable population, high rates of education, great income growth on average and great income disparities within the economy. The world's first foray into modernity two and a half centuries ago, on the other hand, witnessed the polar opposite case of an exploding population, stagnant education, very modest increases in average income and falling income inequality. Traditional endogenous growth theory, able to capture present-time growth, is nevertheless consistent only with a small fragment of human history.

What to make of such disparate pictures? To extrapolate forward from the Industrial Revolution would be to predict an egalitarian society of 40 billion illiterate souls of very modest means.[1] To extrapolate backwards from our modern world would be to suggest an industrial "big bang" of immediate fertility control and skill acquisition. Both exercises are misleading; historical discontinuities frustrate these kinds of simple forward and backward inductions.

In this paper I attempt to link both worlds by employing a model of technology and demography. Using a unified approach such as this has been the *cri de coeur* of Oded Galor, who entreats growth economists to use micro-founded approaches to capture the entire process of development, not merely an episode of it (Galor 2005). This creates a great intellectual challenge - constraining oneself to a single theory to account for the whole process of development will arguably enhance the viability of growth theory overall.

To capture the historical responses to technological changes, I conjecture two main things, one concerning demography and one concerning technology. With respect to demography, we should consider a model of equilibrium growth in which we view households' choices over the number of children to have and the amounts of different kinds of capital to accumulate as simultaneous decisions. By introducing fertility and investment decisions into growth theory, this research leads one to view the industrial revolution and the associated changes in fertility and investment as different consequences of the same underlying cause. Thus we could consider a dynastic utility function, where parent's and children's utilities are linked by the difference equation

[1] Or so might conclude those at *Scientific American*, who published an article in 1976 suggesting that the earth could support a population of 40 billion on a diet of 2,500 calories per day. Of course, the nation of Utopia in H.G. Wells's *Men Like Gods* sounds like an extrapolation of this kind into the *very* distant future: "[the people] spent the great gifts of science as rapidly as it got them in a mere insensate multiplication of the common life. At one time in the Last Age of Confusion the population of Utopia had mounted to over two thousand million."

$$u_t = W\left(c_t, n_t, u_{t+1}\right) \tag{1}$$

where c_t denotes current consumption and n_t denotes the rate of fertility. My approach will be to break down the household's decision to two control variables - the fertility rate (n), and the education rate (e). Thus I transform (1) into

$$u_t = W\left(c\left(n_t, e_t\right), e_t\right) \tag{2}$$

Here current consumption will be a function of both the quantity and the quality of their children, and a balance will need to be struck between the two at each period in time. Further, parents care about their children's utility insofar as they care about their *education*. We will see that this relatively parsimonious utility will be enough to capture the key qualitative aspects of industrialization.

With respect to technologies, I assume that historically knowledge growth has been *factor-biased*; that is, technological innovation has typically affected different factors of production differently. Specifically, we will focus on the skill- and labor-biases of technology; as such we will assume that production is given by

$$Y_t = F(A_{l,t}L_t, A_{h,t}H_t) \tag{3}$$

where A_l can be considered unskilled-bias technology, and A_h can be considered skilled-bias technology. Looking at technologies that are factor-specific has been suggested by Acemoglu (2002) and Voth (2003), among others, as a way to shed further light on the history of industrialization. By analyzing the interactions between these technologies and demographic choices, unified growth theory can be pushed into new areas of understanding.

I should note here that I am only studying the consequences of technological progress, not the sources. Nor am I attempting to account for the timing of industrialization, or motivate the reasons why it happened in England, and not China, India or Japan. For these reasons I treat technological advances as exogenous.[2] However, we should nevertheless investigate the deus ex machina of both the Industrial Revolution and the Demographic Transition simultaneously, for this can help explain some of the historical concomitants of industrialization. Do they each arise from different sources, or do they result from the same underlying forces? The unified approach that follows conjectures the latter to examine what possible forces could have shaped the world into the one in which we currently find ourselves.

[2]Mokyr and Voth 2006 draws from Isaiah Berlin's "The Hedgehog and the Fox" to distinguish between two kinds of researchers - "hedgehogs" looking for a single Theory of Everything, and "foxes" looking for solutions to smaller problems. In keeping certain things exogenous in order to explain some other large phenomena, this paper strives to merge the grand vision of the hedgehog with the talents of the fox.

The rest of the paper proceeds as follows. Section 2 enumerates some of the "stylized facts" of the first and second Industrial Revolutions. Section 3 goes through the model of technology and demography. Section 4 simulates the model to see if it can adequately capture the major qualitative aspects highlighted in section 2. Section 5 briefly addresses some alternative scenarios of industrialization. Section 6 concludes.

2 The Facts to Fit

Galor (2005) asks some of the fundamental questions that unified growth theory aims to answer, one of the most important being "What are the underlying behavioral and technological structures that can simultaneously account for these distinct phases of development?" In this paper we impose a certain technological and behavioral structure, motivated by available historical evidence, that uniquely accounts for these phenomena. The phenomena we wish to address constitute a new set of "stylized facts" that beg explanation by unified growth theories on the Industrial Revolution.

2.1 Income and Productivity Growth

The first challenge for a model of the Industrial Revolution is to account for its fairly *un*-revolutionary beginnings. Productivity increases were confined to a few sectors of the economy during the first Industrial Revolution, keeping aggregate productivity growth, and therefore output per capita growth, quite low. For the aggregate economy, the efficiency of production of income increased only 0.22 percent per year during most of the eighteenth century, a rate perhaps fast by the standards of the Malthusian era but still very slow by modern standards. Only until the second Industrial Revolution did productivity robustly rise throughout the aggregate economy (Figure 1). Rapid productivity growth comparable to that of modern economies did not appear in England until the late nineteenth century. Thus while the preindustrial world was one largely of technological stasis, the transition to modernity and robust income growth took nearly two centuries to achieve.

2.2 The Rise and Fall of Fertility

One reason why incomes did not rise very much during the first Industrial Revolution was the link between productivity growth of this time and the explosion in English population in the years 1750-1850. The English population rose from six million in the 1740s (roughly the maximum attained throughout the previous millennium) to twenty million by the 1860s. Most of this population increase came from increases in fertility, as mortality declined very modestly during

the first Industrial Revolution (falling only to where it had been during the mid-seventeenth century). Crude birth and death rates for England are depicted in Figure 2.

The relationship between income per capita and population growth however evolved non-monotonically. While the first Industrial Revolution witnesses a dramatic increase in birth rates along with increases in per capita incomes, this pattern reversed during the second Industrial Revolution, where further per capita income gains accompanied rapidly falling birth rates (Figures 3 and 4).

2.3 The Role of Education

One of the most difficult challenges for would-be unified growth theorists is attempting to explain education's non-role in the first Industrial Revolution. Despite the implication of most growth theory that industrialization and skill accumulation go hand in hand, the Industrial Revolution appears to be compatible with greater use of *unskilled* labor instead of skilled labor. During this time rates of formal education and training either remained utterly stagnant or rose very modestly. There is much evidence of this pattern. For example, David Mitch suggests that in key expanding sectors of the British economy, such as cotton textiles, educational levels were actually declining. For the general economy, elementary school enrollment figures based on parochial surveys between 1818 and 1833 show enrollment perfectly steady at 42 percent (Mitch 1982). Indeed, according to Sanderson (1995), literacy rates did not increase at all through the whole first wave of industrialization (1750 - 1830). Landes (1969) sums it up best: "Although certain workers - supervisory and office personnel in particular - must be able to read and do the elementary arithmetical operations in order to perform their duties, a large share of the work of industry can be performed by illiterates as indeed it was, especially in the early days of the Industrial Revolution." In short, formal education did not rise during the heart of the first Industrial Revolution, the period between 1750 and 1830.

This makes the contrast between the first and second Industrial Revolutions all the more striking, for education enormously grew in importance in production processes later on. For example, Schofield (1973) shows very sluggish increases in signature rates at marriage from 1780 - 1830, but these subsequently skyrocket, and England achieves nearly universal literacy a mere 70 years later. And Flora et al. (1983) documents that while only 11 percent of children aged 5-14 were enrolled in primary school in 1855, this figure explodes to 74 percent by the turn of the century (see Figures 5 and 6). Thus it appears that education became more and more important in production only with England's *second* wave of industrialization.

2.4 Inequality and the Skill Premium

Based on the evidence on education, one would perhaps suspect that earnings for educated people were quite low during the first Industrial Revolution, and this induced families to keep their children uneducated. Only higher relative earnings for educated children would induce parents to provide their children a formal schooling. But the evidence suggests just the opposite - from 1700 up to the Great War, the premium on education was at its peak *before* industrialization and modernization ever happened.

In fact, the skill premium fell during both of England's Industrial Revolutions (Figures 7 and 8). That is, industrialization appears to be conducive to falling returns to skilled labor relative to the returns to unskilled labor. This is true whether looking at different income levels across a range of countries (Figures 9 and 10) or different growth rates across a range of countries (Figure 11).

There are other sources of evidence to support this as well. For example, there is no sign that the rewards to numeracy and literacy were any higher in England in 1800 than they were in 1200. We cannot measure this directly, but the premium for other skills in the labor market seems to have outright declined through the Industrial Revolution. At the turn of the 19th century, we find absolutely no evidence of any market signal to parents that they need to invest more in the education or training of their children. (Clark 2007).

A rather formidable puzzle emerges when attempting to reconcile all these pieces of industrialization. Although human capital is often center stage in stories of modernization, we see a very poor match between the elements that enter into a human capital story of the Industrial Revolution: the nature of industrialization itself, the average size of families, and the premium paid in the labor market for skills. Some particularly thorny questions arise when looking at the relative returns to skilled labor. Why did the skill premium fall with England's launch into sustainable economic growth? After all, the rising importance of skills has often been equated with increasing modernity. And why did the skill premium continue to fall during the second Industrial Revolution? After all, technological progress during this time clearly relied on human capital more than at any other time in history.

2.5 A Theoretical Solution

To reconcile this puzzle, we need to adequately account for both the *demand* for relative skills and the *supply* of relative skills, and realize that both were shifting throughout the course of industrialization. In fact, given that the first Revolution was characterized by a dramatic rise in population relative to human capital, increases in the demand for unskilled labor relative to skilled labor (due to unskilled-bias technological improvements) outpaced shifts in the supply of unskilled labor relative to skilled labor (to due modestly rising household income). Thus

the first Industrial Revolution witnessed a fall in both relative human capital and the relative returns to that human capital. The second Industrial Revolution, on the other hand, was a case where shifts in the supply of relative skills (due to more robust income increases) outpaced shifts in in the demand for relative skills (due to skill-bias technological improvements). Thus latter industrialization was characterized by both *rising* relative human capital and *falling* relative returns to that human capital. Figure 11 highlights these two cases.

