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THE DECLINING QUALITY OF TEACHERS

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ABSTRACT

Concern is often voiced about the declining quality of American schoolteachers. This paper shows that, while the relative quality of teachers is declining, this decline is a result of technical change, which improves the specialized knowledge of skilled workers outside teaching, but not the general knowledge of schoolteachers. This raises the price of skilled teachers, but not their productivity. Schools respond by lowering the relative skill of teachers and raising teacher quantity. On the other hand, college professors, who teach specialized knowledge, are predicted to experience increases in skill relative to schoolteachers. Finally, the lagging productivity of primary schools is predicted to raise the unit cost of primary education. These predictions appear consistent with the data. Analysis of US Census microdata suggests that, from the 1900 birth cohort to the 1950 birth cohort, the relative schooling of teachers has declined by about three years, and the human capital of teachers may have declined in value relative to that of college graduates by as much as thirty percent, but the teacher-student ratio has more than doubled over the last half century in a wide array of developed countries. Moreover, the per student cost of primary school education in the US has also risen dramatically over the past 50 years. Finally, the human capital of college professors has risen by nearly thirty percent relative to schoolteachers.

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1 Introduction

In today's knowledge-intensive economies, the school, not the factory, may be the most important site of capital accumulation. Since World War II, US investment in human capital has consistently accounted for over 80% of total annual investment.[1] Moreover, spending on *formal* schooling constitutes an increasingly large share of human capital investment. In 1948, formal schooling accounted for roughly 40 percent of human capital investment. Less than 40 years later, it accounted for 63 percent.[2] Overall, therefore, spending on formal schooling accounts for about half of *total* annual investment, and its importance may still be on the rise.

It seems undeniable that investments in schooling play a major role in economic growth. To this indisputable fact, however, Figure 1 appears to pose a challenge. This figure depicts the log change in the relative wages of primary school teachers for several advanced countries, from 1965 to 1994,[3] where teacher wage growth is deflated by growth in the wage of the average employee.[4] Figure 1 demonstrates that the relative wages of primary school teachers have plummeted in many advanced economies over the last half of the twentieth-century. In fact, only one country in this sample, Japan, shows evidence of *any* increase in this relative wage series.[5] Various researchers report results consistent with Figure 1. Bee and Dolton (1995) find that, after a brief upward swing during the post-World War II baby boom years,

[1]See Jorgenson and Fraumeni (1995a).

[2]See Jorgenson and Fraumeni (1995b).

[3]The log change in the teacher wage is constructed as log 1994 educational expenditures per teacher minus log 1965 educational expenditures per teacher. [OECD (1981, 1989, 1990, 1993), UNESCO (1976, 1989, 1993)] This estimate assumes that the proportion of expenditures on teacher salaries is constant. Where data on this proportion are available, this assumption seems to hold.

[4]Wage growth of the average employee is calculated using total employee compensation, from national accounts data, and dividing this by the number of employees. National accounts data are taken from OECD (1983, 1996), while labor force data are taken from OECD (1986, 1997).

[5]All of the Japanese increase took place from 1965 to 1975. It seems likely that this was driven by the entrance of large baby boom cohorts into Japanese primary schools, because Japanese fertility peaked during the mid- to late '60s. (Japanese population data are taken from OECD [1998].)

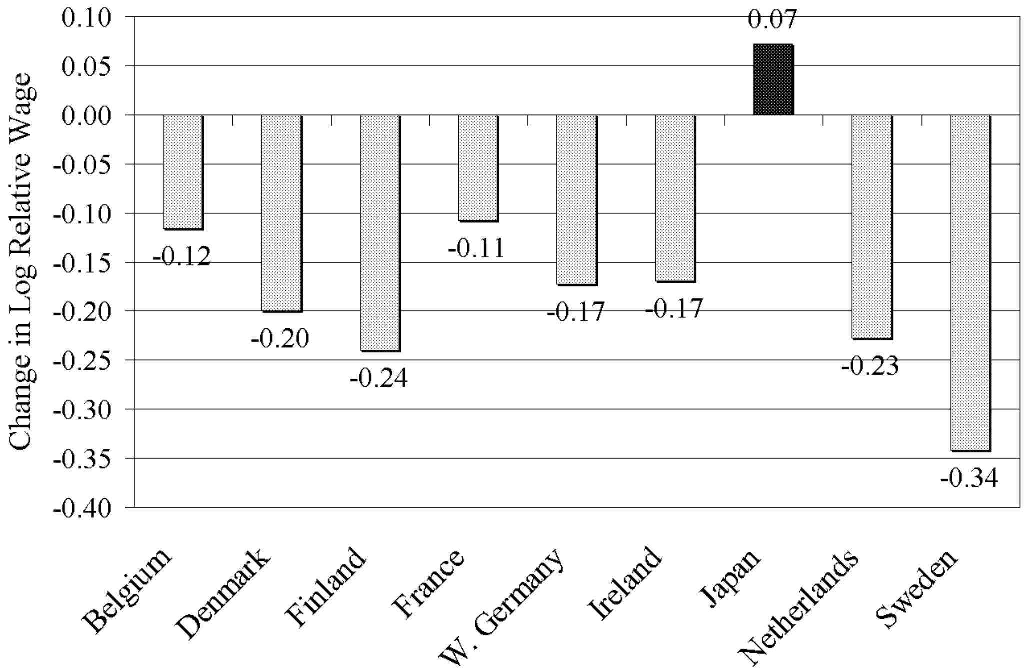

Figure 1: Change in log relative wage of primary school teachers in developed countries, 1965-1994.

the relative wages of British school teachers have fallen twenty percent since 1965. Across the Atlantic, Hanushek and Rivkin (1997) find that since 1940 the wages of US schoolteachers have declined relative to college graduates by ten to twenty percent. Correspondingly, US schoolteachers have skidded nearly twenty percentage points down the earnings distribution for all workers, and almost fifteen percentage points down the earnings distribution for college graduates.[6]

Perhaps most telling of all has been the dramatic decline in the relative quality of teacher training. In the late nineteenth century US, a degree from a teachers' college was so highly prized that non-teachers would often attempt to gain entrance under the pretext of an interest in teaching. This behavior was so pervasive that state-run teachers' colleges would actually require entering students to precommit to teaching careers. (McNeil 1930) Over the next century, however, the relative quality of teacher education declined precipitously. By 1970, teachers had become the dregs of the US college population: by this time, teachers ranked near the bottom of their college classes in both achievement and intelligence tests. (Manski 1985) Surprisingly, this deterioration has occurred while the demand for education and educational attainment have been rising rapidly in the advanced economies.[7] Moreover, educational systems have been utilizing an increasing quantity of teachers. Table 1 demonstrates that the average class size in primary and secondary school has been falling steadily over the same period of time.[8] In other words, the relative wages of schoolteachers in advanced economies have fallen just as dramatically as the demand for schooling has risen, and as the utilization of teachers has become more intense.

This puzzling set of facts raises three important questions. First, what forces can drive

[6]Other researchers who have reported declines in teacher quality include: Weaver (1983), Kershaw and McKean (1962), along with Thorndike and Hagen (1960).

[7]It is interesting and significant to note that relative teacher quality in developing countries exhibits no clear patterns. (Schultz 1987)

[8]Table 1 is found at the end of the paper.

down relative teacher quality in the presence of a rising teacher-student ratio and growing demand for schooling? Second, is this apparent decline empirically robust? Third, does this decline put at risk the future of today's students, or the quality of their schooling? This paper attempts to answer these questions. First, it proposes an explanation for how economic development results in both declining relative wages for schoolteachers and a rising teacher-student ratio. Second, using United States Census data, it examines the change in the relative schooling of teachers, and estimates the change in the relative value of teachers' human capital. The empirical investigation of relative teacher quality helps test the implications of the proposed model. It is of additional interest in its own right, since there has not so far been a systematic economic analysis of changes in teacher quality.[9] Finally, the theoretical and empirical results are used in order to assess the outlook for today's students.

This paper argues that the trends in Figure 1 and Table 1 are caused by skill-biased technical change outside education. The knowledge used by skilled workers outside teaching, such as doctors or engineers, is constantly growing and improving as a result of innovation. This raises the productivity of skilled non-teachers. The productivity of skilled teachers, on the other hand, remains constant, because the general knowledge used by teachers, such as reading or arithmetic, remains largely unchanged.[10] Nonetheless, the price of skill rises, because the demand for skilled workers *outside* teaching rises. This makes skilled teachers more expensive, but no more productive. Since the price of teacher skill rises relative to the price of teacher quantity, schools respond by lowering the skill of teachers and raising the *quantity* of teachers employed. This prediction is consistent with the observed declines in the relative wages of teachers and increases in the teacher-student ratio.

[9] There have, however, been investigations of teachers' relative wages. See, for example, Hanushek and Rivkin (1997). The work presented here will attempt to disentangle changes in relative quality from other changes that affect the relative wage.

[10] A related idea is presented by Baumol (1967), who argues that education is unique in its lack of technical progress.

This theory also has several independent implications which seem consistent with the data. First, the increase in the relative price of skill should raise the overall cost of primary education. Since teaching seems to be skill-intensive,[11] an increase in the relative price of skill raises the cost of the most important educational input. This helps explain the consistent, but puzzling declines in the productivity of the education sector. US educational output, measured by student achievement, has been relatively stagnant, even though real costs per student have nearly doubled over the past 30 years.[12] A second implication is that the skill of college professors should rise relative to that of teachers.[13] Professors should have a different experience than school teachers, because they are likely to benefit from advances in knowledge. The knowledge taught by professors of medicine or engineering, for example, *does* improve and grow with innovation. This prediction is consistent with the evidence, presented in Section 3, that the human capital of professors has risen relative to that of teachers. Finally, the theory predicts substitution away from schools and towards colleges, because innovation makes professors relatively more productive than teachers. That is, the fraction of human capital accumulated in college will increase over time. This result also seems consistent with the data: countries with greater demand for skilled workers also seem to have lower rates of achievement in their primary schools. (Simon and Woo 1995) Put differently, countries which have experienced more skill-biased technical change also invest relatively less in primary school education. This phenomenon would be quite difficult to understand without an increase in the relative productivity of higher education.

