The Skill Premium Puzzle in History*

Ahmed S. Rahman
Department of Economics, United States Naval Academy
589 McNair Road
Annapolis, Maryland 21402
rahman@usna.edu

July 2008

Abstract

Historically, industrialization has been associated with falling relative returns to skills. This fact is at odds with most theories of industrialization, which tend to imply rising skill premia as natural concomitants to economic growth. This paper develops a simple model of economic demography to help solve this puzzle. Conjecturing that households wished to maximize both their levels of income and the levels of education of their children, the model demonstrates how rising education levels, non-monotonic fertility rates, and falling skill premia can all be explained within one theory.

- *Keywords*: endogenous demography, skill premium, unified growth theory
- *JEL Codes*: J11, J31, N33, O33, O41

*Many thanks for comments made by participants at the Southern Economics Association meetings in New Orleans and the 6th annual meeting of the Economic History Society in Nottingham, U.K., and seminars at the University of Delaware and Colgate University. All errors are mine.

1 Introduction

To many, world economic history is surprisingly simple - for the last few hundred years technological progress has allowed some societies to lift themselves out of their timeworn Malthusian-based poverty. Yet while this history is simple, the challenge to theoretically explain it has been anything but. The difficulty has been to capture the qualitative *effects* of these technological changes. In particular, the accessories of today's growth 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, modest increases in average income and *falling* income inequality. Traditional growth theories, able to capture present-time growth, are 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 a fairly 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.

This paper attempts to link both worlds by employing a very simple model of 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 formidable but important 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.

An even greater challenge in unified growth theory is to link different episodes of industrialization in different economies. First the U.K. and then the U.S. led the world in labor productivity from the mid-eighteenth to mid-twentieth centuries (Broadberry 1994), yet few theories can reasonably capture the growth stories of both. In particular, the industrialization histories of both economies show falling relative returns to skilled labor (at least until the latter half of the 20th century). Yet most theories of industrialization tend to imply that rising skill premia are natural concomitants to economic growth (see for example Galor and Weil 2000; Jones 2001; Hansen and Prescott 2002; Lucas 2002). A truly unified approach should endeavor to account for such

[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."

falling relative returns to skills in both economies.

To capture the historical responses to the forces of industrialization in these economies, we develop a very simple model of demography. Specifically, we can 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 industrialization 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

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

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

We should hasten to mention that we are only studying the consequences of technological progress, not the sources. Nor are we attempting to account for the timing of industrialization, or motivate the reasons why it happened in England and the U.S., and not China, India or Japan. For these reasons we 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.

The rest of the paper proceeds as follows. Section 2 enumerates some of the "stylized facts" of the first and second industrial revolutions in England and early 20th century industrialization in the United States. 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

[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.

in section 2. Section 4.3 briefly addresses some alternative scenarios of industrialization. Section 5 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 industrialization in England and the United States.

2.1 Income and Productivity Growth

The first challenge for a model of the English (and later American) 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 in England 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).

For the United States, Jones and Tertilt (2006) document both the sharp fall in fertility throughout most of the 20th century as well as the strong negative relationship between income and fertility for all cohorts. Thus it appears that 20th century American growth continued the late 19th century English trend of general demographic transition (Figure 5).

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 English 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; see Figure 6). 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 Figure 7). Thus it appears that education became more and more important in production only with England's *second* wave of industrialization.

America's growth in the 20th century only reaffirms the importance of human capital in the post mid-19th century world. Goldin (1999) documents the prominent role education played in the U.S. economy during the 20th century (see Figure 8). At the start of the century very few people could afford to attend school; by the end of the century very few could afford *not* to

attend school. This dramatic transformation in America's focus on education leads Goldin and Katz (2008) to dub the 20th century the "Human Capital Century." Any unified theory will have to account for this transformation from education's immaterial role in the eighteenth century to its indispensability in the twentieth.

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 England's first Industrial Revolution and at the dawn of the American 20th century, thus inducing 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 in England was at its peak *before* industrialization and modernization ever happened. Similarly in the United States, the relative return of a high school diploma was at its peak at the turn of the *20th* century, not the 21st.

As can be seen from Figures 9 and 10, the skill premia generally fell during both of England's Industrial Revolutions. Williamson (1982) produces a variety of skill premia for different classifications of workers - here we see that even when farmers are included as unskilled laborers (a group whose wages were relatively stagnant in the first half of the 19th century), skill premia do not reach their 1755 highs even a century later. And these same figures indicate falling premia between 1781 and 1815, right in the heart of the Industrial Revolution. Clark (2007) illustrates that premia continue to fall even during the second Industrial Revolution, a time when education became far more critical as an input to production.

As for the United States, an extensive literature exists on the pre-Second World War wage premium for skilled to manual workers. Almost all papers in this literature find a compression of the wage structure before 1950.[3] Goldin and Katz (2008) suggest a general pattern of falling premia prior to 1950, relatively stagnant premia from 1950 to 1980, and rising premia after 1980 (see Figure 11).

Thus historically 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 12 and 13) or different growth rates across a range of countries (Figure 14).

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

[3] A partial list of this literature includes Bell (1951), Keat (1960), Lebergott (1947), Ober (1948), Woytinsky (1953), and Lindert and Williamson (1980).

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 in England and the United States. 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 early English industrialization: the nature of industrialization itself, the average size of families, and the premium paid in the labor market for skills. And some particularly thorny questions arise when looking at the relative returns to skilled labor later on. 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 England's second Industrial Revolution and America's industrialization during the early twentieth century? After all, technological progress during these times clearly relied on human capital more than at any other time in history.

2.5 A Theoretical Solution

To reconcile these puzzles, we need to adequately account for both the *demand for* relative skills and the *supply of* relative skills, and realize that both may have been shifting throughout the course of industrialization. Getting the supply and demand for relative skills correct means that we must adequately capture both trends in the rewards to particular factors, and changes in demography that dictate the supplies of these factors. This is precisely what unified growth models attempt to do.

What follows is a very simple 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. 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 and American industrialization.

3 A Simple 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:

$$Y = \left((A_l L)^{\frac{\sigma-1}{\sigma}} + (A_h H)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{3}$$

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.[4]

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

$$w_{l,t} = \frac{\sigma}{\sigma-1} \left((A_{l,t} L_t)^{\frac{\sigma-1}{\sigma}} + (A_{h,t} H_t)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}} \left(\frac{\sigma-1}{\sigma} \right) L_t^{-\frac{1}{\sigma}} A_{l,t}^{\frac{\sigma-1}{\sigma}} \tag{4}$$

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

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.

3.2 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.

We 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 you 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

[4]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.

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,[5] and that these two things are imperfectly substitutable.

The welfare function of the parent W is given by

$$W = \left(\lambda \left(S_t + U_t - C_t\right)^{\varepsilon} + (1-\lambda)\left(H_{t+1}\right)^{\varepsilon}\right)^{1/\varepsilon} \tag{6}$$

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 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 we 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). Goldin (1999) summarizes the complex nature of education this way: "Education directly enhances productivity, and thus the incomes of those who receive schooling, by providing individuals with useful skills....Schooling is also a pure consumption good, enabling people to better understand and enjoy their surroundings." The approach taken here is simple enough to be incorporated tractably into an inter-generational setup, yet still able to highlight this multi-dimensional nature of education.

[5]Utility based on the education of childre 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. Acemoglu, in his new book *Introduction to Modern Economic Growth*, would call this an example of "impure altruism," or "warm glow preferences." "Warm glow preferences assume that parents derive utility not from the future utility of their offspring, but from some characteristic of their offspring." (Acemoglu 2008, pg 840).

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

$$\frac{\partial C_t}{\partial n_t} = \frac{\partial U_t}{\partial n_t} \tag{7}$$

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 (6), 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:

$$\frac{\partial C_t}{\partial e_t} - \frac{\partial U_t}{\partial e_t} = \left(\frac{1-\lambda}{\lambda}\right)\left(\frac{S_t + U_t - C_t}{H_{t+1}}\right)^{1-\varepsilon} \frac{\partial H_{t+1}}{\partial e_t} \tag{8}$$

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 (2008), we specify the following:

$$S_t = w_{h,t} H_t \tag{9}$$

$$U_t = w_{l,t}\left(1 - e_t\right) n_t \tag{10}$$

$$C_t = w_{h,t} \phi n_t^{\gamma} \left(1 + e_t\right)^{\gamma} \tag{11}$$

$$L_t = n_t L_{t-1} \tag{12}$$

$$H_{t+1} = \Lambda e_t^{\alpha} \tag{13}$$

where $\alpha < 1$ and $\gamma > 1$. (9) - (11) respectively depict the skilled income generated by the parent, the unskilled income generated by children, and forgone skilled income due to child rearing. (12) and (13) illustrate how fertility and education translate into unskilled and skilled factors of production. That 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 (10) 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 (9) - (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.[6] 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 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, $w_{h,t}$ and $w_{l,t}$ for $t = 1$.