What follows is a dynamic model that mimics these trends. Two general assumptions are necessary to achieve this. First, final output is produced both by skilled and unskilled labor that utilize factor-specific technologies. The second is that households derive benefits from both income (generated from both skilled and unskilled labor) and human capital (generated from the education obtained by children). The next sections make specific some of these ideas, and simulate an economy to replicate the key features of English industrialization.

3 A Model of Industrialization

3.1 Production

Total production in the economy combines the efforts of both unskilled and skilled labor. These labor-types are imperfectly substitutable; thus we assume that aggregate production can be described as a CES production function with factor-specific technologies:

$$Y = \left((A_l L)^{\frac{\sigma-1}{\sigma}} + (A_h H)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{4}$$

where A_l is labor-augmenting technology and A_h is human capital-augmenting technology. Following Acemoglu (2002), we will assume that $\sigma > 1$, so that these factor-augmenting technologies are unambiguously factor-*using* technologies.[3]

Factors are of course paid their marginal products in competitive markets. Assuming this, and introducing time subscripts to highlight those variables that evolve, we have

$$w_{l,t} = \frac{\sigma}{\sigma-1} \left((A_{l,t} L_t)^{\frac{\sigma-1}{\sigma}} + (A_{h,t} H_t)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}} \left(\frac{\sigma-1}{\sigma} \right) L_t^{-\frac{1}{\sigma}} A_{l,t}^{\frac{\sigma-1}{\sigma}} \tag{5}$$

$$w_{h,t} = \frac{\sigma}{\sigma-1} \left((A_{l,t} L_t)^{\frac{\sigma-1}{\sigma}} + (A_{h,t} H_t)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}} \left(\frac{\sigma-1}{\sigma} \right) H_t^{-\frac{1}{\sigma}} A_{h,t}^{\frac{\sigma-1}{\sigma}} \tag{6}$$

Keeping A_l and A_h fixed allows us to plot the demand curve for relative skills by observing how changes in the factors of production translates into changes in factor payments. Any changes in A_l and/or A_h would shift this curve.

[3] With $\sigma < 1$, factors of production become grossly complementary, in which case factor-augmenting technological growth for just one factor will create factor-*saving* behavior for that factor and factor-*using* behavior for the *other* factor.

3.2 Endogenizing Demography

The economic theory of fertility and education suggests that the household demand for children and their education will depend on family preferences, in many ways similar to preferences over standard economic "goods." Thus the demographic choice for a society stems from the perceived price or opportunity cost of child-rearing, and from levels of family income. The question for theorists of unified growth is how to model stable family preferences that are consistent with the very different patterns of behavior observed in history.

I will assume that agents care both about their current consumption of the final good, and the level of human capital of their children. An individual begins life naturally as an unskilled worker, accumulates human capital, and then decides as an adult whether to become a skilled worker or to remain as an unskilled worker. Because using your skilled labor always earns more than using your unskilled labor, adults always decide to work as skilled labor. Consequently the skilled and unskilled are divided into two distinct age groups. That is, an agent evolves naturally from an unskilled worker into a skilled worker; thus his welfare will be affected by both types of wages.

With this in mind, let us adopt an over-lapping generations framework where individuals have two stages of life: young and mature. Only mature adults are allowed to make any decisions regarding demography. Specifically, the representative household is run by an adult who decides two things: how many children she wishes to have (denoted n_t) and the level of education each child will receive (denoted e_t).

Our modeling of demography is as follows. An individual born at time t spends fraction e_t of her time in school (something chosen by her parent), while devoting the rest of her time as an unskilled laborer in the unskilled sector. At $t+1$, the individual (who is by this time a mature adult) works strictly as a skilled laborer, using whatever human capital she had accumulated as a child in the skilled sector. After incurring the resource costs of child-rearing, the adult consumes all the income she and her family have generated. After this she expires and exits the economy.

Given this, we may specify an objective function which a mature adult will wish to maximize. We assume that agents care about both their income and their children's future level of human capital,[4] and that these two things are imperfectly substitutable.

The welfare function of the parent W is given by

$$W = \left(\lambda \left(S_t + U_t - C_t\right)^{\varepsilon} + (1-\lambda)\left(H_{t+1}\right)^{\varepsilon}\right)^{1/\varepsilon} \tag{7}$$

where U is unskilled income produced by the children, S is the skilled income produced by the parent, C is the opportunity costs associated with child-rearing, and H is the average human

[4]Utility based on the education of children need not solely be motivated by altruism. For example, educated children may produce a pleasant and stimulating living environment, or may produce a source of retirement income.

capital endowed to each child. These variables are functions of fertility and eduction choices made by the parent, as well as functions of wages paid to skilled and unskilled labor (which the parent takes exogenously). Specifically, we assume that $\frac{\partial U_t}{\partial n_t} > 0$, $\frac{\partial U_t}{\partial e_t} < 0$, $\frac{\partial S_t}{\partial e_{t-1}} > 0$, $\frac{\partial C_t}{\partial n_t} > 0$, $\frac{\partial C_t}{\partial e_t} > 0$, and $\frac{\partial H_{t+1}}{\partial e_t} > 0$ That is, increasing fertility will raise unskilled income and raise the costs of child-rearing; increasing education on the other hand will raise bequests of human capital to children and raise the costs of child-rearing yet at the same will lower unskilled income (essentially pulling children out of work and into school).

Thus I am treating human capital as both an *investment* good (as adults rely on their education to generate greater returns to their labor) and a *consumption* good (as families derive benefits from educated children unrelated to family income). This approach is simple enough to be incorporated tractably into an inter-generational setup, yet still able to highlight the multi-dimensional nature of education.

The parent will maximize this expression with respect to fertility and education. The first order condition with respect to fertility is simply

$$\frac{\partial C_t}{\partial n_t} = \frac{\partial U_t}{\partial n_t} \tag{8}$$

This states that the marginal cost of an additional child (in the form of higher child-rearing costs) must equal the marginal benefit of an additional child (in the form of greater unskilled-labor income). Note that because fertility is only in the first term of equation (7), the first order condition for fertility is simple and takes no account of education levels.

The first order condition for education on the other hand is slightly more involved:

$$\frac{\partial C_t}{\partial e_t} - \frac{\partial U_t}{\partial e_t} = \left(\frac{1-\lambda}{\lambda}\right)\left(\frac{S_t + U_t - C_t}{H_{t+1}}\right)^{1-\varepsilon} \frac{\partial H_{t+1}}{\partial e_t} \tag{9}$$

The left hand side is the marginal cost of education. This cost arises from two sources - increasing the level of education per child raises the opportunity cost of child-rearing ($\frac{\partial C}{\partial e}$) and lowers the income generated from unskilled-child labor ($\frac{\partial U}{\partial e}$, which is negative). The right hand side is the marginal benefits of education. Education raises the level of human capital per child, which is a positive input in the parent's welfare function. Notice however that these gains from education are augmented by the term $\left(\frac{S_t+U_t-C_t}{H_{t+1}}\right)^{1-\varepsilon}$ - which captures the importance of *balance* between total income and average human capital per child. The greater is net household income relative to human capital per child, the greater are the marginal benefits from additional education. The exponent $1-\varepsilon$ magnifies this effect - the smaller is ε (that is, the more complementary are net income and human capital per child), the greater are the net benefits from education when net income is large relative to human capital. Indeed, these income-human capital complementarities will be a key feature that drives human capital accumulation throughout the Industrial Revolution.

Finally, income levels change with wage changes. These wage shocks arise from technological developments and are exogenous to the family planner.

In order to simulate the economy we will need to explicitly state how the variables in the welfare function (S_t, U_t ,C_t , and H_{t+1}) are functions of both control variables (n_t and e_t) and current wages ($w_{l,t}$ and $w_{h,t}$). Paralleling O'Rourke et al (2007) and Rahman (2007), we specify the following:

$$S_t = w_{h,t}\Omega e_{t-1}^k \tag{10}$$

$$U_t = w_{l,t}\left(1 - e_t\right) n_t \tag{11}$$

$$C_t = w_{h,t}\phi n_t^{\gamma}\left(1 + e_t\right)^{\gamma} \tag{12}$$

$$H_{t+1} = \Omega e_t^k \tag{13}$$

where $k < 1$ and $\gamma > 1$. Here we have a simple production function for human capital that increases in education but experiences diminishing returns, and costs of child rearing (in the form of foregone skilled income for the parent) that rise in both fertility and education. Further, notice that (11) captures our fertility-education tradeoff mentioned above - more education, while increasing H_{t+1}, will necessarily decrease U_t. So long as these things are true, our results will hold, and thus the precise forms of (10) - (13) does not matter for our analysis.

4 Simulating the Past

4.1 Static Equilibrium - Before the Industrial Revolution

In order to simulate the economy we must first establish the appropriate initial conditions.[5] Here we will treat the onset of industrialization as the moment when technological growth becomes positive. Thus we treat our pre-industrial economy as a purely static one, where technology coefficients A_l and A_h are fixed at some pre-determined level. This is of course not an entirely accurate depiction of pre-industrial society, as technologies glacially improved for millennia prior to industrialization. The fact that technological growth was much slower before the Industrial Revolution is what is important, however, and hence we lose nothing in assuming the extreme case of zero growth as our starting point. Further, as there is no particular evidence to suggest

[5]For our simulation, parameter values are set to the following: σ = 5, λ = 0.5, ε = -5, Ω = 2, k = 0.1, ϕ = 0.1, γ = 2.

that productivity differences between skilled and unskilled labor were notably different before the Industrial Revolution, we will assume that $A_l = A_h$ at $t = 1$.

Beyond this, the static equilibrium requires a stable demographic structure. The conditions necessary for this are: $n_t = 1$, and $e_t = e_{t-1}$. That is, the typical dynasty simply reproduces itself, and parents and children have the same education levels. With these criteria, we must solve for e_t, L_t, H_t, $w_{h,t}/w_{l,t}$, $A_{l,t}$ and $A_{h,t}$ for $t = 1$.

Our specific functional forms will allow such a solution. First, setting w_l to some arbitrary number, we simultaneously solve the two first order conditions (8) and (9) for e_t and w_h, maintaining that $n = 1$ and $e_{t-1} = e_t$. Then, our value of e_t provides us a value for H_t through (13). Finally, given our wages and endowment of human capital, we simultaneously solve (5) and (6) for L_t and technological coefficients, with the added assumption that $A_l = A_h$.[6] With these values as our initial condition, all remains static - as households have no incentive to change demographic behavior given current wages, L and H, and thus wages themselves, remain fixed. That is, until technologies begin to improve. This growth in sectoral productivity brings us to simulate the model with growth in A_l and A_h.