[11] Tamura (1999), for example, finds that teacher quality is a more important input into educational production than class size.

[12] See Betts (1996) for the data on student achievement. See Hanushek and Rivkin (1997) for the data on educational costs.

[13] Observe that schoolteachers suffer declining wages relative to occupations which are on average more skilled (college professors) and less skilled (all other workers). Specialization, rather than skill alone, determines marginal productivity growth. This feature distinguishes the theory here from the literature on skill-biased technical change and the rising return to skill. For examples of this literature, see Bartel and Lichtenberg (1987), Katz and Murphy (1992), or Juhn, Murphy, and Pierce (1993).

To test the predicted changes in relative teacher quality, US Census Data are used to estimate the change in the relative quality of schoolteachers and college professors, from the 1900 birth cohort to the 1950 birth cohort. Over this time period, schoolteachers appear to have lost more than four years of schooling relative to the average American worker. They have fared no better relative to skilled workers: among males, the value of college-educated workers' human capital seems to have risen by 15 or 20 percentage points more than the value of teachers' human capital; among females, it may have risen by 25 or 30 percentage points more. We obtain these estimates of the change in relative quality by exploiting some unique features of teachers' age-income profile. The declining relative quality of teachers appears robust to several different methods of estimation, and no evidence seems to support the alternative hypothesis of rising relative quality for schoolteachers. The quality of college professors, however, has not suffered the same fate. The value of male college professors' human capital may have risen by twenty percentage points more than that of male teachers, while the human capital of female college professors may have risen in value by thirty percentage points more. The empirical investigation reveals that these declines have occurred for both male and female teachers, and for teachers in both public and private schools. This helps refute two alternative explanations for declining teacher quality: the expansion of demand for skilled women outside teaching, which would imply falling quality for female teachers, but *not* for male teachers; and the slashing of public budgets, which would imply falling quality for public school teachers, but not private school teachers.

The paper will proceed as follows. Section 2 lays out the model of teacher quantity and quality. It develops a two-sector growth model, with an educational sector and a goods sector. As a result of skill-biased technical change in the goods sector, the relative price of skill rises. This causes the education sector to shift resources away from teacher quality and toward teacher quantity. It also raises the cost of education, because education is skill-intensive, and the price of its more intensive input rises. The model is then extended to include college professors. With this extension, skill-biased technical change in the college education sector is predicted to raise the quality of professors relative to teachers. Technical change lowers the relative wages and relative quality of schoolteachers, both relative to college professors and to other skilled workers. This reduction is partially (but not completely) offset by an increase in the teacher-student ratio. Section 3 then uses US Census data to estimate the change in the relative quality of US schoolteachers. As predicted, schoolteacher quality appears to have declined, relative to both college-educated workers and college professors. In conclusion, section 4 assesses the impact of declining teacher quality on today's students.

2 A Theory of Educational Resources

The knowledge transmitted by schoolteachers changes little over time. However, the specialized fields of knowledge possessed by other skilled workers grow and improve. This is the key idea behind the model presented in this section. For example, in just under 50 years, new discoveries in genetics, ecology, and molecular biology have given new, more useful knowledge to doctors, environmental scientists, and chemists. On the other hand, the reading, writing, and arithmetic taught in primary school have changed little. Therefore, knowledge has become more productive for non-teachers, but no more productive for teachers. This is predicted to have two principal effects. First, it induces substitution away from the human capital, or knowledge, of schoolteachers and towards the human capital of other skilled workers. This lowers the quality of primary school teachers relative to other skilled workers. Second, the demand for skilled workers grows outside teaching. This raises the price of skill for all workers and makes teacher *quantity* relatively cheaper than quality, or skill. As a result, resources flow towards the quantity of teachers, and the teacher-student ratio is predicted to grow.

Throughout this analysis, education is treated as if it were efficiently provided. Of course, there may be both inefficient and efficient forces at work in education. This paper chooses among these alternatives by taking the simplest possible approach. It aims to show how far a standard model of efficiency can go toward explaining the data. As will be shown, it appears that the implications of the efficient model are consistent with many important trends. Based on previous research, it is plausible to assume that efficiency plays at least some role in education production. Since education is often publicly provided, political forces undoubtedly move it away from efficient outcomes. The same may occur as the result of powerful teachers' unions, whose members may not always have an interest in efficiency.[14] On the other hand, however, the pioneering work by Tiebout (1956) argues that competition between local governments favors the efficient provision of public goods such as education.[15] Hoxby (1994b) finds evidence that such competition is empirically significant. Becker (1983) makes a similar argument for efficiency at the level of a legislature, where competition between interest groups, such as parents and taxpayers, should favor the efficient delivery of education. Finally, Hoxby (1994a) finds empirical evidence that competitive pressure from private schools helps promote efficiency in public schools.

[14]For analyses of unionization in education, see Hanushek and Rivkin (1997) or Hoxby (1996). An alternative explanation of inefficiency is given by de Bartolome (1990), who has argued that peer group effects among students create an externality and result in an inefficient allocation of educational resources.

[15]Epple and Zelenitz (1981), however, present an important qualification to Tiebout's work. They argue that since land is immobile, local governments will always be able to extract some rents from their citizens.

2.1 The Allocation of Teachers

For the moment, abstract from the existence of college professors and suppose that all education is provided by teachers. Our hypothetical economy has two sectors, one devoted to goods production, and another devoted to education. Technical change improves the productivity of skilled workers in the goods sector, but not in the education sector. In other words, the goods sector experiences skill-biased technical change, while the education sector experiences no technical change.

Suppose that people in this economy live for two periods, childhood and adulthood, and may choose to be either skilled or unskilled workers. During childhood, a person may choose to attend school and acquire human capital $\bar{H}$, or she may choose to enter the labor force as an unskilled worker. Skilled workers, with human capital $\bar{H}$, are more productive than unskilled workers, but since it is costly to attend school, they are also more expensive. All skilled workers receive the wage w_s, while all unskilled workers receive w_u. Individuals choose the skill level which maximizes their lifetime income. The cost of acquiring skill is assumed to vary across people, who have different abilities. As a result, some people will strictly prefer skilled work, and some will strictly prefer unskilled work.

2.2 Education Production

In order to become a skilled worker, a person must accumulate $\bar{H}$ units of human capital in school. For simplicity, we assume that $\bar{H}$ remains fixed over time. Empirically, this seems a reasonable assumption. From 1960 to 1990, the achievement scores of US high school seniors stayed roughly level. Even though achievement declined during the '60s, a rebound during the '80s helped return it to its 1960 level.[16] To produce human capital, schools employ

[16]The evidence on achievement scores is presented in Bishop (1989). Note that if student achievement actually falls substantially over time, it is possible that the teacher-student ratio will fall along with the

skilled teachers and unskilled teachers. Their output of human capital per student depends on the number of skilled teachers per student, T_s, and the number of unskilled teachers per student, T_u. The output of human capital per student can be written as $E(T_s, T_u)$, where E is increasing and concave in its two inputs.[17] In addition, E is such that skilled teachers are more productive than unskilled teachers, in two senses. First, an additional skilled teacher always produces more than an additional unskilled teacher, so that $E_s > E_u$. Second, a one percent increase in the number of skilled teachers is more productive than a one percent increase in unskilled teachers: $\frac{E_s T_s}{E} > \frac{E_u T_u}{E}$.[18] Tamura (1999) provides some evidence for the latter assumption; he finds that educational output is more elastic to teacher quality than to class size.

Faced with equilibrium wages w_s and w_u, the education sector chooses teaching inputs in order to minimize the cost of producing human capital:

$$c(\bar{H}; w_s, w_u) = \min_{T_s, T_u} w_s T_s + w_u T_u \quad (1)$$

$$s.t.\ \bar{H} = E(T_s, T_u) \quad (2)$$

relative skill of teachers. However, the relative quality of teachers will continue to decline.

[17]There exists much controversy over whether teacher quantity or quality matter at all in educational outcomes. (See, for example, Card and Krueger [1992], Mosteller [1995] and Hanushek [1996] for contrasting views.) However, teaching inputs obviously matter at *some* level: no one could teach a class filled with one thousand 10 year-olds, and no graduate of the sixth grade could teach high school. The dispute in the empirical literature concerns the impact of input variation *within the observed range of input usage*. Therefore, it seems reasonable to assume that these inputs are productive over some, possibly unobserved, range.

[18]In the classical two-sector growth model, if the capital-producing sector is capital-intensive, this results in instability. (Jones 1965, Uzawa 1961) This instability will not pose a problem here, however, because workers are assumed to differ in their ability. This makes it increasingly costly to hire skilled workers, and it means that human capital growth cannot diverge from overall growth.

The first order condition for this problem can be written as:

$$\frac{w_s}{w_u} = \frac{E_s}{E_u} \tag{3}$$

Comparative statics reveals that an increase in $\frac{w_s}{w_u}$ leads to substitution towards unskilled teachers. However, since unskilled teachers are less productive, each skilled teacher must be replaced by more than one unskilled teacher in order to hold output at $\bar{H}$. Therefore, an increase in $\frac{w_s}{w_u}$ lowers T_s, but raises T_u by more. A rise in the relative price of skill will raise the overall teacher-student ratio. Put differently, an increase in the price of skill leads to substitution toward teacher quantity and away from teacher quality. The demand for teachers can then be expressed in terms of the relative price of skill:

$$T_s(\frac{w_s}{w_u}),\ T_s' \ < \ 0 \tag{4}$$

$$T_u(\frac{w_s}{w_u}),\ T_u' \ > \ 0 \tag{5}$$

We can make three important predictions from this cost-minimization analysis. As stated above, the overall teacher-student ratio, $T_s + T_u$, must rise with the price of skill; since a price increase will lower the number of skilled teachers hired, the education system must compensate by hiring more teachers overall. Second, the average skill of teachers, $\frac{T_s \bar{H}}{T_s + T_u}$, will fall when skill becomes more expensive: T_s falls with the price of skill, while $T_s + T_u$ rises. Third, since education is skill-intensive, a relative increase in the price of skill will make education more costly to produce. Specifically, if w_s rises by $y\%$ and w_u falls by $x \leq y$ percent, $c(\bar{H}; w_s, w_u)$ will rise. This result depends only on the skill-intensity assumption that $\frac{E_s T_s}{E} > \frac{E_u T_u}{E}$. To see this, observe that Shephard's lemma and the first-order conditions for cost-minimization allow us to write:

$$\frac{\frac{\partial c}{\partial w_s}\frac{w_s}{c}}{\frac{\partial c}{\partial w_u}\frac{w_u}{c}} = \frac{T_s w_s}{T_u w_u} = \frac{\frac{E_s}{E}T_s}{\frac{E_u}{E}T_u}.$$

Since $\frac{E_s T_s}{E} > \frac{E_u T_u}{E}$, it follows that $\frac{\partial c}{\partial w_s}\frac{w_s}{c} > \frac{\partial c}{\partial w_u}\frac{w_u}{c}$, or that costs are more elastic to increases in w_s than to increases in w_u. In other words, the cost function will rise overall if w_s rises by a greater percentage than w_u falls.