[6]For our simulation, parameter values are set to the following: $\sigma = 2$, $\lambda = 0.5$, ε = -5, $\Lambda = 2$, $\alpha = 0.2$, $\phi = 0.2$, $\gamma = 2$. Note that the key parameters here are those that affect the substitutability of skilled and unskilled labor in production (σ) and the substitutability of income and human capital in utility (ε). While values of ε are purely speculative, much work has been done to estimate σ. The literature tends to value this somewhere between 1 and 2.5 for contemporary labor markets (see Katz and Autor 1999 for a review of this literature).

Our specific functional forms will allow such a solution. Setting A_l and A_h to some arbitrary level, we simultaneously solve (4), (5), (7) and (8) for w_l, w_h, L, and e, maintaining the constraints of $n = 1$ and $e_{t-1} = e_t$.[7] 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.

4.2 Dynamic Equilibria - the Industrial Revolution and the Demographic Transition with "Balanced" Growth

Here we run the simulation for 50 time periods to roughly capture economic and demographic trends in England from around 1750 to the Great War. A_l and A_h exogenously grows 2 percent each time period. With such "balanced" growth, $A_l = A_h \ \forall t$; in this case we can write the skill premium as

$$\frac{w_{h,t}}{w_{l,t}} = \left(\frac{L_t}{H_t}\right)^{\frac{1}{\sigma}} \tag{14}$$

Here the premium paid to skilled labor is strictly a function of relative factors. Thus in order for the skill premium to fall over time, the ratio of skilled to unskilled labor must rise over time.

Figures 15 and 16 illustrate the results of the simulation. At the moment of technological growth, the population is stable, education is quite low and the skill premium is quite large. With early productivity increases, fertility rises and education rises slightly as well. How is this possible in the context of a quality-quantity model of demography? Given (13), we see that the production of human capital follows the *Inada conditions* ($\lim_{e\to 0} H(e) = \infty, \lim_{e\to\infty} H(e) = 0$). Thus if early rates of education are "small enough," human capital will rise with very small increases in education. Households can then raise the human capital of their offspring as their income rises. But because it does not cost them a lot to do this, they can also afford to have more children as well (to take advantage of increases in the unskilled wage). Throughout this process the ratio of skilled to unskilled labor rises, allowing the skill premium to continually fall.

Note that Galor labels this period the "post-Malthusian" era; this is because productivity increases still translate into population increases. This is precisely what we produce here. Even though education is explicitly modeled here as a normal good, increases in productivity creates a lot of fertility with very modest increases in education. While overall income in the economy does grow, income *per capita* is virtually stagnant as a result of population growth. Thus early growth dynamics appear to be dictated by a classic "Malthusian trap."

As balanced technical progress continues, however, there is an endogenous transition where further increases in productivity result in less fertility and more education. Why does the switch

[7] After setting $A_l = A_h = 0.1$, we get initial values of $e = 0.007$, , $L = 2.85$, $H = 0.46$, and $w_h/w_l = 2.5$.

occur? Once education reaches some critical level, diminishing returns to further education are such that these increases become quite expensive. Households are willing to pay this expense as their incomes rise further. But to lower the overall expense for education they have fewer and fewer children. So households become less reliant on the unskilled income generated by their offspring, and more reliant on their own skilled income. This is in essence the transition to modernity; a classic quantity/quality tradeoff of child rearing emerges. And as the demographic transition proceeds, income per capita begins to grow faster than overall GDP.

The simulation stresses that in order to truly unify the stages of economic growth, models must account for constant injections of skilled labor over time. An implicit result of important unified theories such as Galor and Weil (2000) and Galor and Mountford (2004) is that 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 2006) 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* in any model of unified growth.

4.3 Dynamic Equilibrium - Can We Explain Today's Skill-Premium Puzzle?

While this simple model of demography can capture, among other things, the generally low and falling wage dispersion we observe in the Industrial Revolution, we should test whether such a simple theory can also account for the *rising* wage dispersion in the developed world during the last few decades. Figure 11 highlights that skill premia rose in the United States after 1950 (Goldin and Katz 2008); indeed, most OECD countries have experienced rising inequality during this time. Two possibilities suggested for this rise are increased demand for skills due to skill-biased technological change, and stagnating supply of skilled labor. We briefly explore each of these possibilities.

The skill-bias of technological change has been the focus of studies that explore rising inequality between skilled and unskilled labor in developed economies since the 1980s. In particular, it is argued that the introduction and spread in the use of computers, electronic commerce, and the Internet during the last few decades has led to rising returns for marketing and complex problem-solving skills (Bresnahan 1999; Autor, Levy and Murname 2003). However, as detailed

extensively by Goldin and Katz (2007, 2008), skill biased technologies have considerably grown in the U.S. throughout the entire twentieth century. Technological growth had become more skill-intensive towards the end of the 19th century with the adoption of electricity and various capital-intensive technologies associated with batch and continuous-process machinery. These techniques (used for processing non-solid materials and products with few or no moving parts) required a corps of mechanics and engineers to assemble and maintain capital equipment, thus increasing the demand for skilled mechanics, technicians, and various professionals.

Can this very simple model account for the falling skill premium in the first half of the twentieth century even when technological growth is skill biased? And can we account for the rise in premia we observe today with an acceleration of skill-biased technological growth? To answer these questions let us repeat the above experiment, but now let us keep A_l constant and only allow A_h to grow. Such biased technological growth requires us to rewrite the skill premium as

$$\frac{w_{h,t}}{w_{l,t}} = \left(\frac{A_h}{A_l}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{L_t}{H_t}\right)^{\frac{1}{\sigma}} \tag{15}$$

Now we see that the wage gap can rise either from an increase in demand for skilled labor or from a decrease in the relative supply of skilled labor.

Figure 17 illustrates simulation results for this case.[8] In this case we do not produce a fertility boom - rates of fertility and education begin quite flat; soon after however fertility rates fall, education rates rise, and the premium paid to skilled labor begins to fall as supply side forces overwhelm demand driven forces. Thus we can produce a plausible story of American industrialization, consistent with early 20th century skill-biased technological growth, where fertility falls, education dramatically rises, and the skill premium falls.

What about the rise in inequality after 1980? Here increasing the growth of A_h will actually *decrease* the skill premium further, not increase it. The reason is that supply responses of falling L and rising H will more than offset any increase in A_h. In the context of endogenous fertility and education, accelerating skill-biased technologies (the "computers did it" argument, for example) may not produce the rise in inequality we have observed recently in developed countries.

Another possibility then is the slowdown in educational advance for young adults beginning in the 1970s. Indeed, Goldin and Katz 2008 stress that educational change between generations came to an abrupt standstill during this time. To incorporate this into the model, we can simply constrain education to some low predetermined level $\overline{e}$; households then would have only one variable they could change, n_t. In this case, from (7) we can explicitly solve for the optimal fertility rate:

[8] Parameter values are the same as previous.

$$n_t = \left(\frac{w_{h,t}}{w_{l,t}} \frac{\gamma\phi\left(1+\overline{e}\right)}{\left(1-\overline{e}\right)} \right)^{\frac{1}{1-\gamma}} \tag{16}$$

Figure 18 illustrates the case where technology is skill-biased *and* education is constrained at a low level. Initially the model behaves exactly as in the case from Figure 18. However, once the level of education becomes a binding constraint, fertility dramatically falls. The reason is because skill-biased technological growth makes the opportunity cost of children higher and the gains from unskilled income lower; consequently households have fewer children. While the first term in (15) rises, the second term falls (from decreases in L) just enough so that the skill-premium remains constant.

Thus the model sheds light on falling premia in history, but actually deepens the puzzle of rising premia in recent history. With quality-quantity models of demography, households have two ways of reacting to changing relative returns to skills; both would have to be shut down in order for skill-biased technologies to increase the skill premium. This of course begs the question of what forces thwarted households to react to changes in the relative returns to different types of labor. The point here is that a unified explanation for the two halves of the 20th century inequality experience certainly remains a challenge to theoretically explain.

5 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. Explaining the fall in skill premia in early 20th century America followed by its recent rise has constituted another. Here we 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. In the process we have urged that unified growth theories should aim to unify the historic experiences of both economies.

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.

References

Acemoglu, D. 2008. *Introduction to Modern Economic Growth*, Princeton, NJ: Princeton University Press.

Acemoglu, D. 2002. "Technical Change, Inequality and the Labor Market," *Journal of Economic Literature*, vol. 40, pp. 7-72.

Autor, D., F. Levy and R. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics*, vol. 118, pp. 1279-1334.

Bell, Philip W. 1951. "Cyclical Variations and Trend in Occupational Wage Differentials in American Industry since 1914," *The Review of Economics and Statistics* 33 (November): 329-37.