Before we do, I should note that the assumption of completely static productivity prior to 1750 can be particularly galling to many historians. After all the Malthusian model that characterizes most of human history suggests that population growth occurred precisely because there were productivity increases. Yet this model, simplistic though it may be, can address this feature by allowing for discrete increases in A_l - such technological shocks would only momentarily raise living standards since it would induce increased fertility. Such a pseudo-Malthusian feature would imply that macro technological progress was generally unskilled labor using both before and during the first Industrial Revolution, not a terrible assumption considering the evidence suggesting that skill premia were at their peak back in 1300 (before many of the pre-Industrial Revolutionary productivity gains) (Clark 2007), and relative unimportance of education for the overall economy. However, I stress that this is decidedly *not* a model of the Malthusian era, but rather one of industrialization and demographic transition.[7]

4.2 Dynamic Equilibria - the First and Second Industrial Revolutions

The Industrial Revolution that transpired in England in the late 18th century was a situation where certain industries began to 'modernize' - that is, technological progress occurred in a few core industries, mainly in textile and iron production. These industries also tended to employ more unskilled labor at the expense of skilled labor (see for example Mokyr 1990 and O'Rourke et

[6] Initial values are $e = 0.13$, $A_l = A_h = 0.7$, $L = 5$, $H = 1.65$, and $w_h/w_l = 1.8$.

[7] The Malthusian economy is one where population growth occurs more from positive forces of falling death rates rather than from preventive forces of rising fertility rates. Explanations of changes in death rates are however beyond the scope of this paper.

al 2007 for more detailed accounts). For example, if we look at the actual aims of the inventions cited in late 18th century patents, the desire to save "labor" was always insubordinate to the desire to save "capital," whether it be physical or human capital (MacLeod 1988). Mokyr (2005) suggests that growth of "knowledge," a critical feature of industrialization, could nevertheless "be frontloaded in the instructions or artefacts, thus reducing the competence needed to carry out the actual production." And Goldin and Katz (1998) state that products previously manufactured by skilled artisans began to be produced in factories by workers with relatively few skills; the demand for skilled workers in turn declined as many previously complex tasks were simplified.

By the dawn of the second Revolution, two major changes in technological growth occurred - it became much more widespread, and it became far more complementary to skilled workers. Through learning by doing, positive knowledge spillovers among different producers, network technologies and inherent scale economies in railroads, metallurgical and chemical industries, productivity growth extended to nearly every sector of the economy (Mokyr 1990). At the same time, the complexity of technological systems increased. By the early 20th-century the evidence for this was so compelling that Nelson and Phelps (1967), Schultz (1975), and Tinbergen (1975) argued that technological developments of the era *inherently* increased the demand for skills. Indeed, the true antecedents of our world of modern growth can be found in this period, for today personal computers, computer-assisted production techniques, and robotics appear to complement skilled workers and replace many labor-intensive tasks (Acemoglu 2002).

Thus, although we lack detailed econometric studies, there is much evidence to suggest that technology was labor-intensive during the first Industrial Revolution but skill-intensive during the second. So how to incorporate this into the model? To account for continuous U.S. wage productivity throughout the first half of the 20th century, Solow (1956) assumed an exogenous process of labor-augmenting technological progress. My approach will be similar to this, but with a slight twist. To mimic the historic trends of technology, let us assume that the first Industrial Revolution was a period of *unbalanced* growth, while the second Industrial Revolution was a period of robust and balanced growth. Specifically,

Assumption 1 $\frac{(A_{l,t}-A_{l,t-1})}{A_{l,t-1}} = 0.02\ \forall t,\ \frac{(A_{h,t}-A_{h,t-1})}{A_{h,t-1}} = 0 \text{ if } t \leq 15,\ \frac{(A_{h,t}-A_{h,t-1})}{A_{h,t-1}} = 0.02 \text{ if } t > 15.$

In other words, the initial stages of economic growth were characterized by unskilled-labor intensive technological growth, while later stages were characterized by both skilled and unskilled-labor intensive technological growth (O'Rourke et al. 2007 endogenizes this process by modeling micro-inventive activity, and highlights how this evolution of factor-specific technical growth was inevitable given the incentives of inventors). With this assumption we can simulate this simple economy to qualitatively capture some of the key features of 18th and 19th century growth in England.

4.3 Simulation Results

Here we run the simulation for 30 time periods to roughly capture economic and demographic trends in England from around 1750 to the Great War. Figures 13 and 14 illustrate the results. At the moment of technological growth, the population is stable, education is quite low and the skill premium is quite large. Subsequent unskilled labor-intensive technological growth raises unskilled labor income. This induces families to raise fertility rates and, due to the quality-quantity tradeoff imbedded in the way income is generated, puts pressure on families to lower education rates. This trend however is countered by the growth in income, which puts pressure on families to *raise* education rates. The net result is a modest rise in both fertility and education.

The rise in fertility that this unbalanced growth generates is large enough to put downward pressure on income per person levels, so that living standards grow very modestly. At the same time, it is not quite so large as to nullify the wage increases for unskilled labor from rising demand (illustrated in Figure 12). As such the skill premium begins to fall to unprecedented lows. Galor has called the first Industrial Revolution the "post-Mathusian" phase of growth, and in many respects that is precisely what it is. Perhaps Voth (2003) articulates what happened best: "Instead of requiring an ever rising skill level in the workforce, the Industrial Revolution appears to have been quite compatible with the use of relatively unskilled labor. The balance of the evidence...suggests that technological change during the 19th century was more skill-replacing than skill-using. If the nature of technological change initially reduced the direct and indirect cost of rearing children (by turning them into a source of revenue for the family, and thereby also lowering the need to supervise them), it becomes much less difficult to square broadly stagnant real wages with rising fertility." Thus treating children as labor inputs rather than implicit consumption goods helps us de-link income growth from population growth.

Contrast this case with the latter half of the simulation. The balanced growth of the second Industrial Revolution does two things to families - it lowers the relative importance of unskilled labor income in overall income, and it raises the growth of overall income. Both things induce a dramatic reversal of micro behavior that is the essence of the Demographic Transition; fertility rates fall, and education rates rise faster than in any other time in history. At the same time, the skill premium continues to fall, as the non-pecuniary gains from human capital outweigh the continuing fall in the relative return to skills.

5 Two Counter-Factuals

The two assumptions that essentially drive our results are that industrialization was more unskill-intensive in its initial phase, and that income and human capital were complementary in

utility.[8] Here we relax each assumption to illustrate how the qualitative aspects of the model change.

5.1 What If Growth Was "Balanced?"

What if there were no biases in knowledge growth - that is, what if technological developments used skilled and unskilled labor in relatively balanced ways? We can illustrate this by assuming that A_l and A_h equally grew by 2 percent right from the start of industrialization. This case is illustrated in Figure 15. With this kind of balanced growth, the demographic transition occurs immediately; the population continually shrinks while human capital continually rises. This scenario is reminiscent of older unified growth approaches where the Industrial Revolution is essentially equated with the Demographic Transition (such approaches include Kremer 1993, Hansen and Prescott 2002, and Lucus 2002). But this strictly monotonic approach belies the historical evidence, which suggests that there were multiple phases of industrialization. Thus I would argue that simply looking at growth in overall TFP misses an important part of the complicated story of industrialization.

5.2 What If Income and Human Capital Were Substitutes?

What if human capital was viewed as a relatively substitutable good in utility - that is, what if increases in human capital could more readily substitute for increases in family income? We can illustrate this by simply raising ε, the substitutability of educated children for income. This case is illustrated in Figure 16. Here we come across a number of counter-factual results. Although the fertility transition occurs with more balanced growth, the skill premium counter factually rises. This is the implicit result of works such as Galor and Weil (2000) and Galor and Mountford (2004), where the transition to modern growth is associated with rising relative returns to skilled labor (Voth 2003). But as we know this did not happen - skill premia at best remained stagnant. Galor (2005) acknowledges the role of supply of human capital in explaining low skill premia, but must rely on exogenous injections of skilled labor (such as those from compulsory schooling laws enacted in the late 19th century). But one might suggest that these so-called exogenous shocks did not come randomly, but rather were the results of political pressures both from industry (who increasingly saw the importance of a skilled work force to exploit productivity improvements, discussed in Galor and Moav 2002) and from households (who saw the "value" of educated children in increasing the well-being of the family, discussed in Horrell and Humphries 1995). These were changes in the economic incentives for education that arguably should be *endogenous*

[8] The general substitutability of skilled and unskilled labor in production may be considered a third driving assumption. This however should be considered a far less controversial assumption, as it has been employed in many growth and labor studies.

in any model of unified growth.

6 Conclusion

Explaining the non-monotonic evolution of fertility, initial stagnation and subsequent growth of education, and fall in relative returns to skilled labor in the English Industrial Revolution has constituted one of the major puzzles of economic history. Here I have offered an hypothesis to explain the evolution of these variables, suggesting that labor- and skill-using technologies and familial preferences for educated children must play pivotal roles in the explanation.

Human history is far more challenging to explain than natural history, partly because the data on human interactions can be quite scanty, and partly because humans are far less regular in their behavior than natural phenomena. But the approach of the natural historian, to pre-suppose some consistent "laws" of behavior to explain historical events, can serve the growth theorist who is bent on unifying the history of industrialization. The theorist, playing God by setting up the initial laws of behavior, should cease playing God once the model is under way, and discipline him or herself by not arbitrarily changing preferences or exogenously shocking things to fit facts. The aim of the unified growth theorist is precisely that - to understand the connections between technological progress, the formation of human capital and demographic change by creating a faux universe and letting it run its course. It is a difficult task, and the temptation to intervene is strong. But hopefully by "endogenizing" as many things as is tractable, the faux worlds we create can aid the empiricists who are uncovering facts from the real one.