2.3 Goods Production

The goods sector hires skilled and unskilled workers, N_s and N_u, respectively. Just like the education sector, it faces the wages w_s and w_u; however, in addition, it is affected by the level of technology, q. Growth in technology is presumed to raise the productivity of skilled workers in this sector, and to expand the set of production possibilities. This assumption seems consistent with micro-level evidence. Bartel and Lichtenberg (1987) find that, in manufacturing industries, skilled workers have a comparative advantage in implementing new technologies. Innovation should thus raise the comparative advantage of skill.

The goods sector has access to a constant returns production technology of the form $F(N_s, N_u; q)$, where $\frac{F_s}{F_u}$ rises in q, and $F_q > 0$. If it maximizes its profits, this sector solves the problem,

$$\max_{N_s, N_u} F(N_s, N_u; q) - w_s N_s - w_u N_u$$

with the first order conditions,

$$w_s = F_s \qquad (6)$$

$$w_u = F_u \qquad (7)$$

Combining these conditions identifies the input ratio as a function of technology and relative prices:

$$\frac{w_s}{w_u} = \frac{F_s}{F_u} \tag{8}$$

Equation 8 implies that the relative demand for skilled workers falls with the price of skill, but rises with technical change.[19]

Since the scale of the goods sector is uncertain, it is not possible to identify separate demand functions for both N_s and N_u. However, the supply of skilled goods workers N_s can help identify the equilibrium demand for unskilled goods workers, N_u. To derive the supply function, suppose that agents consume only when they are adults, and that there exists a perfect storage technology. Every agent chooses the occupation which maximizes her undiscounted lifetime earnings, and the marginal agent has the same lifetime earnings in skilled and unskilled work.[20] An unskilled worker has lifetime earnings totaling $2w_u$. The lifetime earnings of a skilled worker depend on her underlying ability. Suppose ability is indexed over $[0, 1]$, where the individual $i = 0$ is the most able member of her generation, and $i = 1$ is the least able. The time cost of schooling goes down with ability. Specifically, if individual i chooses to become skilled, she must spend $1 - \rho(i)$ of her adulthood on her schooling, where ρ is some decreasing function of i.[21] Therefore, an individual who chooses to become skilled has the lifetime earnings $w_s\rho(i) - c(\bar{H}; w_s, w_u)$, where she has to pay back the cost of her own schooling.[22] For the marginal skilled worker i, $w_s\rho(i) - c(\bar{H}; w_s, w_u) = 2w_u$.

[19]These results follow, because $\frac{F_s}{F_u}$ increases in q but decreases in $\frac{N_s}{N_u}$.

[20]In this steady-state analysis, individuals are assumed to have perfect foresight about future demand conditions. Zarkin (1985) considers the decision to become a teacher in the context of uncertainty, where people have rational expectations about future demand conditions.

[21]Note that the agent must spend her own time on school during her adulthood, without the help of any teachers. This assumption is made for tractability.

[22]One can think of a "pay-as-you-go" system in which adults pay back the costs of their own childhood schooling. Since this is a steady-state equilibrium, the educational system will always be solvent, in that revenues will always be exactly equal to costs.

The marginal skilled worker will be $i = S$, where S is the total number of skilled workers. In a steady-state, the current number of skilled workers S will be equal to the number of students λ. Moreover, the total number of skilled workers can be written as $S = N_s + T_s\lambda$, the number of skilled goods workers plus the number of skilled teachers. Since $S = \lambda$, it follows that $S = \lambda = \frac{N_s}{1-T_s}$. The marginal individual will be $i = \frac{N_s}{1-T_s}$, and the steady-state indifference condition can be written as:[23]

$$w_s\rho(\frac{N_s}{1-T_s}) - c(\bar{H}; w_s, w_u) = 2w_u \tag{9}$$

Dividing by w_s transforms equation 9 into:

$$\rho(\frac{N_s}{1-T_s}) = \frac{c(\bar{H}; w_s, w_u)}{w_s} + 2\frac{w_u}{w_s} \tag{10}$$

Equation 10 implies, not surprisingly, that an increase in the relative price of skilled labor $(\frac{w_s}{w_u})$ will raise the supply of skilled workers, $\frac{N_s}{1-T_s}$, which is independent of technology.[24] Now recall that the demand for skilled teachers T_s falls in $\frac{w_s}{w_u}$, and is independent of technology. Since $\frac{N_s}{1-T_s}$ rises in $\frac{w_s}{w_u}$, the equilibrium supply of N_s must rise in $\frac{w_s}{w_u}$, but must be independent of technology.

It is now possible to derive the equilibrium demand for N_u as a function of $\frac{w_s}{w_u}$ and q. Equation 8 implies that the relative demand for skilled goods workers $(\frac{N_s}{N_u})$ falls in the relative

[23]If we denote by x_t the quantity of x at time t, the off steady-state condition has the more general form:

$$w_{st}\rho(N_{st} + T_{st}) - c(\bar{H}; w_{s,t-1}, w_{u,t-1}) = w_{u,t-1} + w_{ut}$$

[24]To see this, observe that all cost functions are increasing and homogeneous of degree one in input prices. Therefore, holding $\bar{H}$ constant, $\frac{c(\bar{H};w_s,w_u)}{w_s}$ is simply a decreasing function of $\frac{w_s}{w_u}$. Since c is increasing, concave, and homogeneous of degree one in wages, it can be written as $c(\bar{H}; w_s, w_u) = w_s\gamma(\bar{H}; \frac{w_u}{w_s})$, where γ is a concave, increasing function of $\frac{w_u}{w_s}$.

price of skill ($\frac{w_s}{w_u}$) and rises with technology. The supply of skilled goods workers rises in $\frac{w_s}{w_u}$, but is independent of q. Therefore, the demand for unskilled goods workers (N_u) must be rising in the relative price of skill $\frac{w_s}{w_u}$, and falling in technology q. This gives us a useful way to write N_s and N_u in terms of prices and technology:

$$N_s(\frac{w_s}{w_u}), \quad N_s' > 0 \tag{11}$$

$$N_u(\frac{w_s}{w_u}, q), \quad \frac{\partial N_u}{\partial w} > 0, \quad \frac{\partial N_u}{\partial q} < 0 \tag{12}$$

2.4 A Steady-State Equilibrium

So far, we have identified demand functions for T_s, T_u, and N_u, along with a supply function for N_s. Every input has been expressed in terms of the relative price and technology. We can now use the market-clearing condition for labor to characterize the steady-state equilibrium.

Recall that the total number of skilled workers in the economy is $\frac{N_s}{1-T_s}$, while the total number of unskilled workers is $T_u + N_u$. The total number of workers available, on the other hand, is equal to the number of adults plus the number of working children, which is $1 - \lambda = 1 - \frac{N_s}{1-T_s}$. This implies the labor market-clearing condition,

$$(N_u + T_u) + \frac{N_s}{1 - T_s} = 1 + (1 - \frac{N_s}{1 - T_s}),$$

which simplifies to

$$(N_u + T_u) + 2\frac{N_s}{1 - T_s} = 2 \tag{13}$$

Now suppose that q increases. Holding the relative price of skill constant, the demand for unskilled goods workers N_u falls; however, the demand for teachers and the supply of N_s do not change. To clear the labor market, therefore, the relative price of skill must rise. This price increase clears the labor market by raising the demand for unskilled workers, $N_u + T_u$, and raising the supply of skilled workers $\frac{N_s}{1-T_s}$. Therefore, technical change will continue to raise the relative price of skill. This prediction is consistent with the findings of Juhn, Murphy, and Pierce (1993), who argue that the price of skill has risen consistently in the US, from around 1960 onwards.[25]

This leads to several important predicted relationships between technical change and the education sector. First, by raising the relative price of skill, technical change encourages substitution towards unskilled teachers and raises the teacher-student ratio. Second, it lowers the average skill of teachers, but raises the average skill of production workers, whose skill becomes more highly prized.[26] This implies that the relative skill of teachers compared to other workers will fall. Moreover, the average skill of teachers will also fall relative to other *skilled* workers. That is, even though teachers continue to produce skilled workers of a fixed skill level $\bar{H}$, their own average skill declines over time. Finally, the model predicts that technical change should raise the cost of education. Specifically, technical change, by raising the demand for skilled workers, raises the absolute and relative price of skill.[27] Since

[25]It is interesting to note that Juhn, Murphy, and Pierce find significant increases in the returns to *unobserved* skill, which we do not model explicitly here.

[26]The relative skill of goods workers will rise if $\frac{N_s}{N_u}$ rises. $\frac{N_s}{N_u}$ will rise with technical change, because technical change expands the set of production possibilities; in other words, $F_q > 0$. Since $F_q > 0$, technical change must increase the output of goods, or the outcome cannot be Pareto efficient. Now suppose that $\frac{N_s}{N_u}$ actually falls. If the proportion of skilled workers falls, but output rises, the total quantity of workers must rise, because each skilled worker must be replaced by more than one unskilled worker. In other words, $N_s + N_u$ rises. In order for the labor market to clear, therefore, the total number of teachers must fall. However, we know that the teacher-student ratio rises. This implies that the number of students, $\frac{N_s}{1-T_s}$ must fall. However, according to equation 10, this quantity falls only if $\frac{w_s}{w_u}$ falls. This contradicts the fact that $\frac{w_s}{w_u}$ rises in equilibrium.