Bresnahan, T. 1999. "Computers and Growth," in *The Puzzling Relations Between the Computer and the Economy.* MIT Press

Broadberry, S. N. 1994. "Technological Leadership and Productivity Leadership in Manufacturing since the Industrial Revolution: Implications for the Convergence Debate," *Economic Journal*, vol. 104(423), pp. 291-302.

Clark, G. 2007. *A Farewell to Alms: A Brief Economic History of the World.* Princeton University Press: Princeton.

Flora, P., Kraus F. and Pfenninf W. 1983. *State Economy and Society in Western Europe, 18151975. Volume I: The Growth of Mass Democracies and Welfare States.* Frankfurt: Campus Verlag.

Galor, O. 2005. *From Stagnation to Growth: Unified Growth Theory.* in P. Aghion and S. N. Durlauf, eds., *Handbook of Economic Growth*, volume 1, part 1, pp. 171293. Amsterdam: North Holland.

Galor, O., and A. Mountford. 2004. "Trading Population for Productivity." Brown University Working Paper No. 38-01.

Galor, O., and O. Moav 2006. "Das Human-Kapital: A Theory of the Demise of the Class Structure." *Review of Economic Studies* vol. 73, pp. 85117.

Galor, O., and D. Weil. 2000. "Population, Technology and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond." *American Economic Review* vol. 90, pp. 80628.

Goldin, C. 1999. "A Brief History of Education in the United States," NBER Historical Paper No. 119.

Goldin, C. and L. Katz. 1998. "The Origins of Technology-Skill Complementarity," *Quarterly Journal of Economics* vol. 113, pp. 693-732.

Goldin, C. and L. Katz. 2007. "The Race Between Education and Technology: The Evolution of U.S. Educational Wage Differentials, 1890 to 2005," NBER Working Paper No. 12984.

Goldin, C. and L. Katz. 2008. *The Race Between Education and Technology.* Boston: Harvard University Press.

Hansen, G.D., and E.C. Prescott. 2002. "Malthus to Solow." *American Economic Review* vol. 92, pp. 120517.

Horrell, S., and J. Humphries. 1995. "The Exploitation of Little Children: Child Labor and the Family Economy in the Industrial Revolution." *Explorations in Economic History*, vol. 32, pp. 485516.

Jones, C. I. 2001. Was the Industrial Revolution Inevitable? Economic Growth over the Very Long Run. *Advances in Macroeconomics* 1(2): 1028–28.

Jones, Larry E. and Tertilt, Michele. 2006. "An Economic History of Fertility in the U.S.: 1826-1960" (December). NBER Working Paper No. W12796

Katz, L. F., and D. H. Autor. 1999. "Changes in the Wage Structure and Earnings Inequality." In O. Ashenfelter and D. Card, eds., *Handbook of Labor Economics*, vol. 3A. Amsterdam: Elsevier Science: 1463-555.

Keat, Paul G. 1960. "Long-Run Changes in Occupational Wage Structure, 1900-1956," Journal of Political Economy 68 (December): 584-600.

Kirby, P. 1999. "The Historic Viability of Child Labor and the Mines Act of 1842." Chapter 4 of *A Thing of the Past? Child Labour in Britain in the Nineteenth and Twentieth Centuries*, edited by Michael Lavalette. Liverpool: Liverpool University Press.

Landes, D.S. 1969. *The Unbound Prometheus. Technological Change and Industrial Development in Western Europe from 1750 to the Present*, Cambridge University Press: Cambridge.

Lebergott, Stanley. 1947. "Wage Structures," The Review of Economic Statistics 29 (November): 274-85.

Lindert, Peter H. and Jeffrey G. Williamson. 1980. *American Inequality: A Macroeconomic History.* New York: Academic Press.

Lucas, R. E. 2002. "The Industrial Revolution: Past and Future." In *Lectures on Economic Growth.* Cambridge, Mass.: Harvard University Press.

Maddison, A. 2003. *The World Economy: Historical Statistics* CD-ROM (OECD, Paris).

MacLeod, C. 1988. *Inventing the Industrial Revolution: The English Patent System, 1660-1800.* Cambridge University Press: Cambridge.

Mitch, D. 1982. The Spread of Literacy in Nineteenth-Century England. Ph.D. dissertation, University of Chicago.

Mitch, D. 1999. "The Role of Education and Skill in the First Industrial Revolution," in Joel Mokyr, ed., The British Industrial Revolution: An economic perspective. Boulder, CO: Westview, pp. 241-79.

Mokyr, J. 1990. *The Lever of Riches - Technological Creativity and Economic Progress.* Oxford University Press: Oxford.

Mokyr, J. 2005. "Long-Term Economic Growth and the History of Technology." In Philippe Aghion and Steven Durlauf (eds.), *Handbook of Economic Growth*, volume 1, pp. 111380. Amsterdam: Elsevier.

Mokyr, J. and H. Voth. 2006. "Understanding Growth in Europe, 1700-1870: Theory and Evidence," Prepared for the Minerva Conference on Economic Growth, Jerusalem.

Nelson, R. and E. Phelps. 1966. "Investment in Humans, Technological Diffusion and Economic Growth," *American Economic Association Papers and Proceedings*, vol. 56, pp. 69-75.

Ober, Harry. 1948. "Occupational Wage Differentials, 1907-1947," Monthly Labor Review (August): 27- 134.

O'Rourke, K., A. Rahman and A.M. Taylor, 2007. "Trade, Knowledge and the Industrial Revolution," NBER Working Paper # 13057.

Rahman, A. 2008. "The Appropriate Technology Frontier - Lessons for the Developing World," USNA Department of Economics Working Paper #16.

Sanderson, M. 1995. *Education, Economic Change and Society in England 1780-1870*, Cambridge University Press: Cambridge.

Schofield, R. S. 1973. "Dimensions of Illiteracy, 1750-1850," *Explorations in Economic History* vol. 10: 437-454.

Schultz, T. 1975. "The Value of the Ability to Deal with Disequilibria," *Journal of Economic Literature*, vol. 13, pp. 827-846.

Solow, R. 1956. "A Contribution to the Theory of Economic Growth," *Quarterly Journal of*

Economics vol. 70: 65-94.

Tinbergen, J. 1975. *Income Difference: Recent Research*, North-Holland Publishing: Amsterdam.

van Zanden, J. 2007. "The Skill Premium and the Great Divergence," unpublished manuscript.

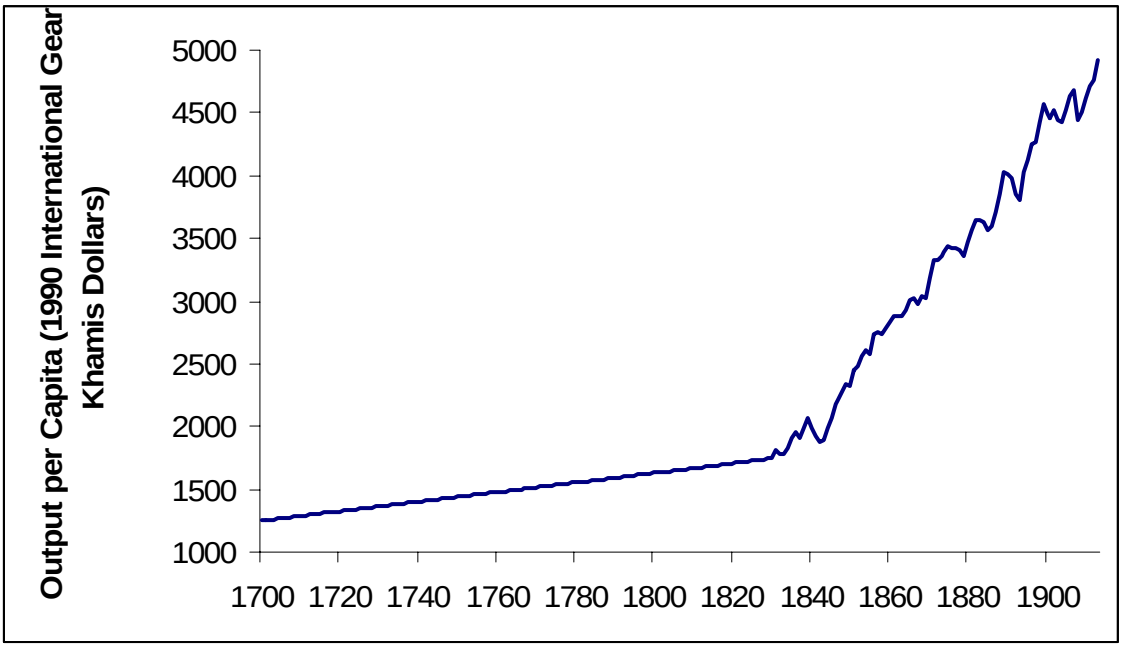
Voth, J. 2003. "Living Standards during the Industrial Revolution: An Economist's Guide," *American Economic Review* vol. 93, pp. 221-226.