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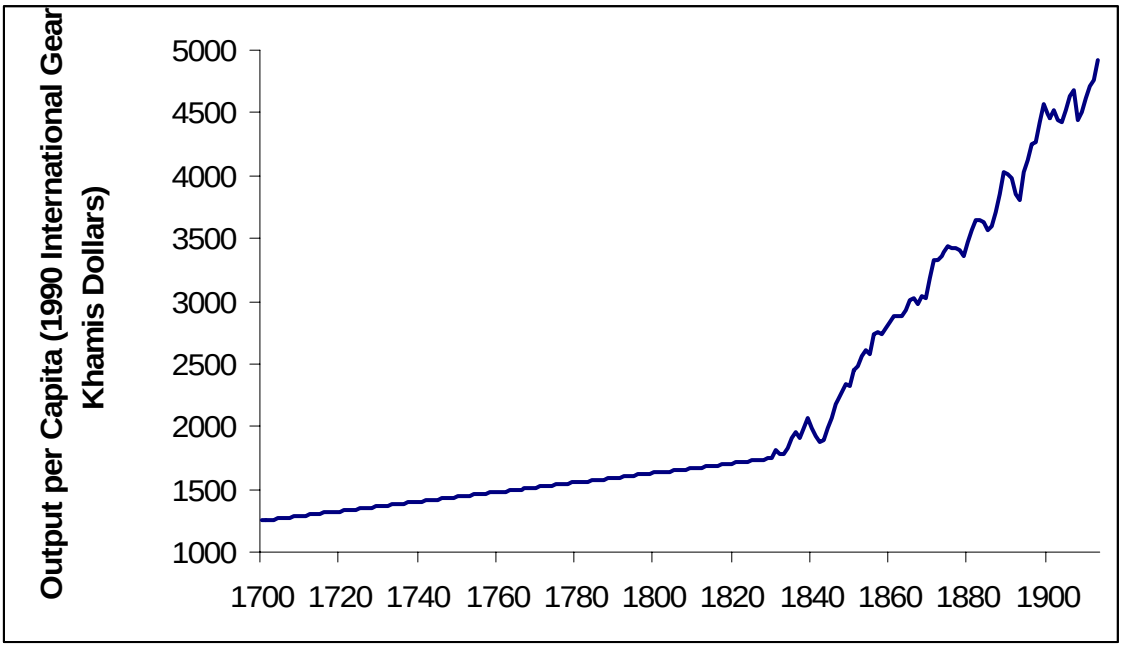
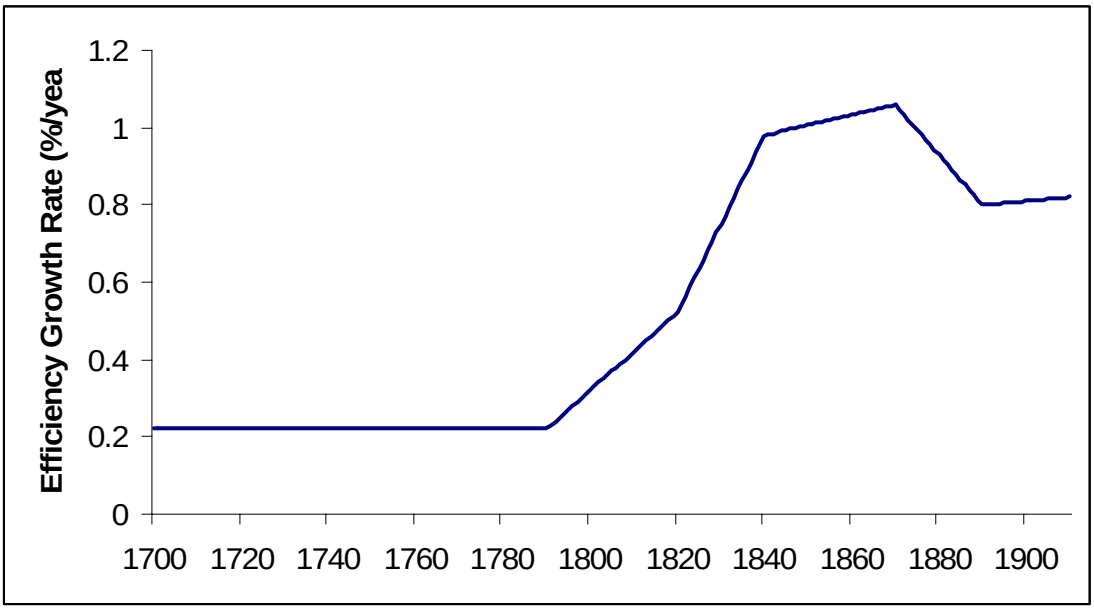
Figures

Figure 1 – Estimated Output per Capita and Efficiency Growth Rates, England 1700 - 1910

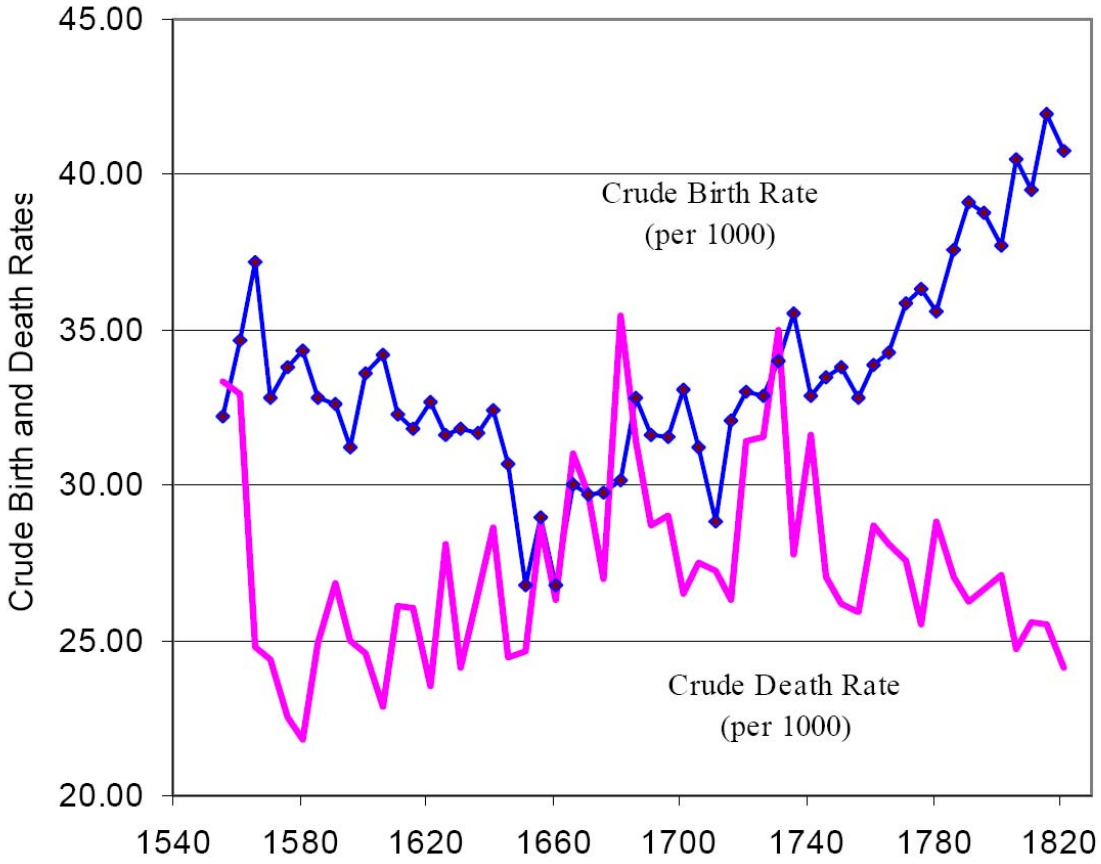


Source: Maddison (2003).



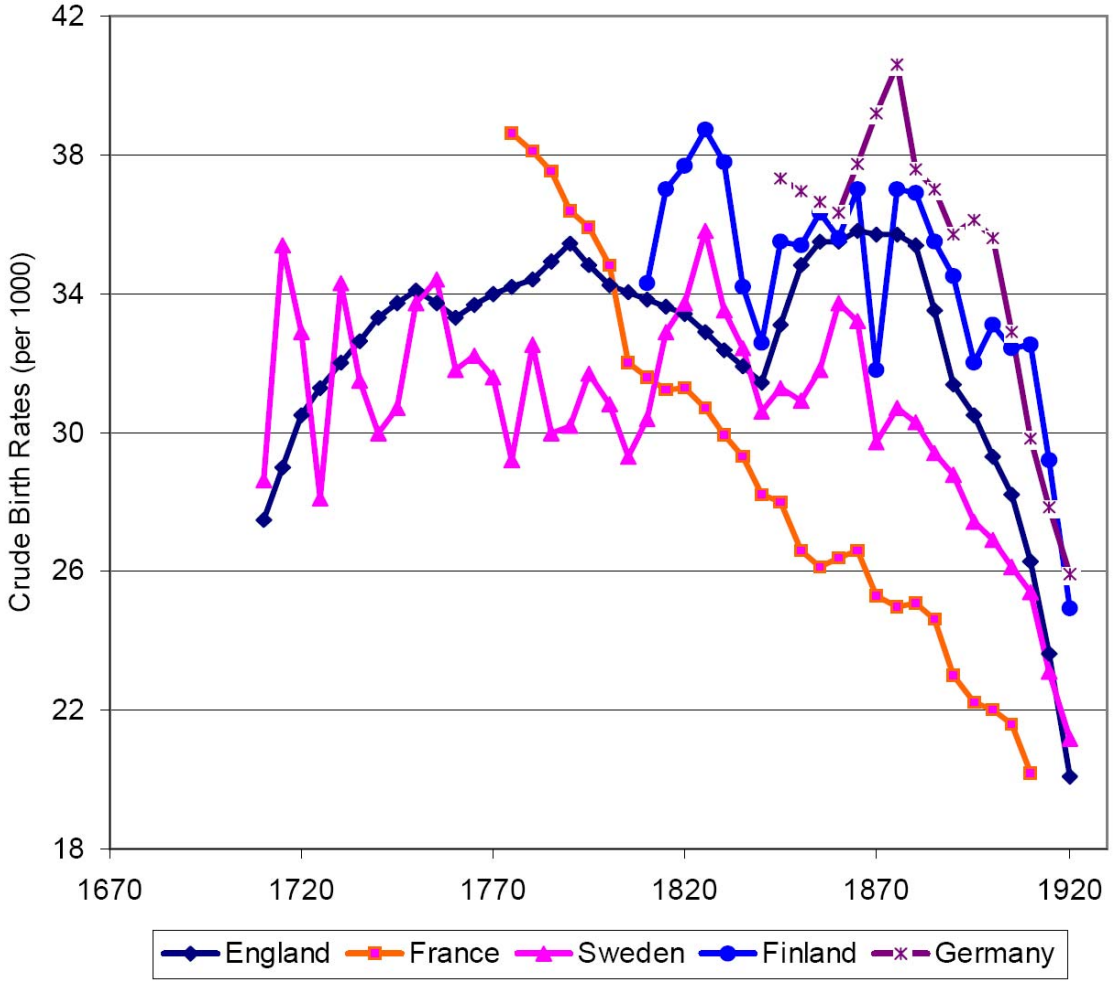
Source: Clark (2003), based on Crafts and Harley (1992) and Deane and Cole (1967).