[27]Rewrite $F(N_s, N_u; q) = N_s f(\frac{N_u}{N_s}; q)$; f must be concave, while $f_q > 0$ and $f_q' < 0$. The first order conditions in equations 6 and 7 can then be rewritten as:

$$w_s = f - \frac{N_u}{N_s} f'; \quad w_u = f'$$

Each equation implicitly defines $\frac{N_u}{N_s}$ in terms of q, given a constant price. Therefore, we can differentiate the first equation with respect to q, while holding w_s constant, to obtain $\frac{\partial \frac{N_u}{N_s}}{\partial q}|_{w_s} = \frac{f_q}{f''}\frac{N_s}{N_u} - \frac{f_q'}{f''}$. This represents education is skill-intensive, these absolute and relative price increases will raise the cost of education, $c(\bar{H}; w_s, w_u)$, as was shown earlier.

These implications are consistent with the declining relative wages of teachers in developed countries, depicted in Figure 1, and with the rising teacher-student ratios depicted in Table 1. They are also consistent with the estimates of section 3, which imply that the quality of US teachers has declined relative to other skilled workers. The final prediction, of rising educational costs, also appears consistent with the facts. In the US, real per student expenditures have risen consistently,[28] while scores on standardized achievement tests have either remained constant or fallen slightly over the past thirty years.[29] It has apparently become more costly to achieve the same level of educational output. Moreover, these trends seem to have more to do with formal schooling rather than with parental inputs which precede the start of schooling. Bishop (1989) reports that IQ scores for young children entering school have remained level or risen slightly, in spite of test score declines at later ages. Therefore, it seems that parental inputs into early childhood education, at the very least, have not declined significantly. As predicted, the *formal* schooling of children must have grown more costly over time.

the amount that $\frac{N_u}{N_s}$ would have to decrease in order to offset exactly a technology-driven increase in the price of skill. We can repeat this exercise on the second first order condition to obtain $\frac{\partial \frac{N_u}{N_s}}{\partial q}|_{w_u} = -\frac{f'_q}{f''}$. Now suppose that technical change causes $\frac{N_u}{N_s}$ to decline so much that w_s fails to rise. In this case, $\frac{N_u}{N_s}$ must have declined by at least $-\frac{\partial \frac{N_u}{N_s}}{\partial q}|_{w_s}$, which represents the decline necessary to keep w_s constant. However, $-\frac{\partial \frac{N_u}{N_s}}{\partial q}|_{w_s} > -\frac{\partial \frac{N_u}{N_s}}{\partial q}|_{w_u}$. Therefore, $\frac{N_u}{N_s}$ has declined by more than enough to keep w_u constant. As a result, w_u will have risen overall, while w_s will not have. This contradicts the fact that $\frac{w_s}{w_u}$ rises in equilibrium.

[28] Hanushek and Rivkin (1997) report that real spending per student has risen nearly tenfold from 1940 to 1990.

[29] See, for example, Betts (1996), who argues that Scholastic Aptitude Test (SAT) scores among college-bound 18 year-olds have fallen, even during periods in which the proportion of 18 year-olds taking the test has fallen. This suggests that selection bias is not to blame.

2.5 The Allocation of Professors

Not all teachers teach general knowledge. College professors, for example, teach specialized knowledge which does benefit from innovation. Since the knowledge of professors benefits from and improves with technical progress, the skill of professors should rise more rapidly than the skill of teachers. Furthermore, there should be substitution away from primary education and towards college, where specialized knowledge is taught.

2.5.1 A Model of Higher Education

Once again, consider a model with an education sector and a production goods sector, but suppose that education takes place in two stages: primary school and college. Anyone wishing to become a skilled worker must go through both stages of education. In primary school,[30] teachers provide students with general human capital G, which consists of general skills such as reading, writing, and arithmetic. After completing primary school, students go on to college, where they use their general skills to accumulate specialized knowledge and become skilled workers with human capital $\bar{H}$.[31] The more general human capital G a student acquires, the more productive she will be in college. The output of college thus depends on teaching inputs and the general human capital of students.[32]

[30] Throughout this theoretical section, "primary schooling" will be synonymous with "pre-college schooling."

[31] Once again, we assume that $\bar{H}$ remains fixed. The results of this section, however, are affected only if $\bar{H}$ falls over time. Therefore, the results are valid so long as college graduates are not becoming less skilled over time. This seems a reasonable assumption, for two reasons. First, as is argued in Section 2.5.3, students are accumulating an increasing proportion of their human capital in college. Second, as argued in Section 2.4, the achievement of high school graduates is roughly constant. Therefore, the quality of college graduates cannot be falling.

[32] To be sure, we are overlooking some differences in the structure of education which appear across even a set of developed countries. In the US, for example, admission to college is much more lenient, and high school grades are less significant. (Bishop 1990) This induces American high school students to spend less time on their studies. (Simon and Woo 1995) These kinds of differences are ignored, largely because they do not appear to be driving the changes in teacher quality, which seem to be the same across developed economies.

In primary school, skilled and unskilled teachers produce general human capital. To simplify this two-stage problem, consider the case of Cobb-Douglas production, where $G = T_s^{\alpha} T_u^{1-\alpha}$, and $\alpha > \frac{1}{2}$, so that skilled teachers are more productive than unskilled teachers. Primary schools solve the cost-minimization problem:

$$\begin{aligned} c(G; w_s, w_u) &= \min_{T_s, T_u} w_s T_s + w_u T_u \\ s.t.\ G &= T_s^{\alpha} T_u^{1-\alpha} \end{aligned}$$

This problem has the first order condition,

$$\frac{w_s}{w_u} = \frac{\alpha}{1-\alpha} \frac{T_u}{T_s}$$

and the optimal input demands,

$$T_s = G \left(\frac{w_u}{w_s} \frac{\alpha}{1-\alpha} \right)^{1-\alpha} \tag{14}$$

$$T_u = G \left(\frac{w_s}{w_u} \frac{1-\alpha}{\alpha} \right)^{\alpha} \tag{15}$$

As before, the demand for skilled teachers falls with the relative price of skill, while the demand for unskilled teachers rises with the relative price of skill. In addition, note that teaching inputs are proportional to the level of general human capital produced; this results from the constant returns to scale specification. These input demand functions imply the equilibrium cost function:

$$c(G; w_s, w_u) = G \left(\frac{w_s}{\alpha} \right)^{\alpha} \left(\frac{w_u}{1-\alpha} \right)^{1-\alpha}$$

Since skilled teachers are more productive ($\alpha > \frac{1}{2}$), a relative increase in the price of skill will raise the cost of producing general human capital. Specifically, if w_u falls by $x\%$ and w_s rises by $y > x\%$, the cost of primary schooling will rise. This is the same implication as before.

Given the cost of primary schooling, there is an optimal value for G and a quantity of professors to minimize the cost of producing $\bar{H}$. For simplicity, suppose there are skilled and unskilled professors, D_s and D_u. Unskilled professors are much less productive than skilled professors. In addition, technical change is assumed to improve the quality of the specialized knowledge held by professors. As a result, increases in q raise the comparative advantage of skilled professors relative both to general knowledge inputs, and to unskilled professors. Therefore, suppose that human capital output in college satisfies $\bar{H} = D_s^{\beta_1 q} D_u^{\beta_2} G^{1-\beta_1 q-\beta_2}$. Colleges solve the cost-minimization problem:

$$\begin{aligned} c(\bar{H}; w_s, w_u) &= \min_{G,D_s,D_u} c(G; w_s, w_u) + w_s D_s + w_u D_u \\ s.t.\ \bar{H} &= D_s^{\beta_1 q} D_u^{\beta_2} G^{1-\beta_1 q-\beta_2} \end{aligned}$$

Using the equilibrium cost function for G results in the first order conditions,

$$\begin{aligned} \frac{\left(\frac{w_u}{w_s}\right)^{1-\alpha}}{(\alpha)^{\alpha}(1-\alpha)^{1-\alpha}} &= \frac{1-\beta_1 q}{\beta_1 q}\frac{D_s}{G} \\ \frac{w_s}{w_u} &= \frac{\beta_1 q}{\beta_2}\frac{D_u}{D_s} \end{aligned}$$

and the optimal input demands, (for compactness of notation, $\psi \equiv \beta_1 q + \beta_2$; the share of human capital in higher education)

$$D_s = \bar{H}\left(\frac{\beta_1 q}{1-\psi}\frac{1}{(\alpha)^\alpha(1-\alpha)^{1-\alpha}}\right)^{1-\psi}(\frac{\beta_1 q}{\beta_2})^{\beta_2}\left(\frac{w_u}{w_s}\right)^{(1-\alpha)(1-\psi)+\beta_2} \quad (16)$$

$$D_u = \bar{H}\left(\frac{\beta_1 q}{1-\psi}\frac{1}{(\alpha)^\alpha(1-\alpha)^{1-\alpha}}\right)^{1-\psi}(\frac{\beta_2}{\beta_1 q})^{1-\beta_2}\left(\frac{w_s}{w_u}\right)^{\beta_1 q+\alpha(1-\psi)} \quad (17)$$

$$G = \bar{H}\left(\frac{1-\psi}{\beta_1 q}(\alpha)^\alpha(1-\alpha)^{1-\alpha}\right)^{\psi}(\frac{\beta_1 q}{\beta_2})^{\beta_2}\left(\frac{w_s}{w_u}\right)^{(1-\alpha)\psi-\beta_2} \quad (18)$$

The optimal input demand equations have two useful implications. First, when skilled workers become more expensive, it is cheaper to substitute away from skilled professors, and toward unskilled professors or primary education.[33] An increase in the relative price of skill, $\frac{w_s}{w_u}$, raises the quantities of G and D_u, but lowers the quantity of D_s. Second, innovation makes general knowledge account for a smaller proportion of human capital.[34] Technical change makes the specialized knowledge of skilled professors relatively more productive than general knowledge. Therefore, it induces substitution away from general human capital and towards the human capital of professors. Technical change thus lowers the proportion of human capital acquired in primary school, $\frac{G}{H}$, and raises the proportion acquired in college. This prediction is consistent with relative declines in the output of primary schools, as discussed later.