Williamson, J. 1982. "The Structure of Pay in Britain, 1710-1911," in P. Uselding (ed.), *Research in Economic History* vol. 7, Greenwich, CT: Johnson Associates.

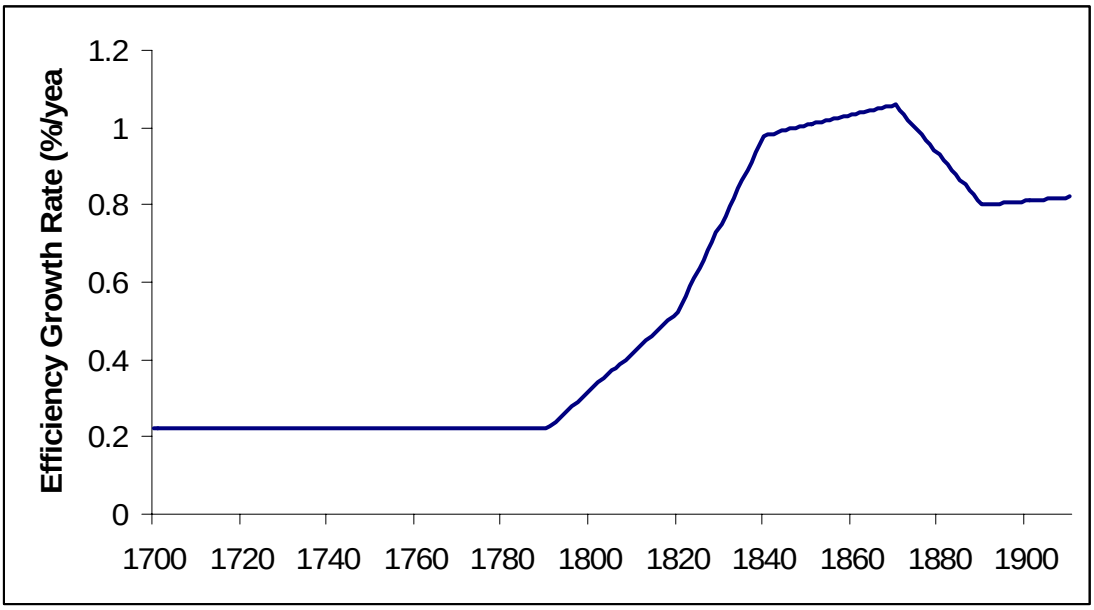
Woytinsky, W.S. (and associates). 1953. *Employment and Wages in the United States*. New York: the Twentieth Century Fund.

Figures

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

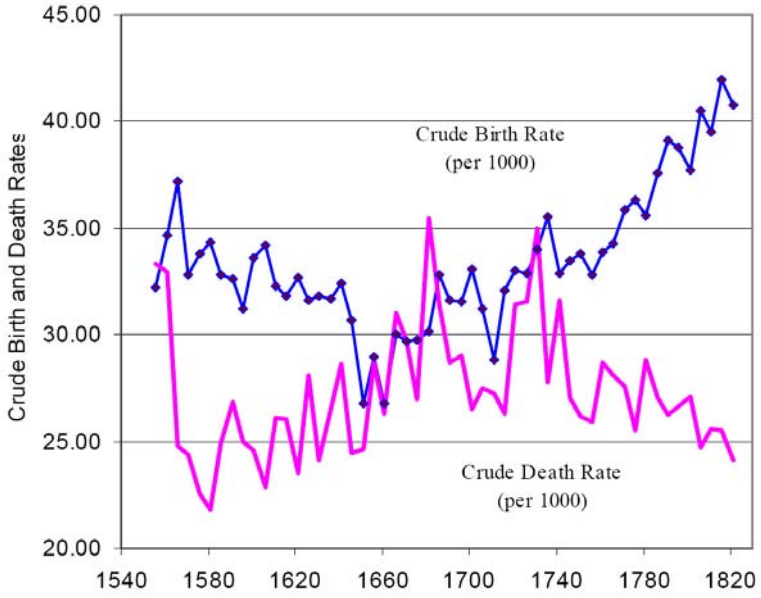


Source: Maddison (2003).



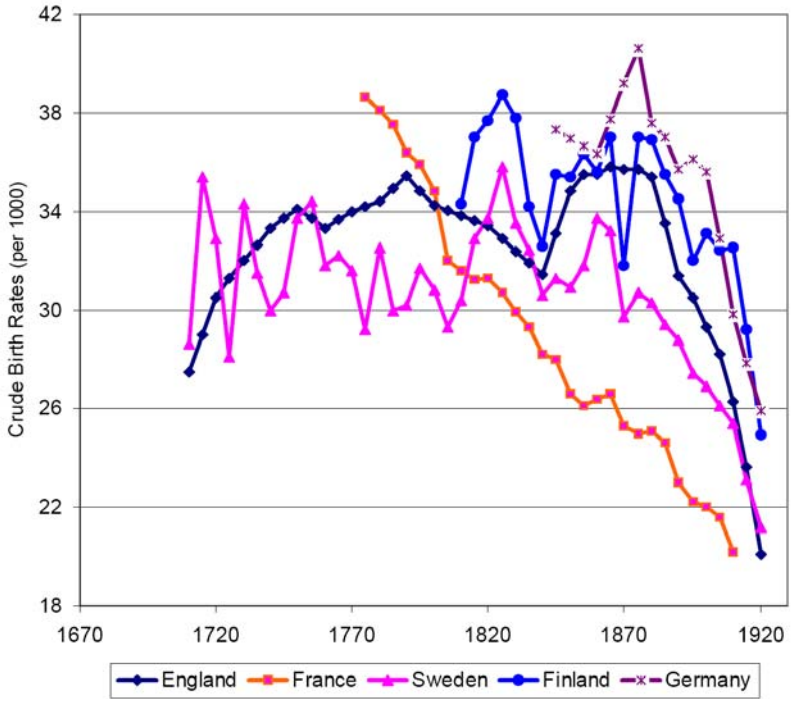
Source: Clark (2003), based on Crafts and Harley (1992) and Deane and Cole (1967).