Figure 2 – Fertility and Mortality, England 1540 - 1870



Source: Galor (2005), based on Wrigley and Schofield (1981)

Figure 3 – Crude Birth Rates in Western Europe, 1710 - 1920



Source: Galor (2005), based on Andorka (1978) and Kuzynski (1969)

Figure 4 – The Demographic Transition, 1540 - 1990

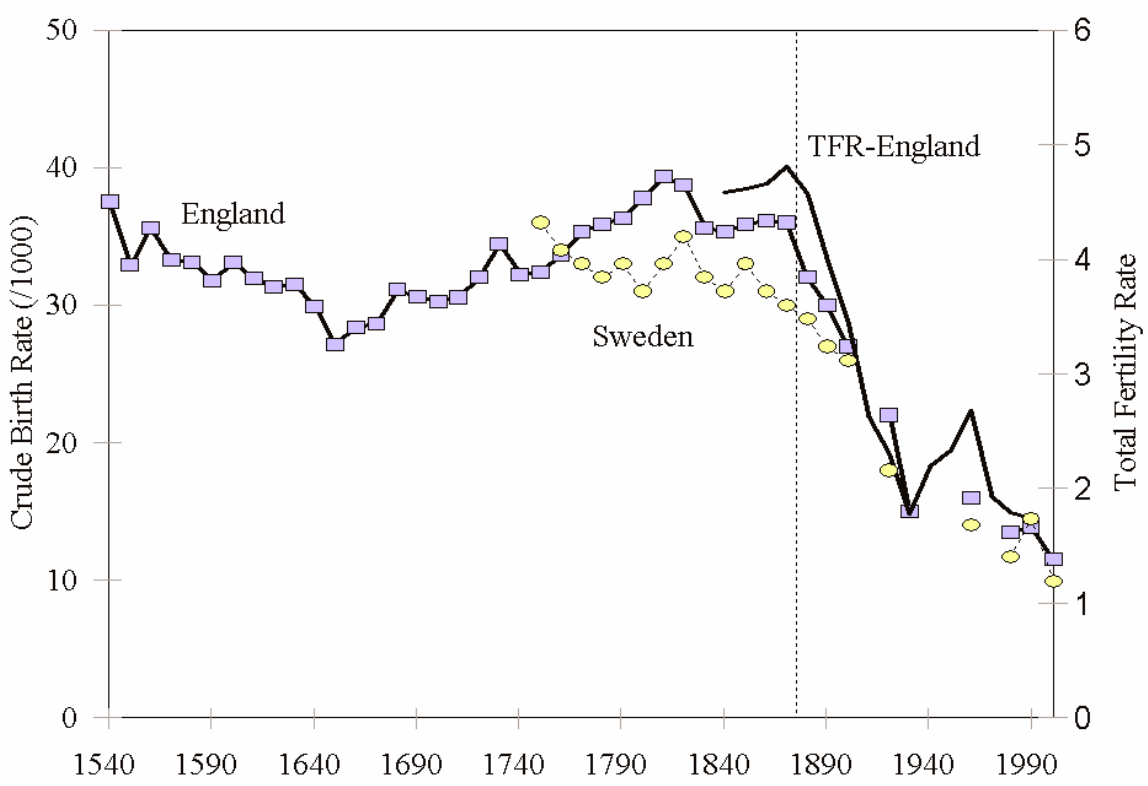
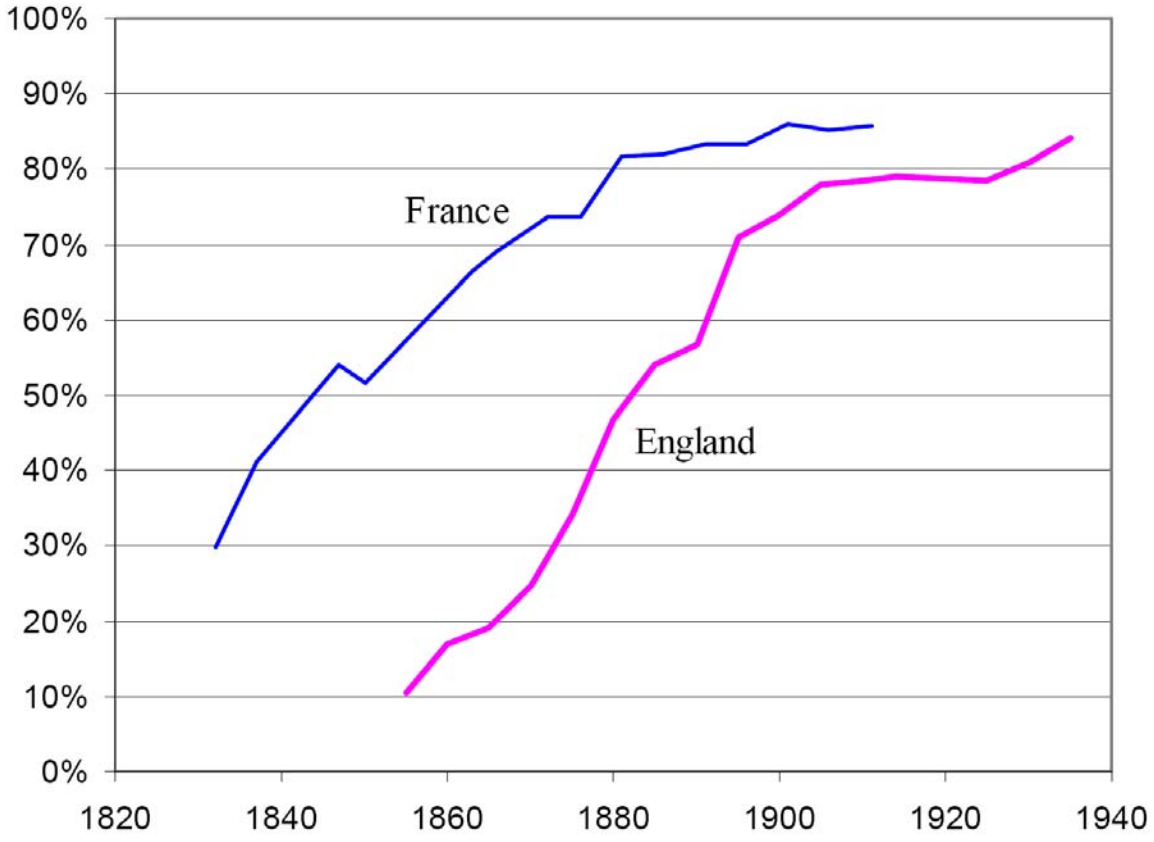
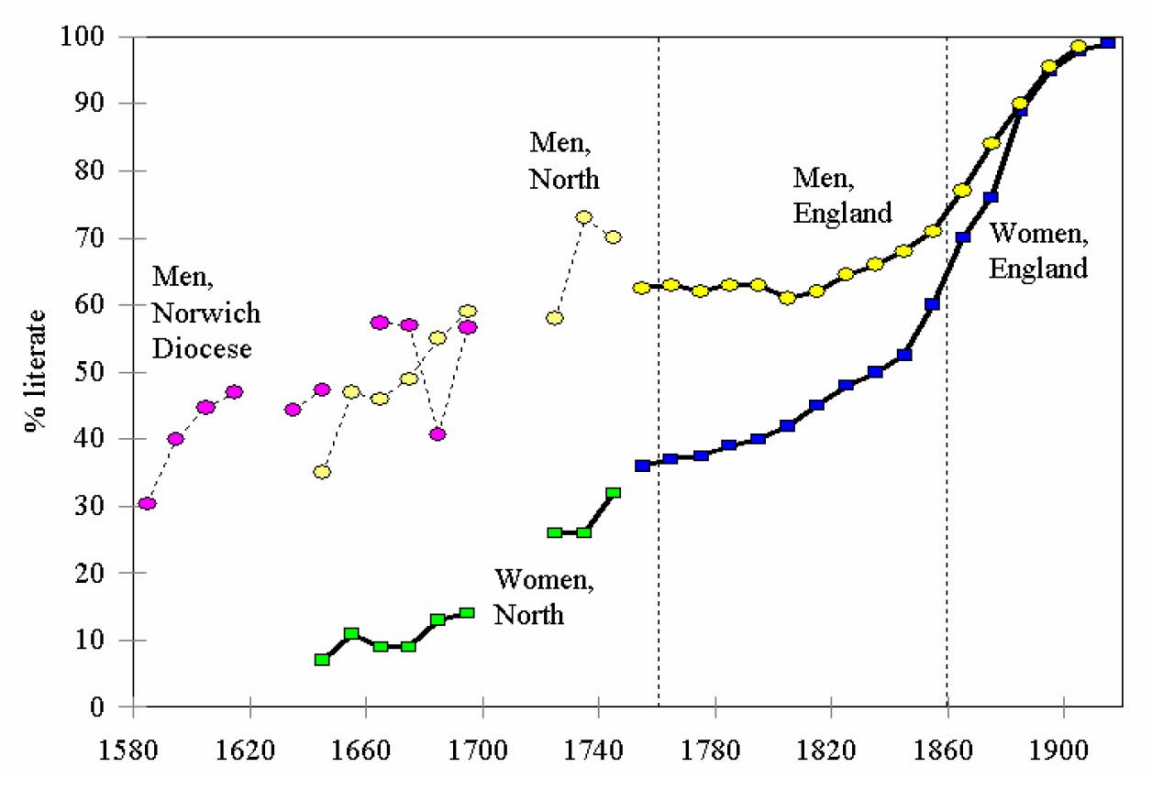


Figure 5 – The Fraction of Children Aged 5-14 in Public Primary Schools, 1820 - 1940



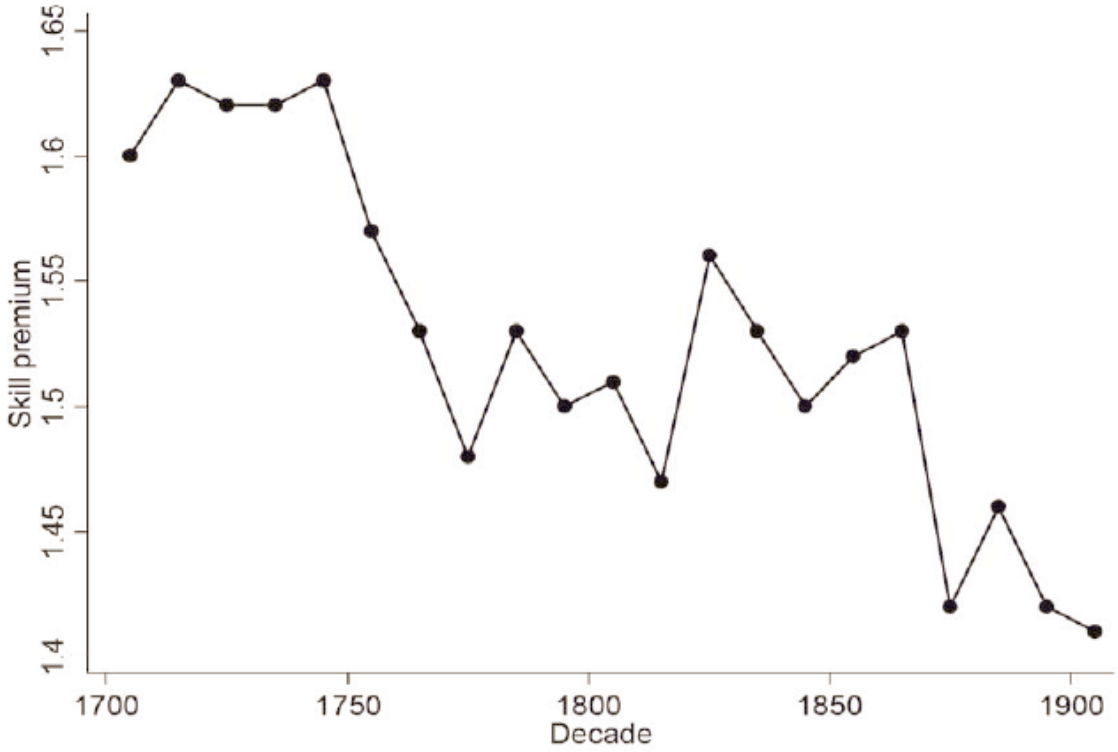
Source: Galor (2005), based on Flora et al. (1983)