Technology has different effects on the demand for skill at different levels of education. It raises the demand for skilled professors, but lowers the demand for skilled teachers. Overall, one can show that the demand for skilled educators, $T_s + D_s$, falls in the relative price of skill ($\frac{w_s}{w_u}$), but rises with technology, q. The first relationship is standard: an increase in

[33]Since primary education employs a mix of skilled workers and unskilled workers, relative increases in the price of skill make skilled professors relatively more costly than primary education.

[34]This will be true, so long as unskilled professors are sufficiently unproductive, or β_2 is sufficiently small. If β_2 is sufficiently small, the problem behaves like a two-input problem, with skilled professors and general human capital. In this case, increases in q raise D_s and lower G. If β_2 is quite large, complementarity between G and D_u could reverse these results.

the relative price of skill naturally reduces the demand for skilled educators. Skill-biased technical change, on the other hand, will end up raising the overall demand for skilled workers, as long as skilled professors are sufficiently "important," in the sense that β_2 is sufficiently close to zero. In other words, if higher education is sufficiently skill-intensive, technology will raise demand for skilled professors more than it lowers demand for skilled teachers. To understand this more formally, observe that,

$$\begin{aligned} T_s + D_s &= \bar{H}\frac{(\frac{w_u}{w_s})^{(1-\alpha)(1-\beta_1 q)+\alpha\beta_2}}{(1-\alpha)^{1-\alpha}(\alpha)^{\alpha}}\left(\alpha^{\alpha}(1-\alpha)^{1-\alpha}\frac{1-\beta_1 q-\beta_2}{\beta_1 q}\right)^{\beta_1 q+\beta_2} * \\ &\left(\frac{\beta_1 q}{\beta_2}\right)^{\beta_2}\left(\alpha+\frac{\beta_1 q}{1-\beta_1 q-\beta_2}\right) \end{aligned}$$

By inspection, it is clear that this quantity falls in $\frac{w_s}{w_u}$, because $(1-\alpha)(1-\beta_1 q)+\alpha\beta_2 > 0$. The effect of technology, however, is ambiguous in the most general case: technology raises the demand for skilled professors, but it lowers the demand for general human capital and skilled teachers. However, this equation implies that $T_s + D_s$ rises with technology if β_2 is close enough to zero.[35] The more important are skilled professors, the more important is the increased demand for skilled professors caused by technical change.

The overall demand for unskilled educators, $T_u + D_u$, rises with the relative price of skill and falls with technical change. The price relationship is straightforward: increases in the relative price of skill raise the demand for unskilled workers. An inspection of the demand functions for T_u and D_u, in equations 15 and 17, reveals this to be the case. Moreover, if

[35] One can compute the following derivative:

$$\begin{aligned} \frac{\partial \ln(T_s+D_s)}{\partial q} &= \beta_1 \ln\left((\frac{w_s}{w_u}(1-\alpha))^{1-\alpha}\alpha^{\alpha}\frac{1-\beta_1 q-\beta_2}{\beta_1 q}\right) + \\ &\frac{\beta_1(1-\beta_2)}{1-\beta_1 q-\beta_2}\left(\frac{1}{\alpha(1-\beta_1 q-\beta_2)+\beta_1 q} - \frac{\beta_1 q+\beta_2}{\beta_1 q}\right) \end{aligned}$$

The first of the two terms is positive if $\frac{w_s}{w_u}$ is sufficiently high (which occurs if $\bar{H}$ is sufficiently high), while the second is positive if β_2 is sufficiently close to zero.

β_2 is sufficiently close to zero, the number of unskilled professors D_u will be negligible. In this case, technical change will lower $T_u + D_u$ by lowering the number of unskilled teachers. Specifically, one can see in equation 18 that if β_2 is small, G falls with technical progress. Since T_u is proportional to G, it must also fall with technical progress. In sum, the relative demand for skilled educators falls in the relative price of skill, but rises with technical change:

$$\begin{aligned}\frac{\partial}{\partial \frac{w_s}{w_u}}(T_s + D_s) &< 0; \ \frac{\partial}{\partial \frac{w_s}{w_u}}(T_u + D_u) > 0 \\ \frac{\partial}{\partial q}(T_s + D_s) &> 0; \ \frac{\partial}{\partial q}(T_u + D_u) < 0\end{aligned}$$

2.5.2 The Goods Sector

The behavior of the goods sector is quite similar to its behavior in the earlier model. In a steady-state, the number of students (λ) is equal to the total number of skilled workers, $N_s + (T_s + D_s)\lambda$. Therefore, $\lambda = \frac{N_s}{1-T_s-D_s}$ represents the number of students and the number of skilled workers. The labor market arbitrage condition in equation 10 can thus be extended as:

$$\rho(\frac{N_s}{1 - T_s - D_s}) = \frac{c(\bar{H}; w_s, w_u)}{w_s} + 2\frac{w_u}{w_s}$$

As before, the right-hand side of this equation falls in $\frac{w_s}{w_u}$. The effect of technical change, however, is complicated by an additional feature. Technical change now also expands the set of production possibilities in education and thus lowers the cost of education, $c(\bar{H}; w_s, w_u)$. Potentially, this could offset the increased demand for skilled workers and drive down the price of skill in equilibrium. This supply effect, however, becomes increasingly less significant as the level of skill $\bar{H}$ rises. To see this, observe that unskilled teachers are relatively inexpensive at high levels of $\bar{H}$. Moreover, technology lowers costs by reducing the use of unskilled teachers. Therefore, technology will reduce educational costs by less when $\bar{H}$ is higher.[36] We will proceed under this assumption, that the reduction in educational costs is sufficiently small, and the supply of skilled workers, $\frac{N_s}{1-T_s-D_s}$, is thus not much affected by technology. Empirically, it seems quite plausible to assume that this supply effect has not been consistently large.[37]

The preceding analysis demonstrates that the supply of skilled workers, $\frac{N_s}{1-T_s-D_s}$, rises in the relative price of skill, and does not respond much to technology. It can now be shown that the equilibrium supply of skilled goods workers N_s must rise in the relative price of skill, but fall in technology. Provided that $\frac{N_s}{1-T_s-D_s}$ is not much affected by a rise in q, N_s must fall in q, because the demand for skilled educators $(T_s + D_s)$ rises with q. Since the supply of N_s rises in $\frac{w_s}{w_u}$ and falls in q, the same must be true of the *demand* for N_u: this follows from the relative demand for factors, by which $\frac{N_s}{N_u}$ falls in $\frac{w_s}{w_u}$ and rises in q. Therefore, an increase in the price of skill will raise the demand for unskilled workers, while technical change will once again *reduce* the demand for unskilled workers, who are made less productive by innovation.[38] To summarize, labor inputs into the goods sector satisfy:

$$\begin{aligned} N_s(\frac{w_s}{w_u}, q), \ \frac{\partial N_s}{\partial w} &> 0, \ \frac{\partial N_s}{\partial q} < 0 \\ N_u(\frac{w_s}{w_u}, q), \ \frac{\partial N_u}{\partial w} &> 0, \ \frac{\partial N_u}{\partial q} < 0 \end{aligned}$$

[36]Observe that $\frac{c(\bar{H};w_s,w_u)}{w_s} = T_s + D_s + \frac{w_u}{w_s}T_u$. If $\frac{w_u}{w_s}$ is sufficiently low, the third term becomes negligible. Therefore, since $T_s + D_s$ rises in q, so must $\frac{c(\bar{H};w_s,w_u)}{w_s}$.

[37]Murphy and Welch (1989), suggest that the demand for skill in the US has risen quite consistently since 1960, but that the supply of skill managed to keep pace only during the '70s, which witnessed the labor force entrance of college-educated baby boomers. Murphy and Welch (1993a) argue that consistent growth in the skill premium seems to have been the result.

[38]The relative demand for $\frac{N_s}{N_u}$ falls in $\frac{w_s}{w_u}$ and rises in q. Therefore, since N_s rises in $\frac{w_s}{w_u}$ and falls in q, the same must be true of N_u.

2.5.3 A Steady-State Equilibrium

Since the steady-state student population can be written as $\lambda = \frac{N_s}{1-T_s-D_s}$, the market-clearing condition in equation 13 can be generalized to:

$$2\frac{N_s}{1 - T_s - D_s} + (N_u + T_u) = 2$$

When q rises, the demand for unskilled workers $N_u + T_u$ falls. As long as the supply of skilled workers does not rise enough to offset this effect, the relative price of skill $\frac{w_s}{w_u}$ must rise in response. This increase in $\frac{w_s}{w_u}$ induces more workers to invest in skill, and thus clears the labor market. This implies that, once again, technical change raises the price of skill, because it raises the demand for skilled educators and skilled goods workers.