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

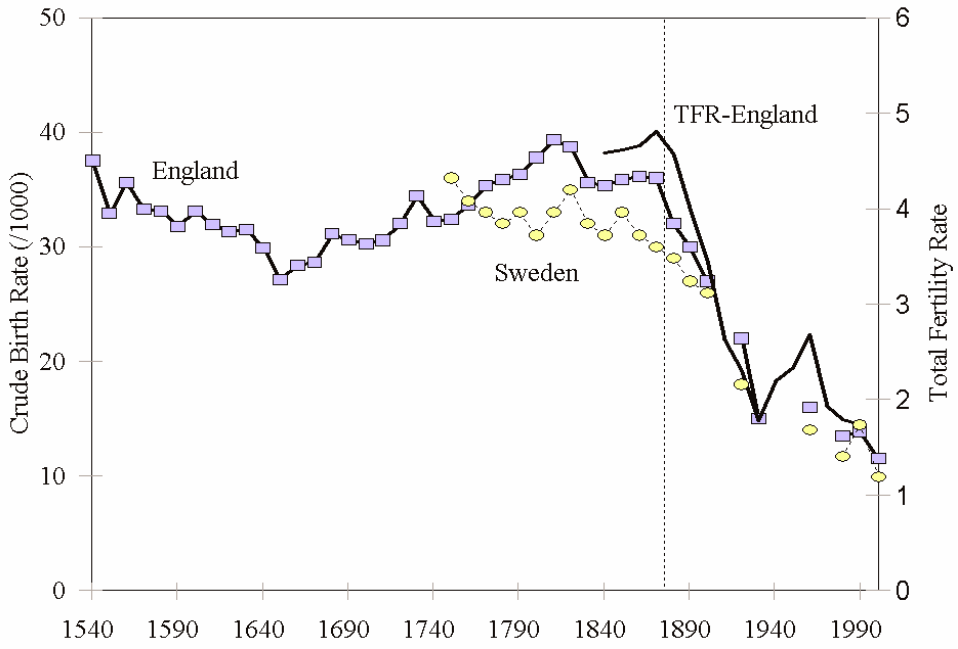
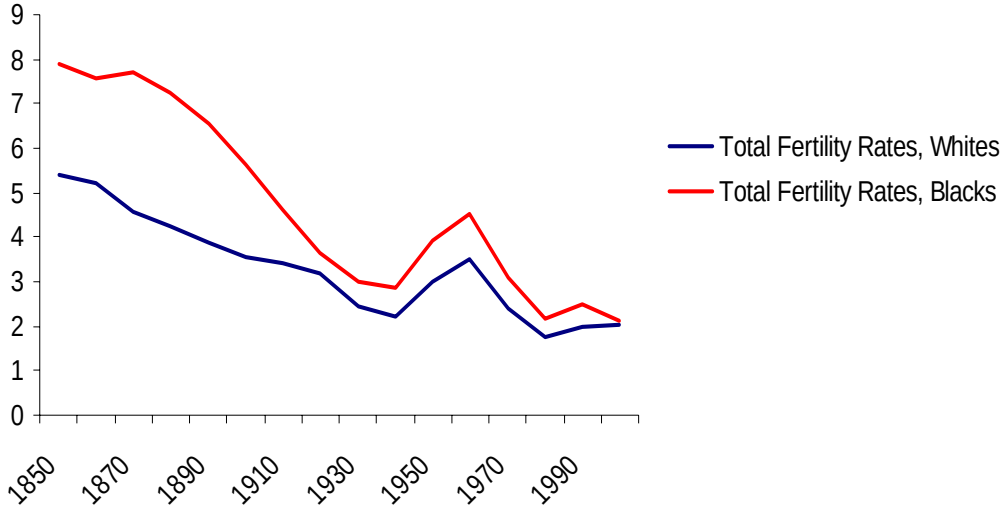
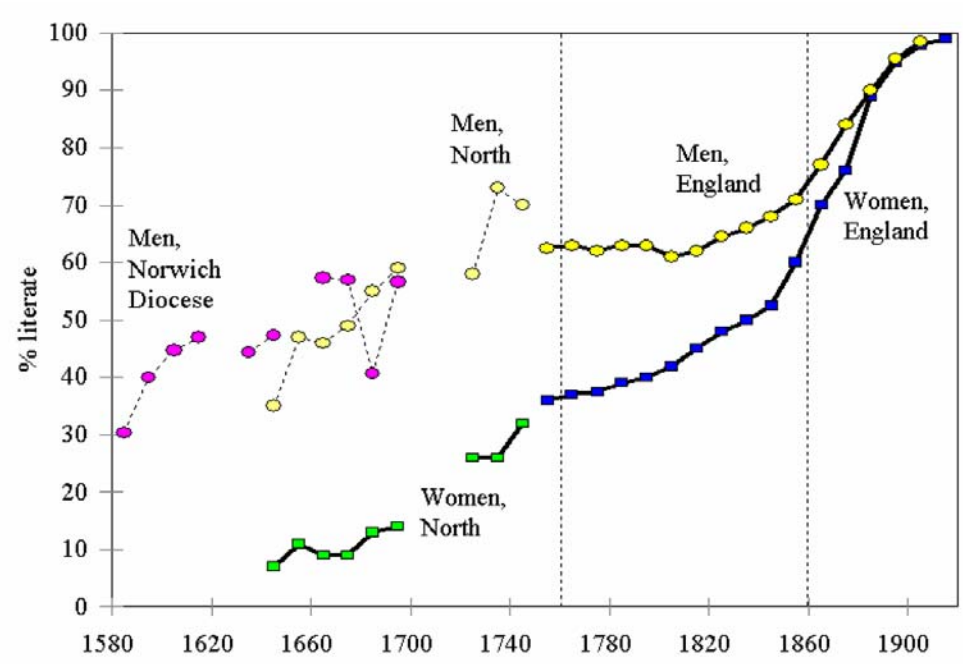


Figure 5 – Fertility Rates in the United States



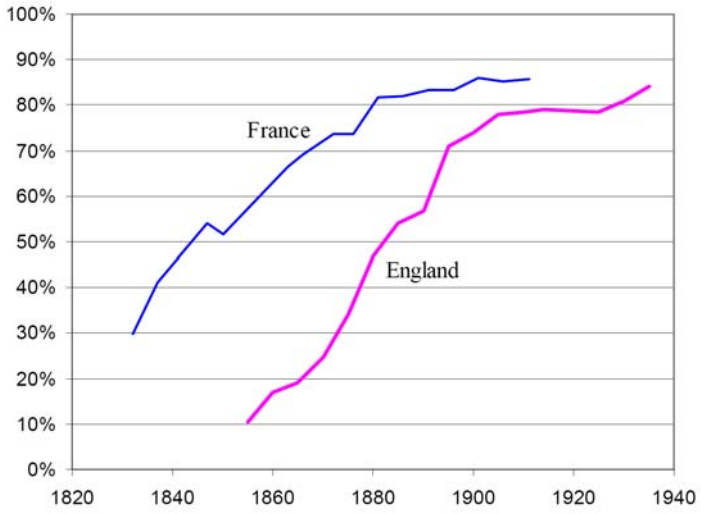
Source: eh.net

Figure 6 – Literacy in England, 1580 - 1920



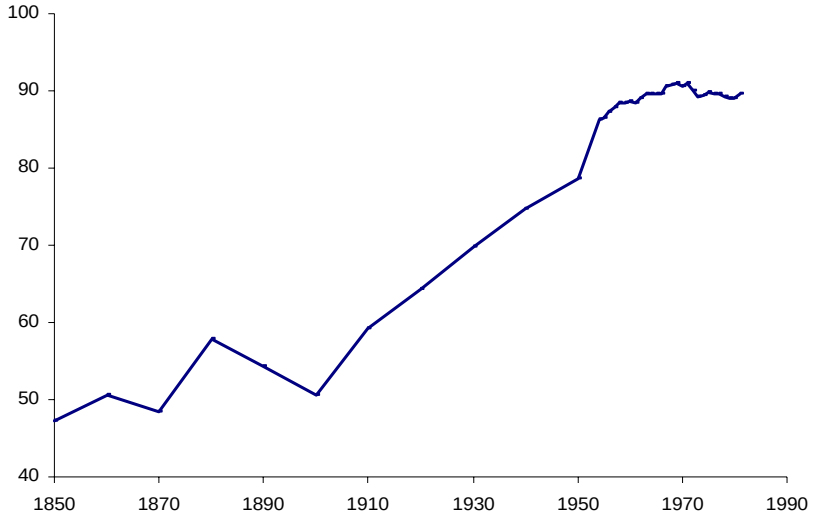
Source: Clark (2005), based on Schofield (1973), Houston (1982), and Cressy (1997)

Figure 7 – The Fraction of Children Aged 5-14 in Public Primary Schools, 1820 - 1940



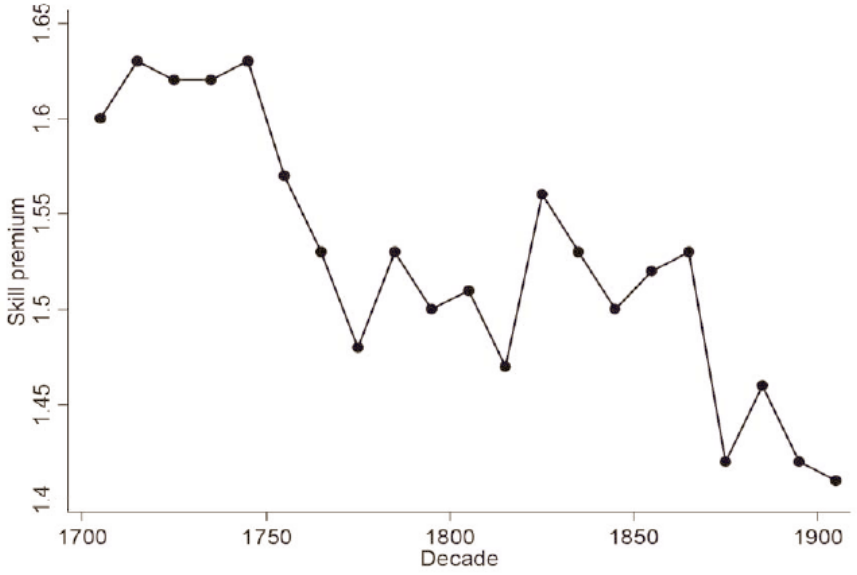
Source: Galor (2005), based on Flora et al. (1983)

Figure 8 – U.S. School Enrollment of 5-19 Year-Olds, %, 1850 – 1980



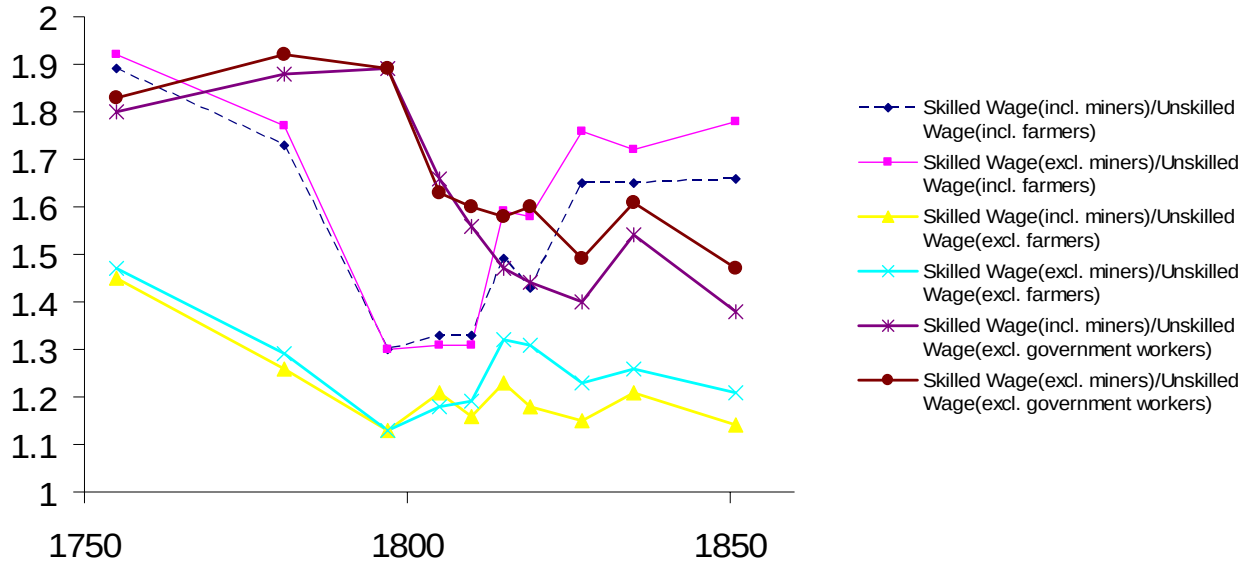
Source: Goldin and Katz (2008)