Figure 6 – Literacy in England, 1580 - 1920



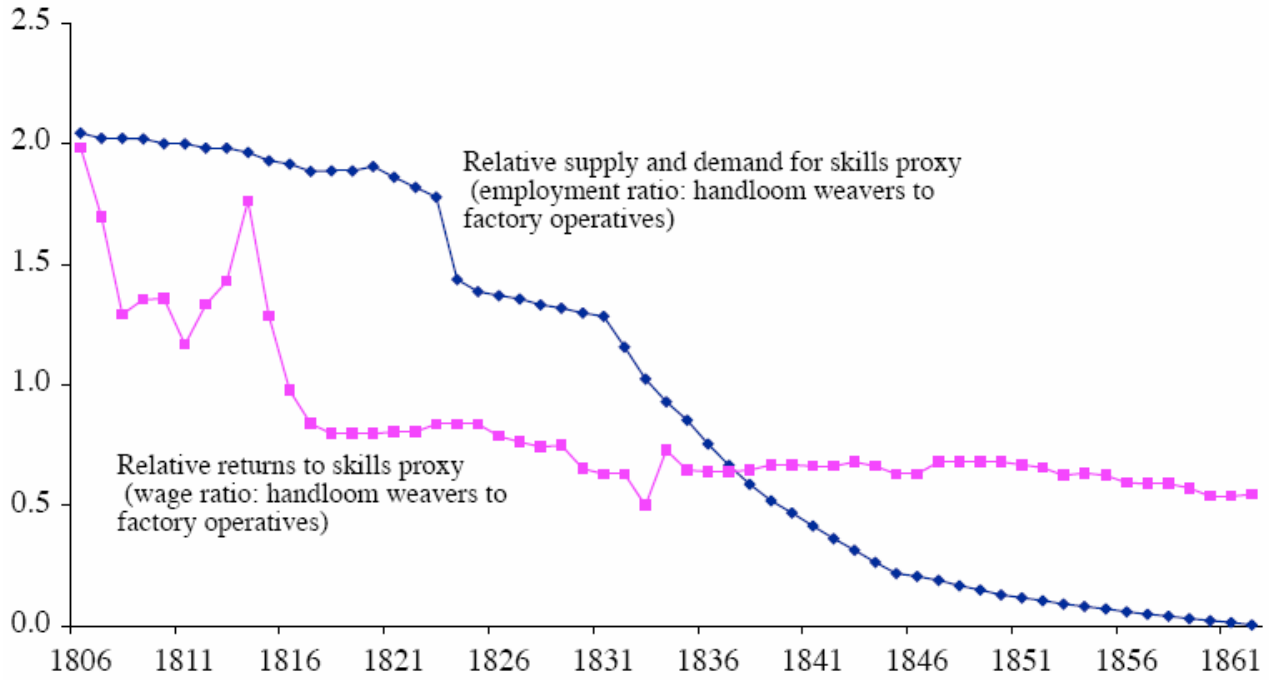
Source: Clark (2005), based on Schofield (1973), Houston (1982), and Cressy (1997)

Figure 7 – English skill premium in housing, 1700-1910



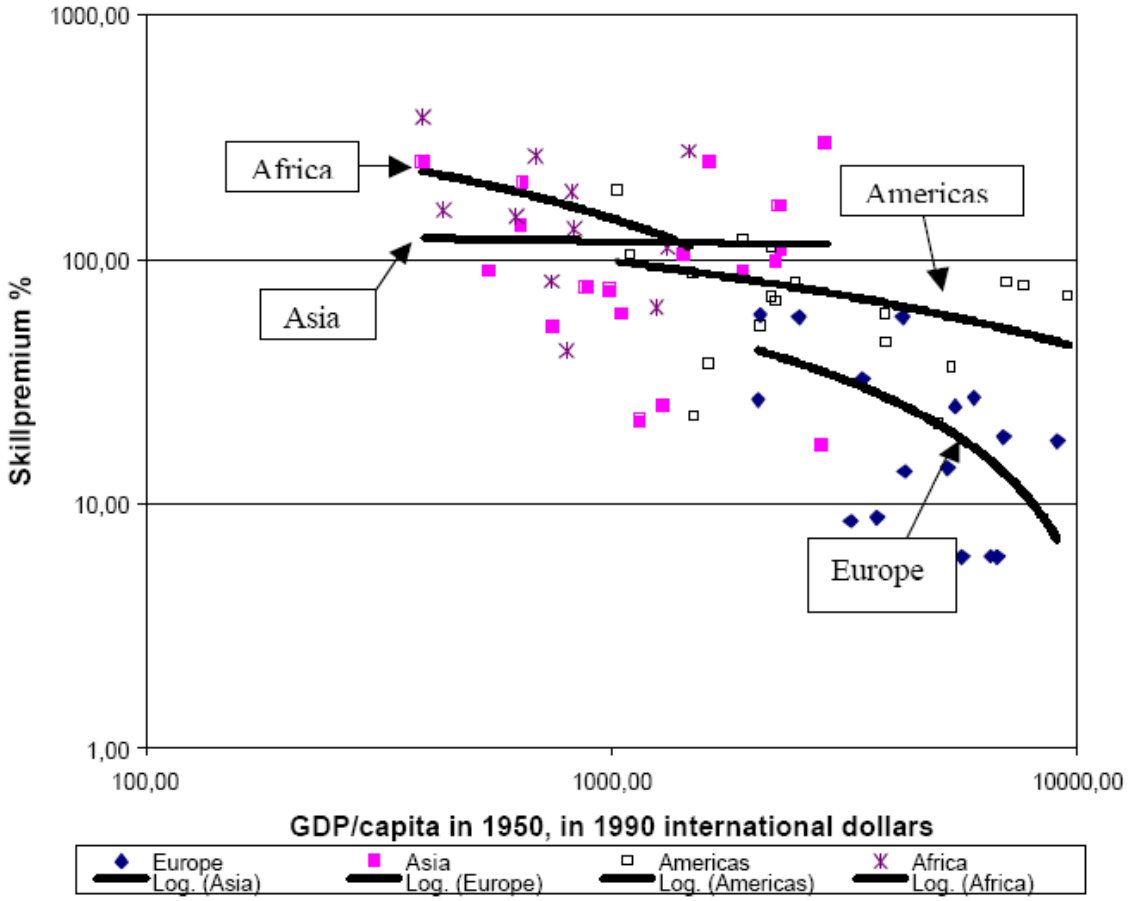
Source: Clark (2007)

Figure 8 – Skilled and Unskilled in British Textiles, 1806-1860



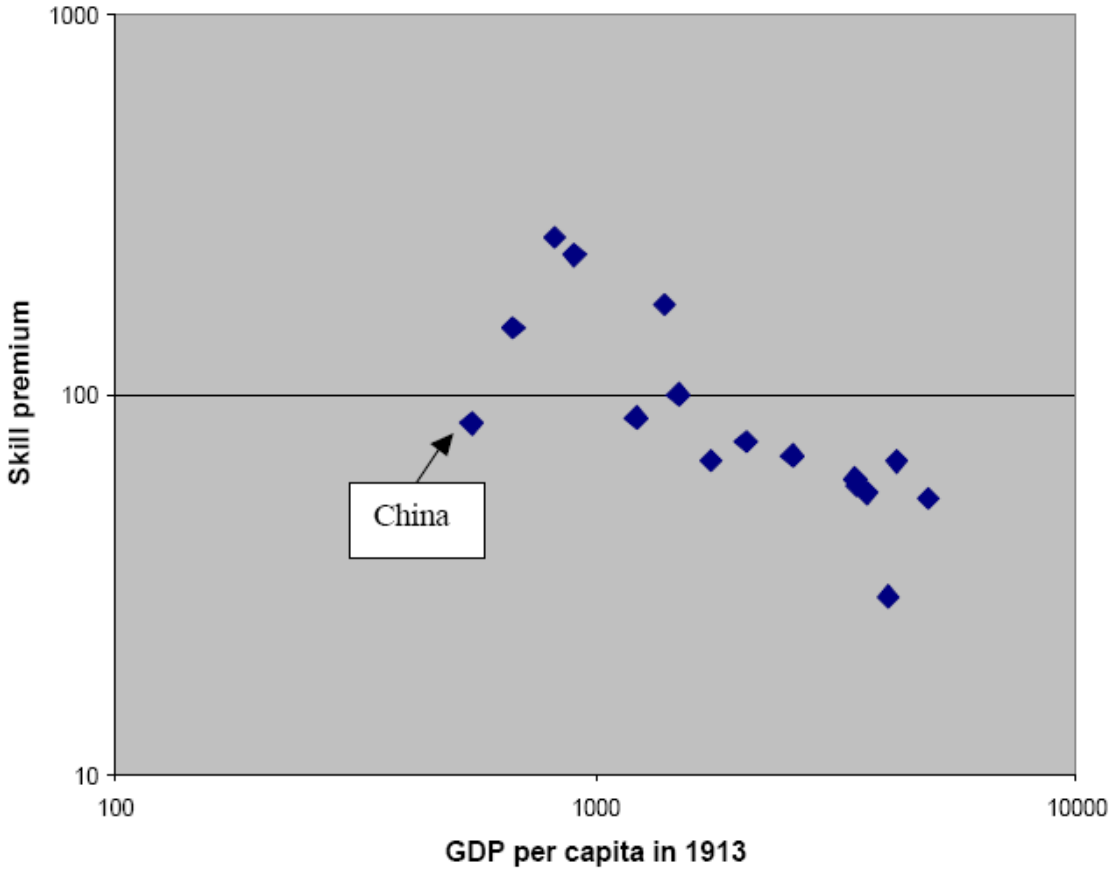
Source: Wood (1910)

Figure 9 – Relationship between GDP per capita and the skill-premium of building craftsmen (c 1950)