To sort out all the implications of technical change, it is important to distinguish between technical change in higher education and technical change in the goods sector. Both raise the relative price of skill, but they may differ in their effects on educational inputs. Consider first the three effects of technical change in higher education. First, by raising the price of skill, it lowers the average skill of teachers, and raises the teacher-student ratio. Second, by making skilled professors more productive, technical change in higher education encourages substitution toward skilled professors and away from unskilled professors; logically, the increase in the price of skill can only partially offset this, because it is itself driven by the rising productivity of skilled professors. As a result, average professor quality rises,[39] and the quality of professors rises relative to teachers. Finally, technical change in higher edu-

[39]The effect on the professor-student ratio is theoretically ambiguous. The substitution towards skill lowers it, but the substitution away from primary education and towards college will tend to raise it. Empirically, the US professor-student ratio has not changed much since 1960. This is evident in Table 2, which may be found at the end of this paper, and is based on data given in Andersen (1998) and Andersen et al (1989).

cation lowers the relative demand for general human capital.[40] At a constant level of total human capital, $\bar{H}$, technical change lowers the use of general human capital G, because the comparative advantage of G falls with respect to skilled professors. As before, the increased price of skill will only partially offset this substitution away from primary education. As a result, $\frac{G}{H}$ falls, so that students accumulate a larger proportion of their human capital in college, rather than primary school.[41]

Now consider technical change in the goods sector. By raising the price of skill, it also lowers the quality of teachers and raises the teacher-student ratio, but it may have offsetting effects on other educational inputs. If technical change in the goods sector bids up the price of skill sufficiently, it could encourage substitution away from skilled professors and towards primary education. However, as long as technical change in higher education is large enough relative to technical change in the goods sector, this will not occur. In this case, we would continue to predict growth in the quality of professors and declines in $\frac{G}{H}$, the proportion of human capital accumulated in primary school.

As discussed earlier, the substitution away from schoolteacher quality and towards quantity is consistent with the empirical evidence. Moreover, the predicted rise in the quality of professors, relative to teachers, is consistent with the estimates presented in Section 3. There, we find that the value of professors' human capital has risen by about twenty percentage points more than the value of teachers' human capital. Finally, the predicted decline in $\frac{G}{H}$ seems consistent with relative declines in the primary education output of advanced countries. Across countries, increases in the rate of college enrollment appear to be negatively correlated with primary school achievement. (Simon and Woo 1995) If college enrollment

[40] This could offset the growth in the teacher-student ratio, if the decline in primary education output is sufficiently large.

[41] Analytically, it is possible that this could push down the teacher-student ratio back below its initial level.

rates are correlated with the relative demand for skilled labor, this suggests that skill-biased technical change is correlated empirically with lower primary education output. This is consistent with the model, because technical change encourages college enrollment, but has two negative effects on primary school output. First, it bids up the relative price of skill, which makes primary education more costly. Second, it lowers the relative productivity of primary education, relative to college education. Therefore, primary school output is predicted to decline as a result of a price effect and a technology effect.

3 An Empirical Analysis of Teacher Quality

So far, this paper has offered several key predictions about the market for teachers. First, it has predicted that the teacher-student ratio should rise for pre-college education. This prediction is consistent with the observations reported in Table 1. It has also predicted that, across successive educational cohorts of workers, the human capital and wages of schoolteachers will decline relative to the average worker, the average skilled worker, and the average college professor. The empirical analysis offered in this section aims to test these predictions for the human capital of teachers. Since there is no definitive way to measure human capital, several approaches are taken; all reveal declining relative quality for teachers. We will show that the schooling of teachers has declined relative to the schooling of other workers, and other skilled workers. Later, a regression framework is used to measure the value of the relative human capital decline for teachers, compared to skilled workers and to college professors. The results appear quite consistent with the theory presented here, and do not support alternative explanations of declining relative quality for teachers.

3.1 The Relative Schooling of Teachers

The central finding of this section is that the schooling of US teachers has been declining relative to other groups of workers. Consider Figure 2, which illustrates this point most simply. The figure depicts, for different birth cohorts of US teachers, the additional years of schooling possessed by a male or female schoolteacher, compared to the average male or female worker.[42] Over the twentieth-century, there has been a steady and fairly rapid decline in the additional schooling possessed by schoolteachers. Teachers born at the beginning of the century received roughly six or seven more years of schooling than their non-teaching counterparts, but those born in the middle of the century received only two or three more. Significantly, this downward trend has been quite similar for male and female teachers. This suggests that the demand for skill outside teaching has been growing for *both* males and females. In other words, the expansion in demand for skilled women outside teaching is not in itself enough to explain the observed declines in quality. There appears to have been an overall increase in the demand for skilled workers of any gender, as hypothesized in this paper.[43] In addition, this trend in relative schooling is similar for public and private schoolteachers. Figure 3 demonstrates that, from the 1900 to 1950 birth cohorts, female private schoolteachers lost about 3 years of relative schooling, which is exactly the amount of schooling lost by female teachers as a whole.[44] This supports the claim that the decline in quality stems from technological forces which affect the entire education sector. If these

[42]Data are from the US Census. (Ruggles and Sobek 1997) Five-year birth cohorts are defined, and cohort-specific educational averages are computed for schoolteachers, and for all workers in the labor force. A cohort's average schooling is constructed by taking the yearly educational averages for the years in which all members of the cohort are between the ages of 30 and 60, and then computing the unconditional average over these years.

[43]Later, however, we will find evidence that the demand for skill outside teaching has grown more for women than for men. Nonetheless, this force alone cannot explain the declining relative quality for both male and female teachers.

[44]The figure for male teachers, available from the author, shows a qualitatively similar pattern

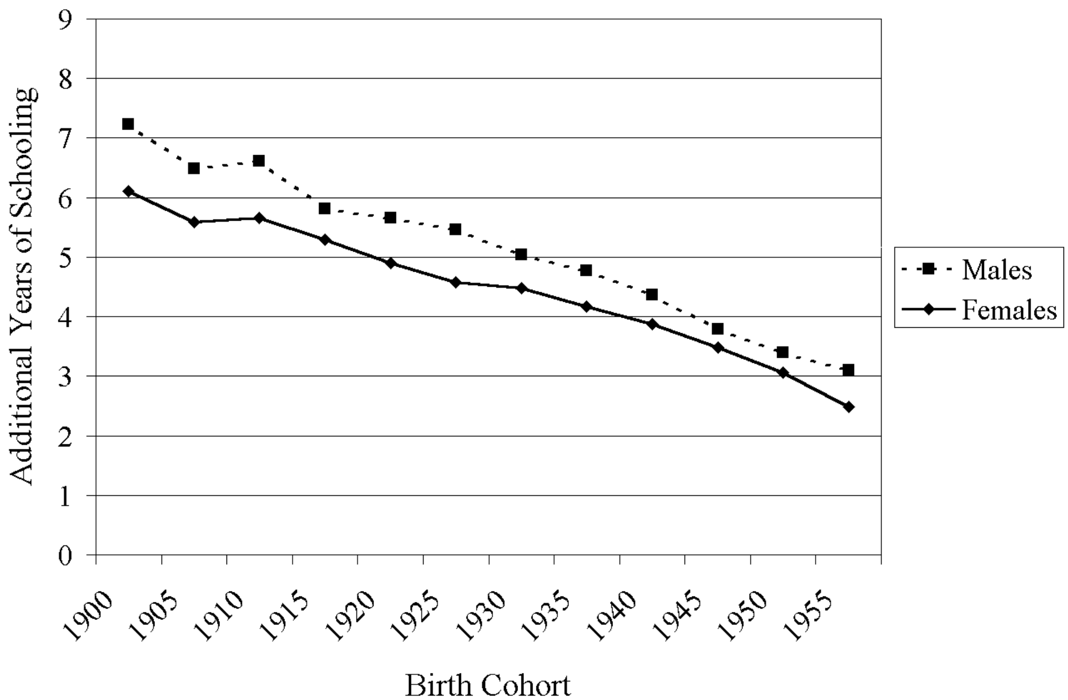

Figure 2: Schooling premium of US school teachers, compared to the average worker, by birth cohort and sex.

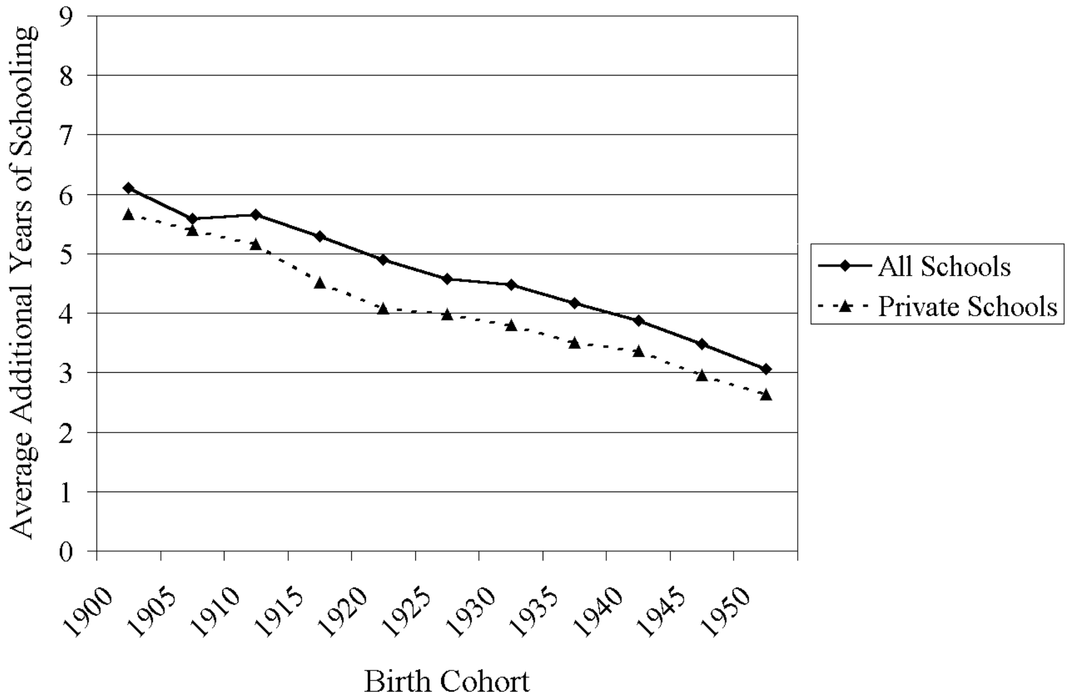

Figure 3: Schooling premium of US female teachers, compared to the average female worker, in all schools and in private schools.

declines are not confined to public education, they would not seem to result simply from idiosyncratic public policy decisions. It is also relevant to note here that teachers have lost considerable ground to other public employees. Male teachers, for example, have lost approximately four years of schooling to other male public employees.[45]

The similarity of public and private school teachers is also quite consistent with similarities between public and private school outcomes. For most American students, private Catholic schools do not seem to improve educational achievement.[46] (Noell 1982) Indeed, only urban minority students seem to benefit significantly from a private Catholic school education.[47] (Neal 1997) Presumably, if the vast majority of public schools were hiring teachers of sub-optimal quality, and producing a sub-optimal level of educational output, private schools could attract students by producing higher quality education. If this were the case, private school education would benefit a wide cross-section of students, not just urban minorities. It is also significant to note that, while the share of black and Hispanic students enrolled in private schools has risen, the overall share of students enrolled in private schools has remained fairly stable, at around 11%, from 1970 to 1996.[48] The stable enrollment share is consistent with the claim that the quality of public schools has not declined substantially relative to the quality of private schools.