Figure 9 – English Skill Premium in Housing, 1700-1910



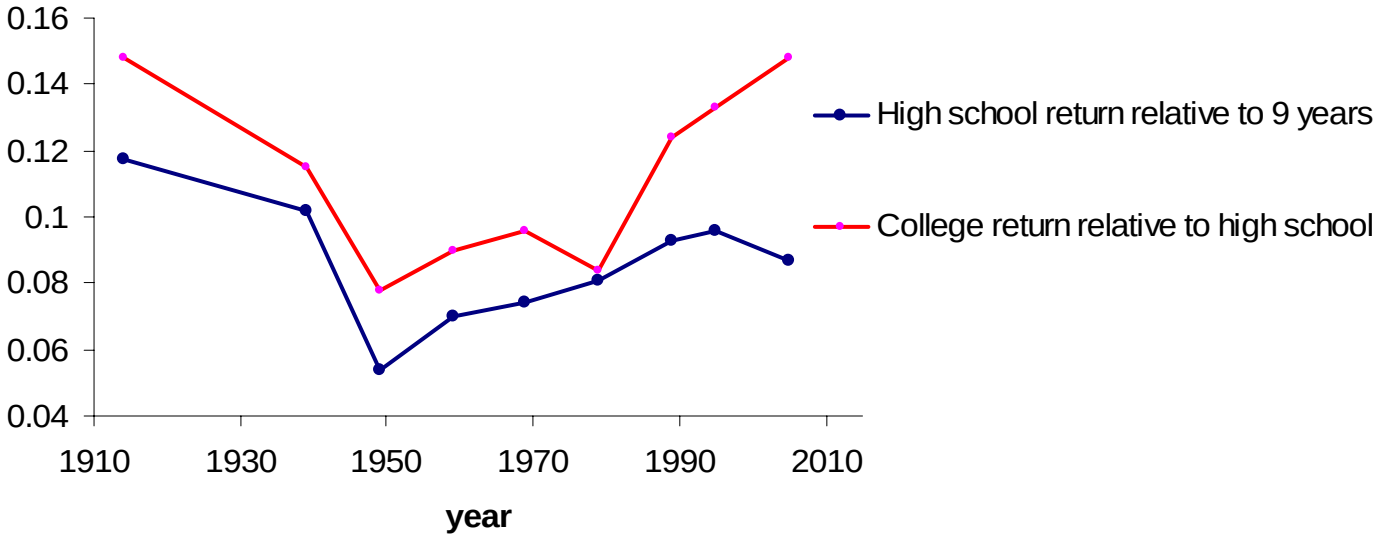
Source: Clark (2007)

Figure 10 – English Skill Premia for Various Industries, 1750-1850



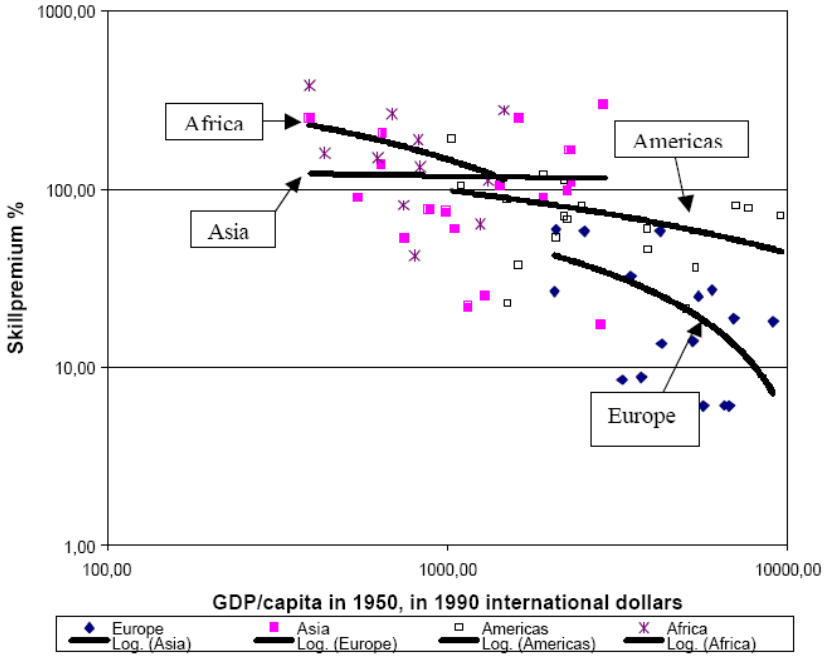
Source: Williamson (1982)

Figure 11 – Relative Returns to a Year of Schooling for Young Men in the United States, 1910 - 2005



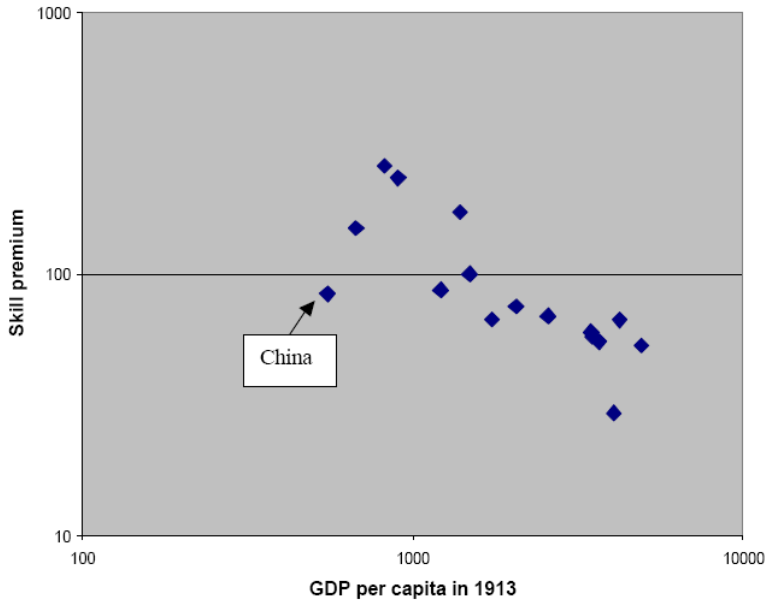
Source: Goldin and Katz (2008)

Figure 12 – Relationship between GDP per capita and the skill-premium of building craftsmen (c 1950)



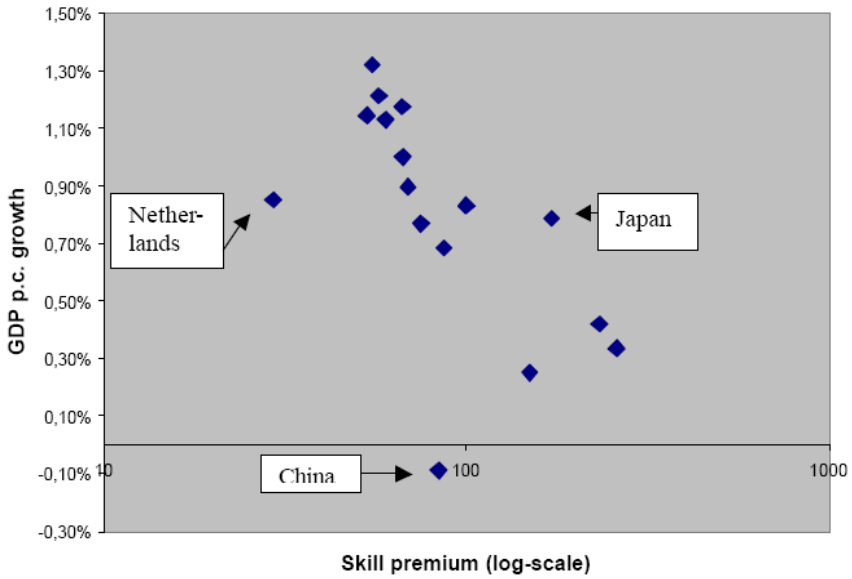
Source: van Zanden (2006)