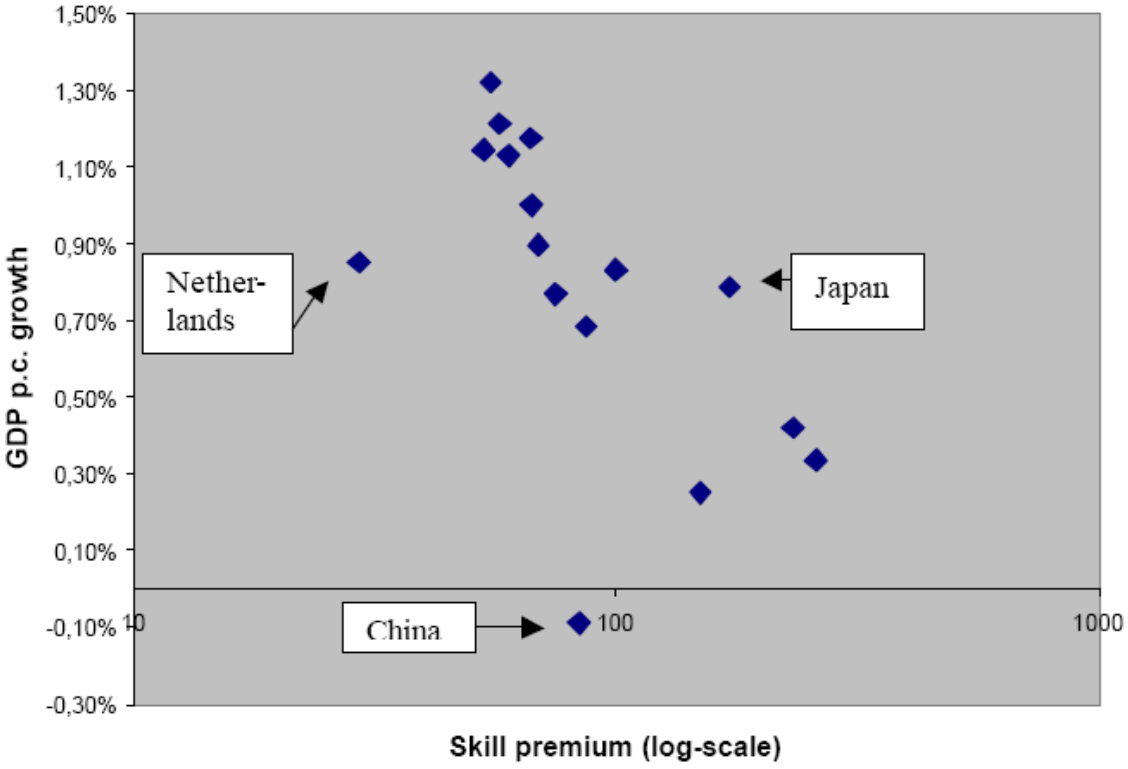
Source: van Zanden (2006)

Figure 10 – The skill premium in 1750/1820 and GDP per capita in 1913 (log scale)



Source: van Zanden (2006)

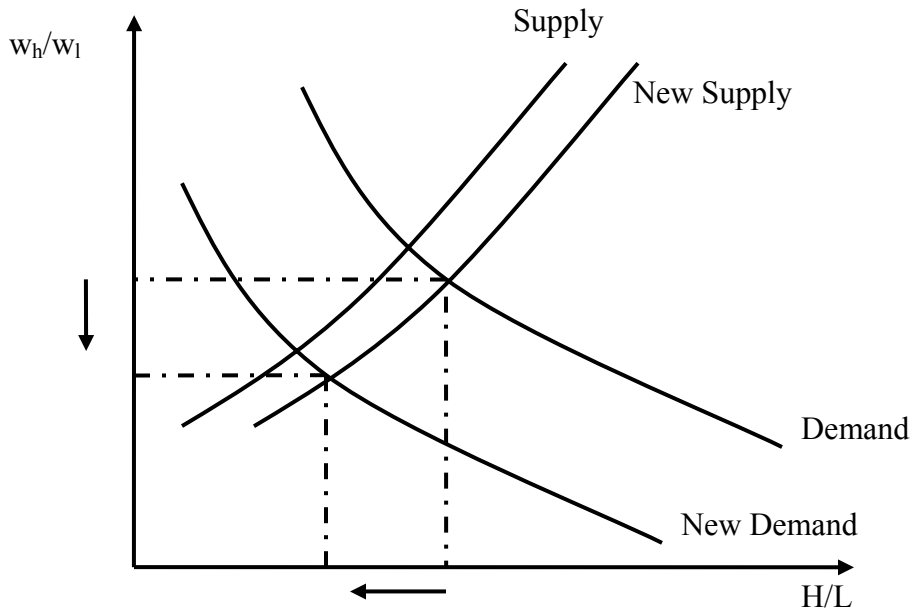
Figure 11 – Average skill premium of construction workers between 1750 and 1820 and GDP per capita growth in 1820-1913



Source: van Zanden (2006)

Figure 12 – Supply and Demand for Relative Skills

First Industrial Revolution (unskilled-labor intensive and unbalanced growth)



Second Industrial Revolution (more skilled-labor intensive and balanced growth)

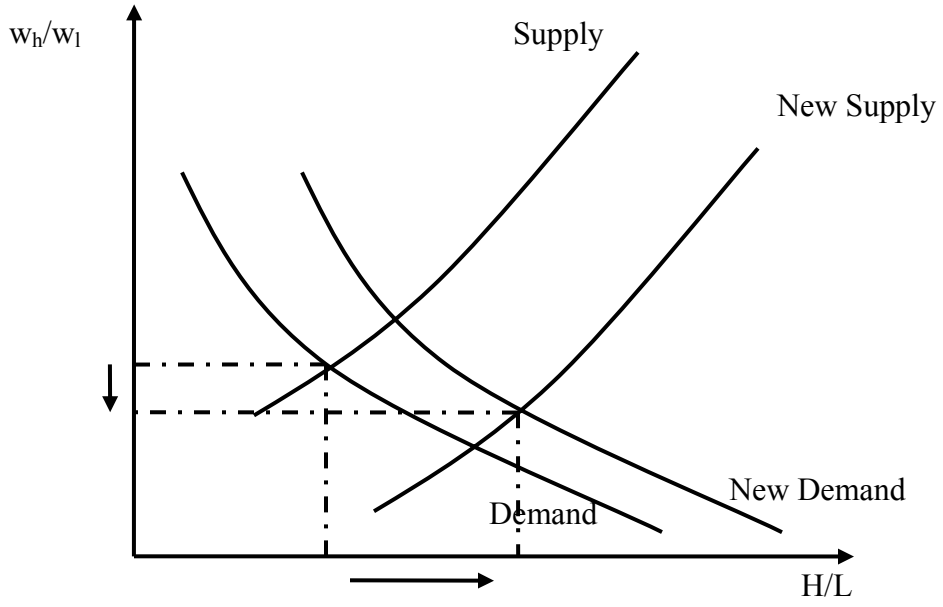
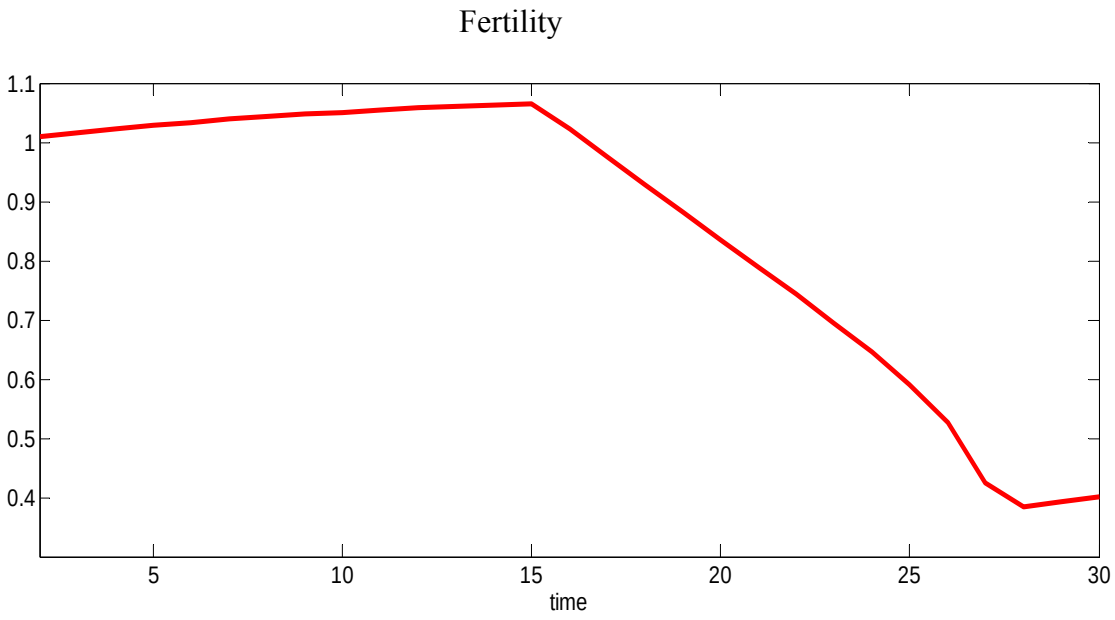