While Figures 2 and 3 usefully characterize the major trends in teacher schooling, they raise a few specific questions which must be investigated. First, over the last century, there

[45]This figure is available upon request from the author.

[46]Contrary findings are reported by Coleman, Hoffer, and Kilgore (1982), who argue that private schools do raise student achievement. However, Goldberger and Cain (1982, 1983) point out that their study is of little value, because it overlooks issues of selection bias and nonrandom sampling.

[47]"Minority" here means black or Hispanic. Overall, black and Hispanic students accounted for about one-quarter of the school-age population, throughout the period beginning in 1970 and ending in 1993. Urban minorities will thus account for less than this. (Data are taken from the National Center for Education Statistics Web Site, http://nces.ed.gov/pubs/ce/c9540a01.html.)

[48]Data are from National Center for Education Statistics Web site, at http://nces.ed.gov/pubs/ce/c9744a01.html.

has been a considerable shift in employment out of less skilled occupations and into more skilled occupations. Therefore, even if schooling remained constant within every occupation, the schooling of any given occupation would appear to have declined relative to the average worker.[49] To control for this force, we calculate the within-occupation schooling change. This is accomplished by first calculating the average change in schooling for each occupation, in each birth cohort.[50] The average change for each occupation is then weighted by the occupation's share of employment in the 1900 birth cohort.[51] Figure 4 illustrates the change in the schooling of male teachers, as well as the within-occupation change in the average male worker's schooling; the corresponding figure for female teachers and workers is quite similar. The schooling of teachers rises by about one year, while the schooling of the average worker rises within occupation by about three years. Teachers lose about two years of relative schooling, when the composition of employment is held fixed, and about about three and a half years of schooling overall. Therefore, more than half of the decline in schooling results from within-occupation changes in schooling and is unrelated to changes in the composition of employment.

To test the model further, we should investigate whether or not teachers are losing ground relative to similarly skilled workers, as predicted. This distinction may be empirically important, since the opportunity cost of an additional year of education is much larger for highly skilled workers like teachers. Therefore, small increases in the schooling of teachers may be just as valuable as larger increases in the schooling of the average worker. To control for this, male teachers will be compared to a group of male workers which was similarly

[49] See Murphy and Welch (1993b) for a discussion of the shift in employment composition.

[50] Average schooling is constructed by taking the yearly educational averages for the years in which all members of the cohort are between the ages of 30 and 60, and then computing the unconditional average over these years.

[51] An occupation's share of employment is given by the number of workers in the occupation as a share of the total labor force. Different weighting schemes, such as that based on the occupation's share of total wages, or share of hours worked, produced roughly similar results.

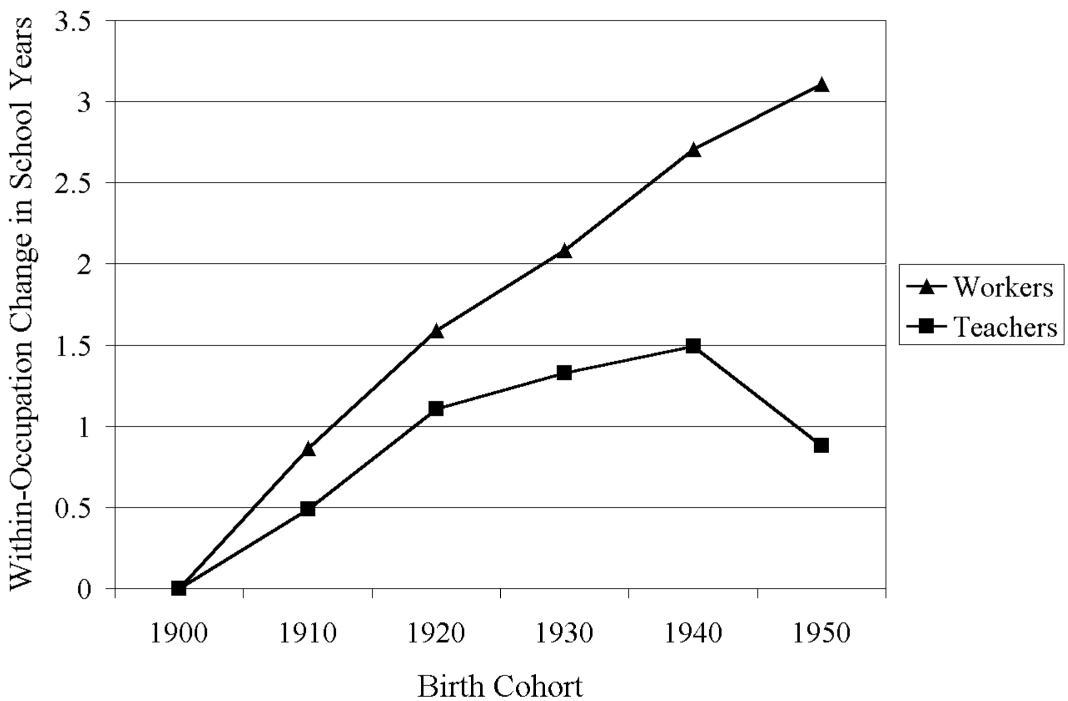

Figure 4: Within-occupation changes in schooling for male teachers and for male workers, by birth cohort.

educated in the 1900 birth cohort.[52] Workers in the top educational decile appear to be an appropriate comparison group, because the average schooling for this group of workers in the 1900 birth cohort is almost identical to the average for male schoolteachers.[53] However, Figure 5 demonstrates that the schooling of workers in the top decile subsequently grew much more quickly than the schooling of teachers. In the 1900 birth cohort, the groups were virtually indistinguishable, but by the 1950 birth cohort, the top decile had roughly one and a half additional years of schooling. Therefore, teachers seem to have lost considerable ground to similarly skilled workers.[54] Teachers used to be among the most skilled workers in the economy, but that is no longer the case.

Finally, one might ask if teachers are receiving more value for each year of schooling than non-teachers. In this case, relative schooling may decline, even if the relative human capital of teachers does not. However, the relative wages of teachers would not decline in this case. To examine this hypothesis, we can measure the position of the average teacher in the earnings distribution. Figure 6 displays the results of this exercise. The figure shows that female teachers have fallen roughly 15 percentage points down the annual earnings distribution, while male teachers have fallen nearly 20 percentage points.[55] This suggests that the changes in relative schooling indeed reflect changes in the value of teachers' skill. The following section examines this issue in much greater detail.

[52] A similar comparison cannot be made for female teachers, because virtually all skilled female workers were teachers for at least the first three birth cohorts.

[53] A worker is defined to be in the top decile if he is in the top ten percent of his cohort for any year during which he is between the ages of 30 and 60.

[54] Topcoding in the Census is probably not responsible for this relative decline. If we examine the proportion of teachers and top decile workers with at least 5 years of college, the figure looks qualitatively similar, but even more dramatic. This figure is available upon request from the author.

[55] Once again, private school teachers have the same experience as public school teachers. The corresponding figure for male private school teachers, available from the author, demonstrates the male private school teachers seem to have lost just as much ground as male schoolteachers overall. Along the same vein, other public employees have hardly fallen at all in the earnings distribution. Other female public employees have lost barely five percentage points in this distribution, while other male public employees have held steady in it.

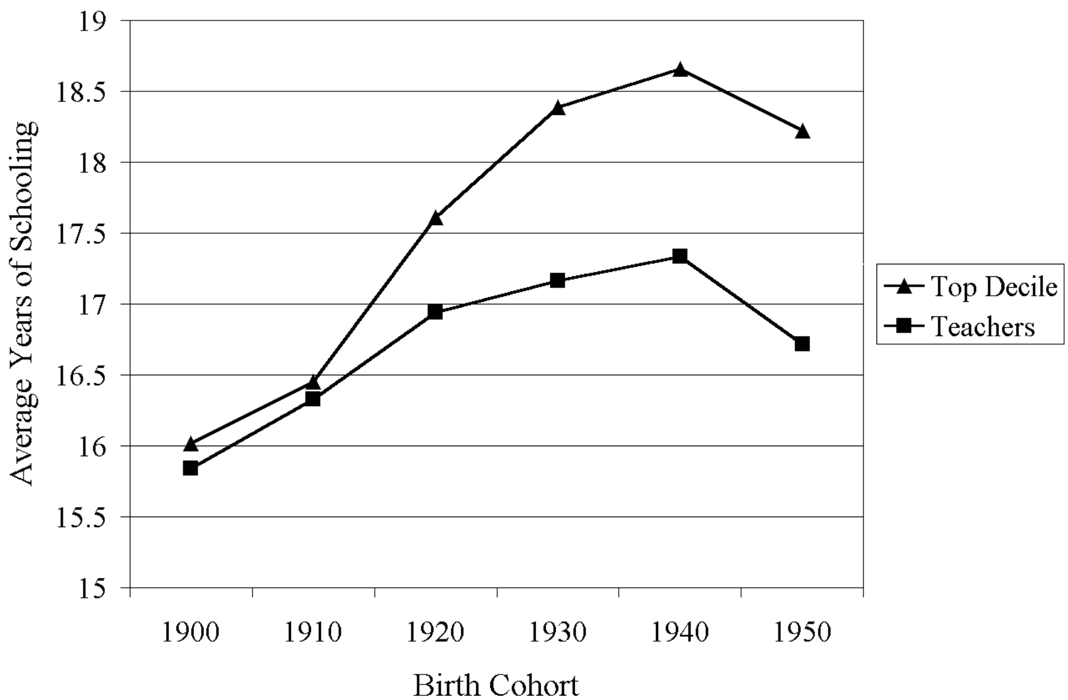

Figure 5: Average schooling of male teachers, and average schooling of male workers in the top decile of the educational distribution, by birth cohort.