Figure 13 – The skill premium in 1750/1820 and GDP per capita in 1913 (log scale)



Source: van Zanden (2006)

Figure 14 – Average skill premium of construction workers between 1750 and 1820 and GDP per capita growth in 1820-1913



Source: van Zanden (2006)

Figure 15 – Simulated Fertility and Education Rates
(Balanced Growth)

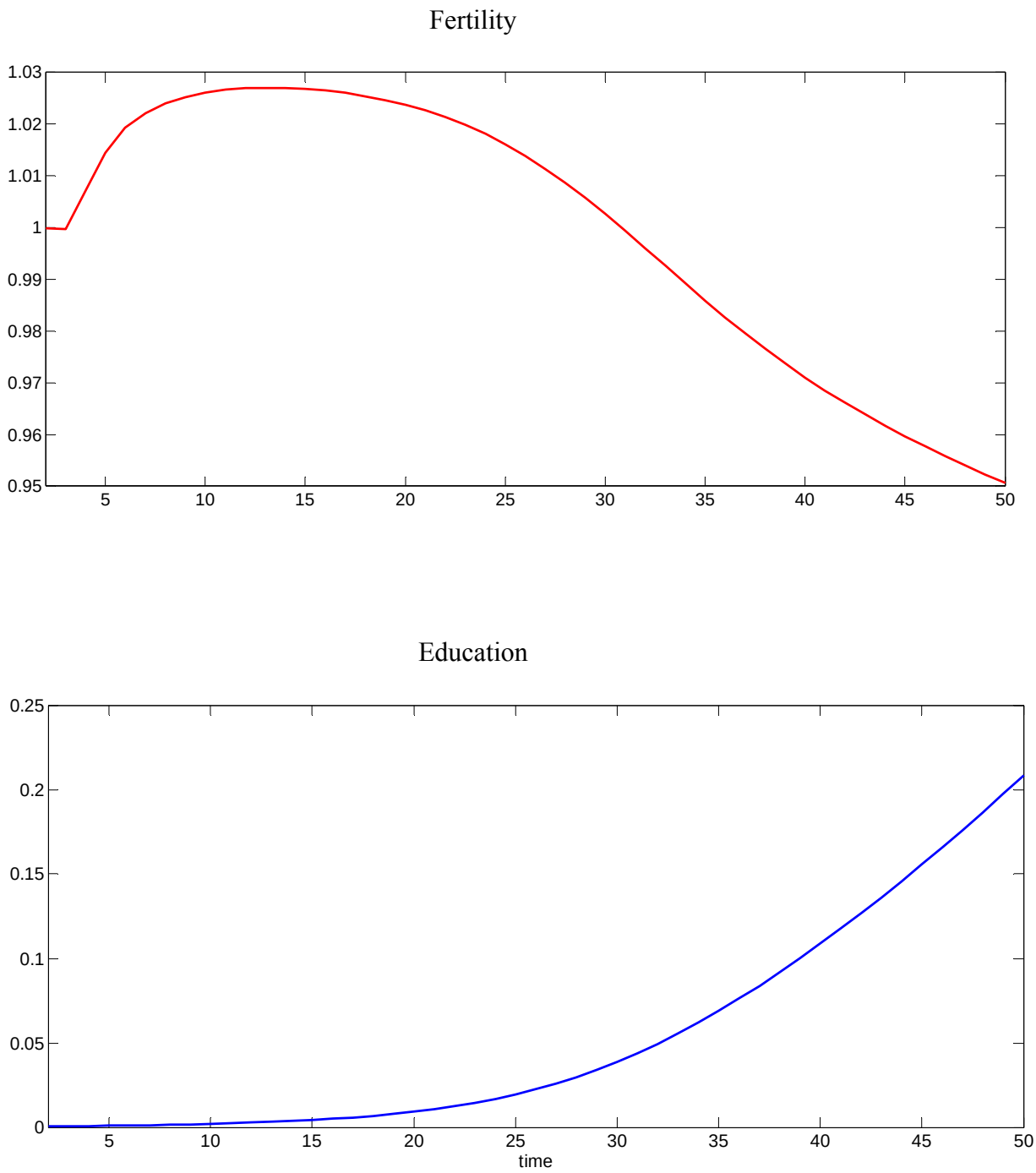
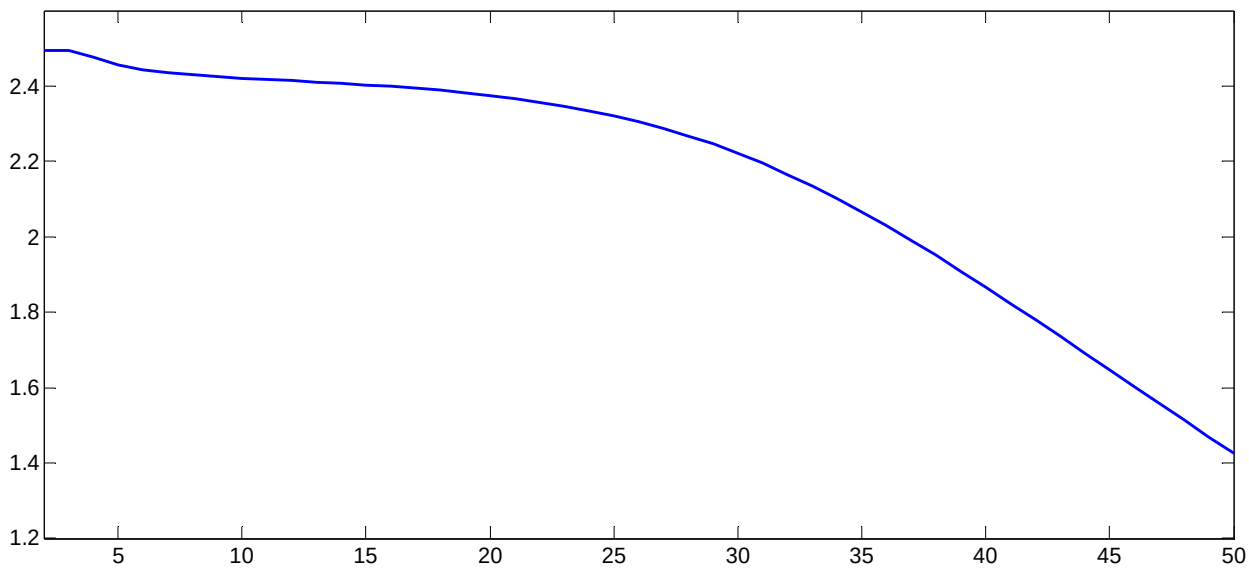


Figure 16 – Skill-Premium and Output (Balanced Growth)