Figure 13 – Simulated Fertility and Education Rates



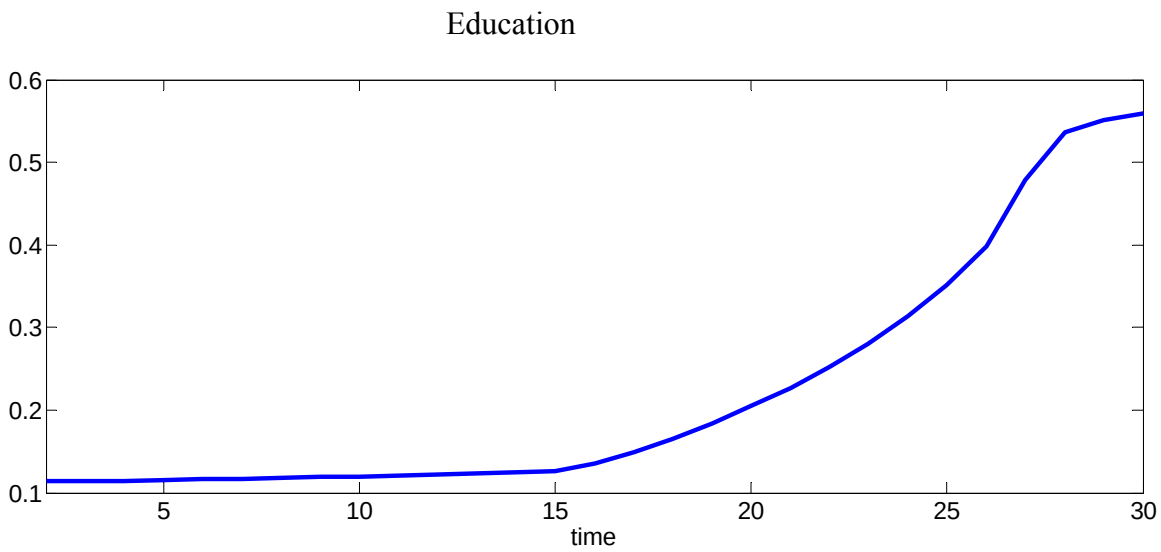


Figure 14 – Simulated Wages, Skill-Premium and Output per Capita

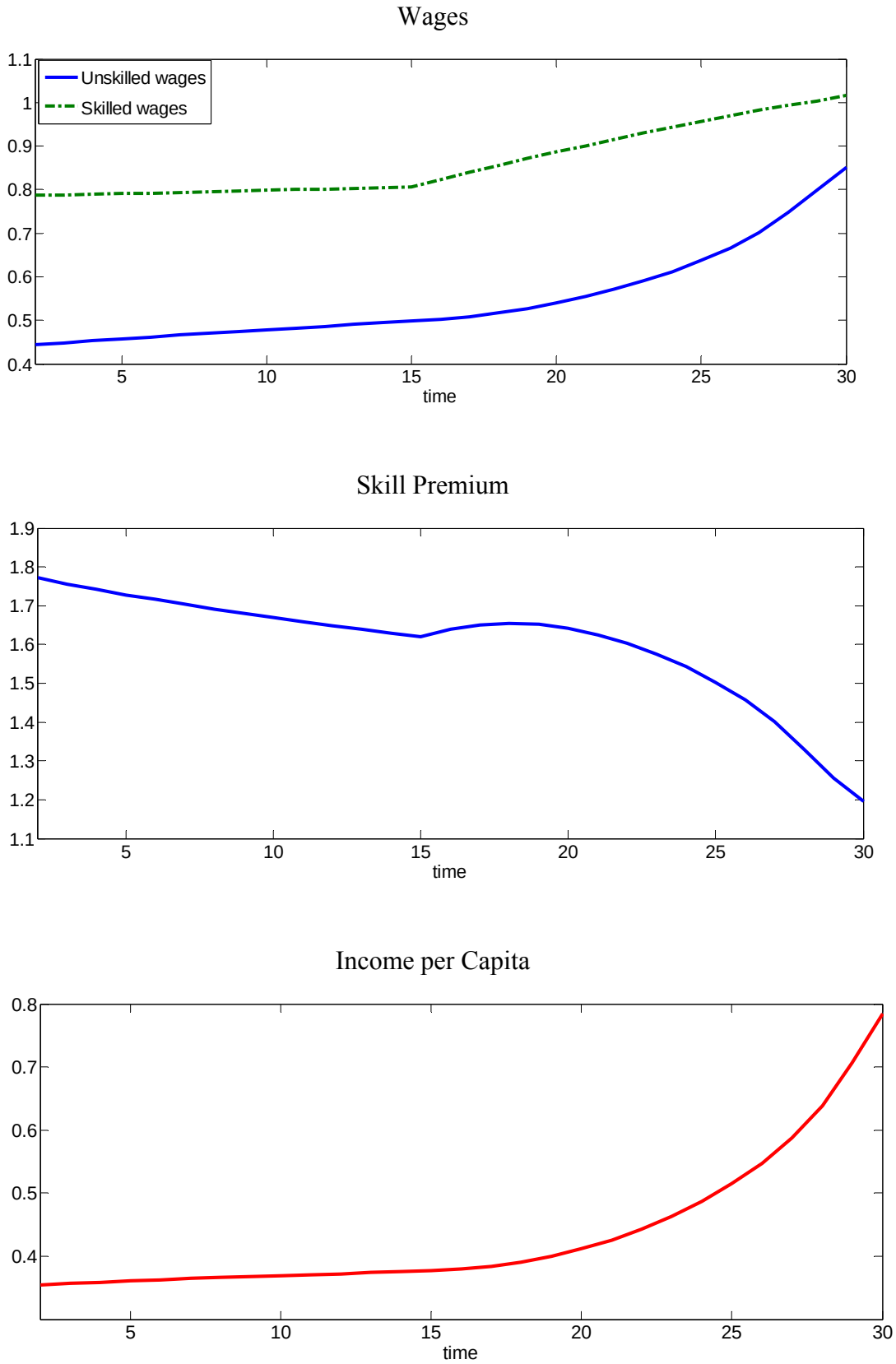


Figure 15 – Simulation Results when Growth of A_l Always Equals Growth of A_h

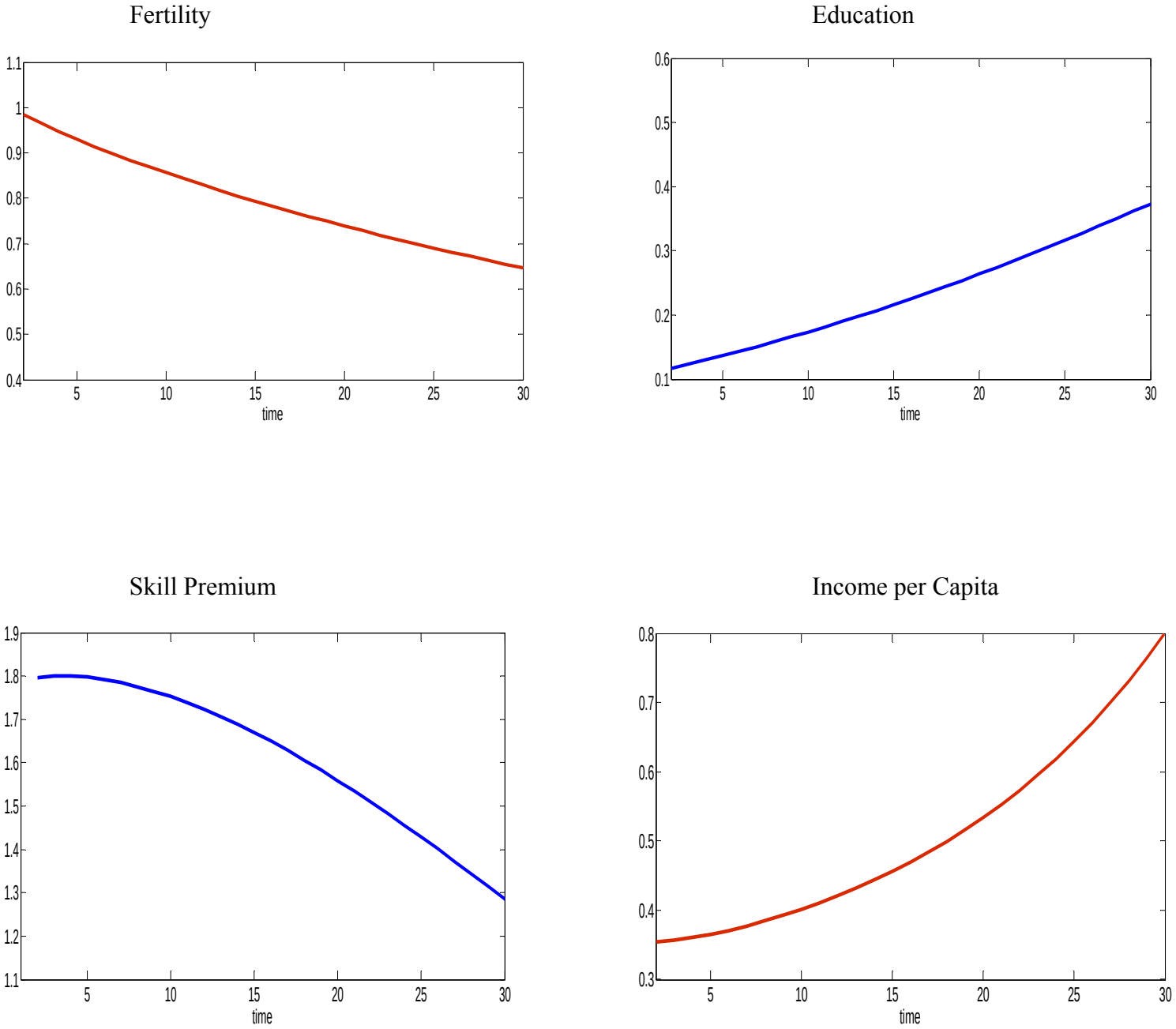
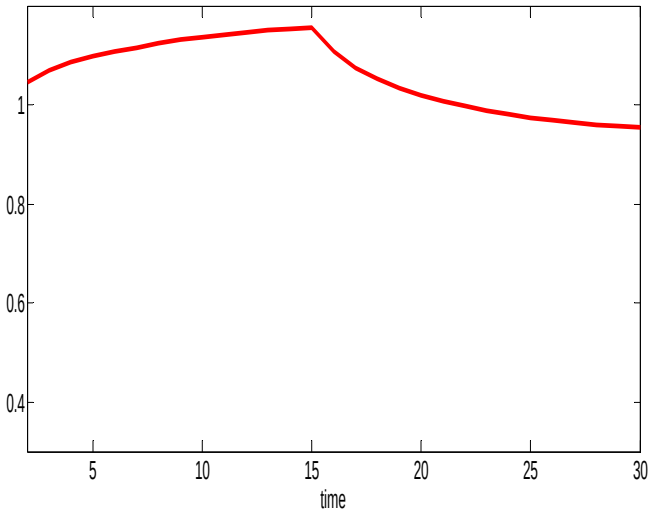
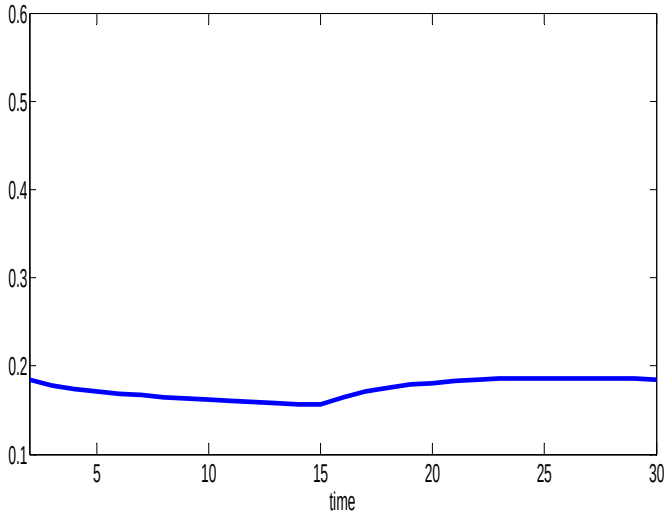


Figure 16 – Simulation Results when ε = 0.5

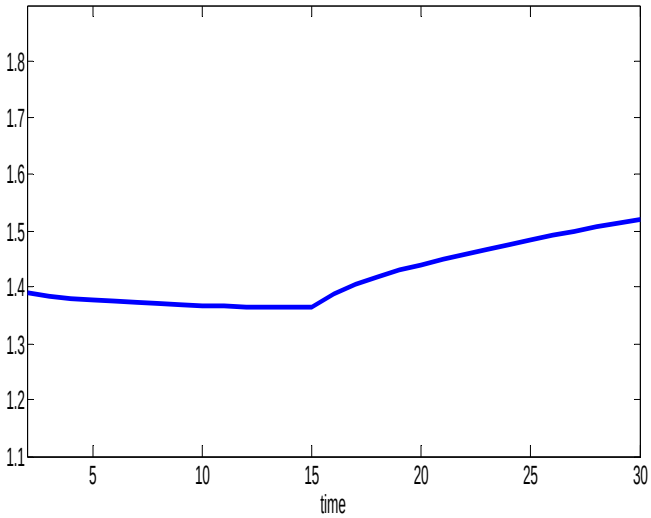
Fertility



Education



Skill Premium



Income per Capita