Skill Premium



Income per Capita

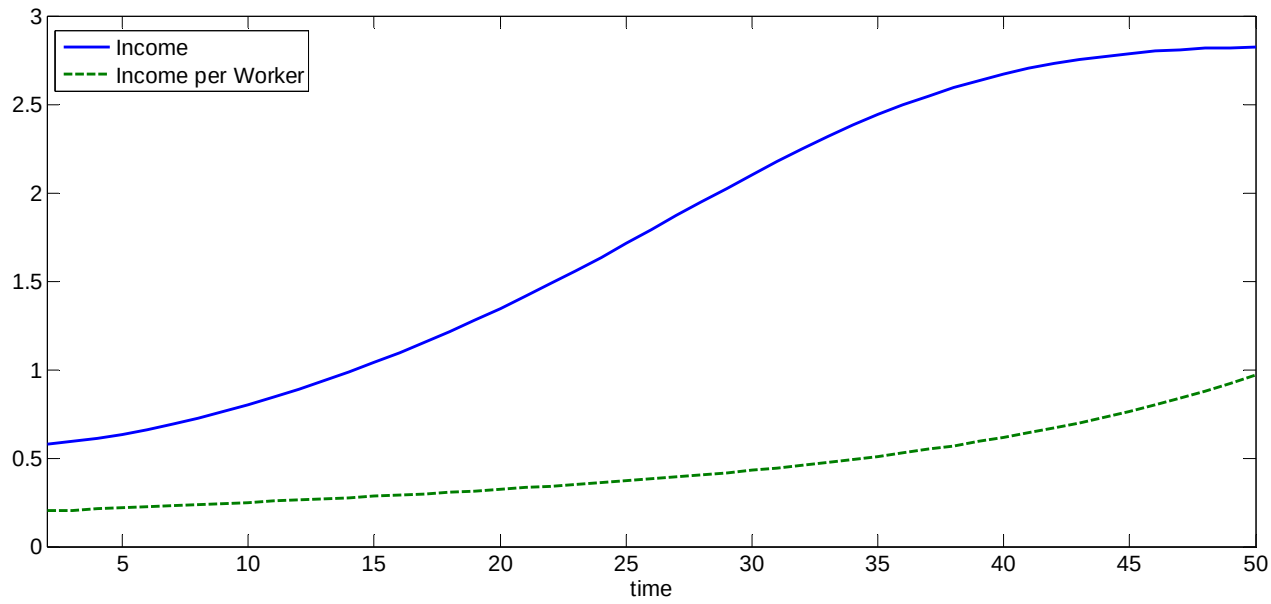


Figure 17 – Simulation Results with Growth Only in A_h

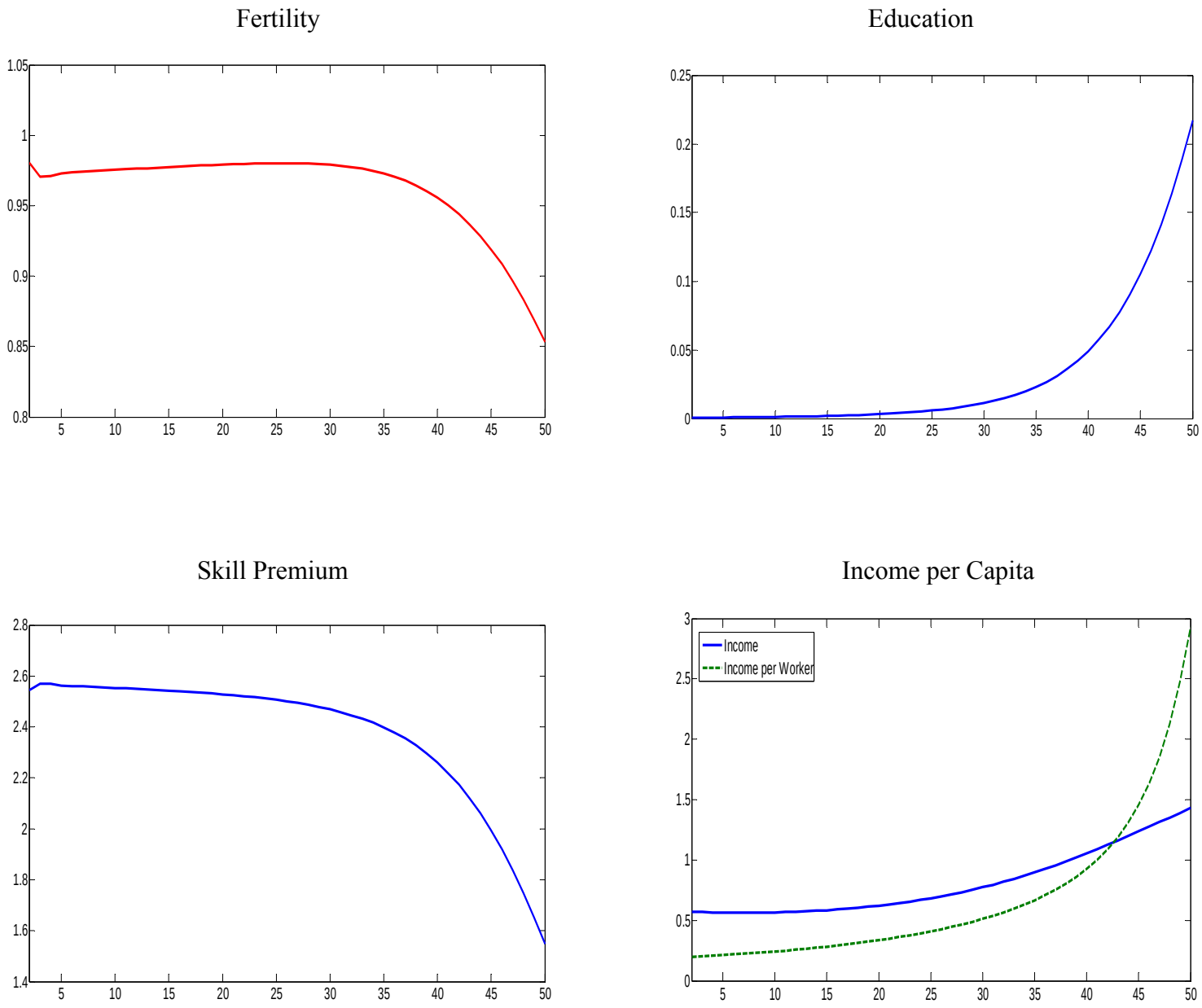
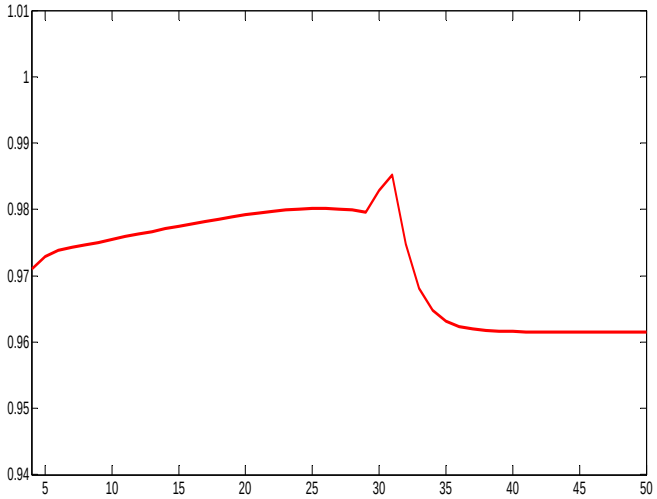
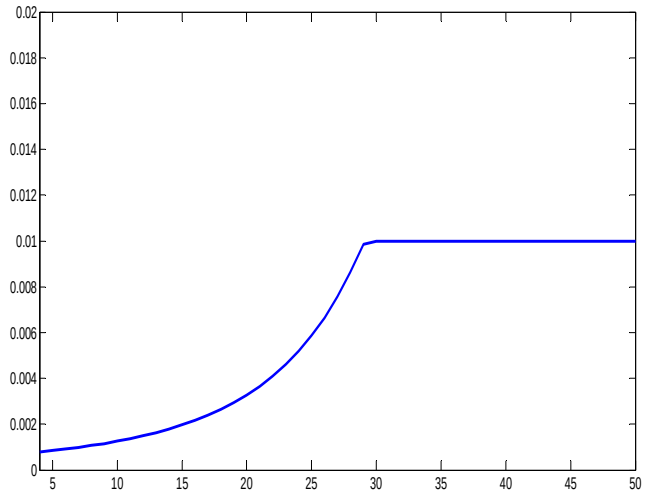


Figure 18 – Simulation Results with Growth Only in A_h, and $e \leq 0.01$

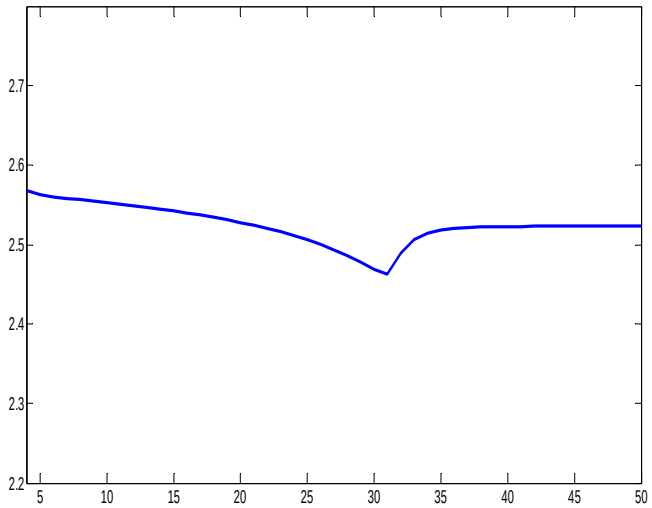
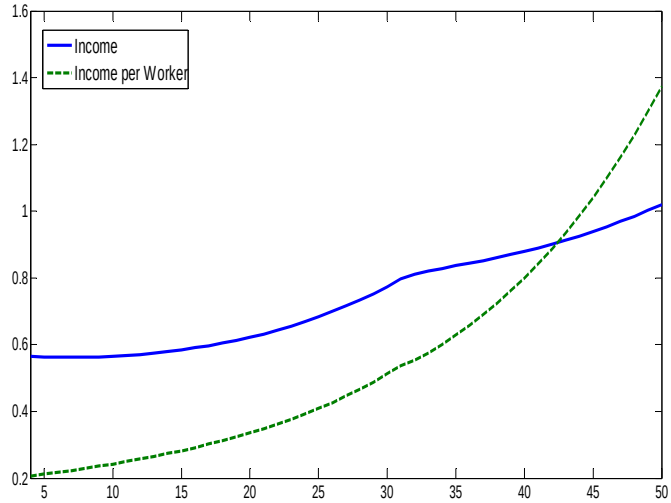
Fertility



Education



Skill Premium



Income per Capita