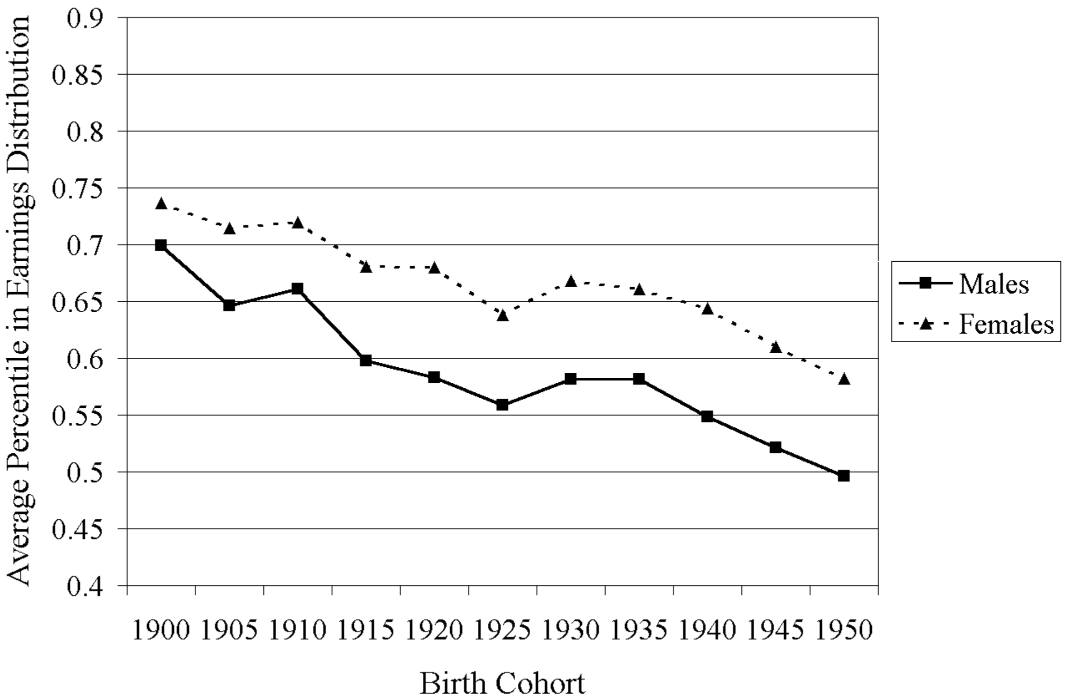

Figure 6: Changes in the position of the average teachers in the annual earnings distribution, by sex.

3.2 Measuring Changes in Teacher Human Capital

Using wage and demographic data from the US Census, the change in the relative value of teachers' human capital, compared to the human capital of college graduates, can be estimated more precisely. These estimates can be used to test the prediction that the relative quality of teachers declines across successive cohorts of workers.

3.2.1 A Regression Model

The goal of this section is to infer from relative wage data the relative quality of teachers. This strategy presents a challenge, because the relative wage reflects various factors unrelated to quality. First, the relative wage includes relative price changes. For example, during a baby boom, teachers might get paid more even though they are of the same quality, simply because they are scarce relative to the student population. To isolate these relative price changes, we will use a dummy for the calendar year. This dummy can identify relative price changes, since a shock to relative supply or demand should affect the wages of all teachers in a given year. Second, the relative wage may reflect differences in the relative returns to experience.[56] That is, experience may benefit teachers more or less than other kinds of workers; changes in the relative wage could thus reflect nothing more than changes in the average experience of different occupational groups. To identify this second component, we will include a dummy variable for each group of similarly experienced workers, and interact these variables with occupational dummies. Once these two non-quality components are identified, a worker's quality is identified from two other elements: her schooling, and a cohort-specific fixed-effect. The estimated return to schooling measures the worker's observed quality. The cohort-

[56]It is possible that changes in relative quality could take place through changes in the relative returns to experience. We abstract from this possibility, in large part because it would be impossible to identify changes in both educational quality and the shape of the experience profile. For an investigation of economywide changes in the shape of the experience profile, see Murphy and Welch (1992).

specific fixed-effect, on the other hand, helps estimate unobserved differences in quality across cohorts. Since the relative quality of teachers is predicted to decline across cohorts, teachers in younger cohorts may be of lower relative ability, even if schooling is held constant.

This reasoning suggests a basic regression model, which may be adorned with additional explanatory variables. Consider worker i, in occupation j, cohort c, experience group x, at time t. This worker's log-earnings are modeled as:

$$\begin{aligned} \ln E_i^{ctxj} &= \beta_0^j + (\beta_1^j + \beta_2^{cj} Coh_c + \beta_3^{tj} Yr_t) * Sch_i + \\ &\quad \beta_4^{cj} Coh_c + \beta_5^{tj} Yr_t + \beta_6^{xj} Exp_x + \varepsilon_{ijctx} \end{aligned} \tag{19}$$

Observe that each coefficient is allowed to vary across occupations j. The variable Sch_i represents worker $i's$ years of schooling. Coh_c is a dummy variable which reflects a worker's membership in cohort c. Similarly, Yr_t and Exp_x are dummy variables for the calendar year t and experience group x.

The returns to schooling are allowed to vary across occupation, cohort, and calendar year. In addition to the baseline return to schooling within an occupation, β_1^j, there is also a cohort-specific return to schooling, β_2^{cj}, and a year-specific return, β_3^{tj}. The cohort-specific return reflects the possibility that schooling quality changes across cohorts. The year-specific return, on the other hand, reflects transient changes in the demand for skilled workers. As a result, $\beta_1^j + \beta_2^{cj}$ represents the permanent return to schooling for a worker in cohort c. In addition to the schooling variables, there are dummy variables for the cohort, calendar year, and experience group.

Estimating equation 19 yields a natural measure of skill in an occupation. Suppose that $\overline{Sch}^{cj}$ represents the average schooling possessed by workers in occupation j and cohort c.

The average value of skill in occupation j, and cohort c, is then given by:

$$V_c^j = \beta_1^j \overline{Sch}_c^j + \beta_2^{cj} \overline{Sch}_c^j * Coh_c + \beta_4^{cj} Coh_c \qquad (20)$$

The first two terms represent the permanent return to schooling. The last term represents the unobserved quality common to occupation j in cohort c. If $j = tch$ for teachers and $j = col$ for other college graduates, $V_c^{tch} - V_c^{col}$, represents the skill of teachers relative to the skill of college graduates. We will be interested in measuring how $V_c^{tch} - V_c^{col}$ moves across birth cohorts c.

Before proceeding further, we must tackle a thorny identification issue raised by the model in equation 19. Cohort, calendar year, and experience group are linearly dependent. Identification of these three components thus requires some linear restriction on equation 19.[57] Since such a restriction is fundamentally untestable, we will impose different kinds of restrictions and check whether or not they yield similar results. Two very different kinds of restrictions will be used; it is significant that both yield estimated declines in the relative quality of teachers. The first restriction assumes that the supply of teachers' labor is perfectly elastic.[58] In this case, price effects will be negligible, and the calendar year dummies, $\beta_5^{tj} Yr_t$, may be dropped from the regression. This elasticity restriction then yields an estimate of the change in the relative quality of teachers. The second restriction relies on prior information about the experience profile of teachers. It has been found (see, for example, Flyer and Rosen [1997]) that the earnings profile of teachers is approximately linear, while the earnings profile of other college graduates is concave. Early in their careers, the wages of teachers grow more slowly than the wages of other college graduates, while the reverse is true later in their

[57] For a detailed discussion of this "age-period-cohort identification problem," see Mason et al (1973).

[58] Zabalza (1979) estimates the elasticity of teaching supply for new entrants into the labor force. He finds elasticities which range from one to three.

careers. This generates a U-shaped relative earnings profile for teachers, compared to college graduates. Figure 7 bears witness to this fact. The figure depicts the unconditional log relative wage profile of male school teachers, relative to male college graduates, in each birth cohort.[59] Every birth cohort shows the same pattern, of initial wage decline for ten years and subsequent wage growth. The same trends appear for female teachers in the Census data.[60] This U-shaped relative earnings profile has also been found in Current Population Survey data, in which the relative wages of teachers decline for the first 11 years of experience, and rise thereafter. (Flyer and Rosen 1997)

The U-shaped relative earnings profile can be used to estimate lower and upper bounds on the decline in $V_c^{tch} - V_c^{col}$. To estimate an upper bound, we impose the restriction that the relative wage profile of teachers is flat for the first ten years of experience, when in reality it is decreasing. This amounts to the restriction that $\beta_6^{xj} Exp_x$ is constant for all workers with under ten years of experience. To understand why this restriction yields an upper bound, consider a comparison between a new cohort and a cohort with ten years of experience, in a single year. The older cohort has a lower relative wage, by virtue of its experience. However, the restriction forces us to overlook this. Instead, we infer incorrectly, from the lower relative wage, that the older cohort is of lower relative quality. Therefore, we intentionally understate the decline in relative quality from the older cohort to the younger cohort. We pursue the mirror image of this strategy to estimate a lower bound. Consider the restriction that the relative wage profile of teachers is flat after twenty years of experience, when in reality it is increasing. This is implemented by imposing the restriction that $\beta_6^{xj} Exp_x$ is constant for all workers with at least twenty years of experience. To understand the lower bound, think of

[59]Each separate curve in the figure corresponds to a different birth cohort, while the x-axis represents the midpoint of the cohort's age range at the time of the observation. For example, the point for the 1910 cohort (individuals born between 1910 and 1919) at age 25 represents the log relative wage of this cohort in the 1940 census, during which cohort members were between 20 and 30.

[60]The figure for female teachers is available from the author upon request.

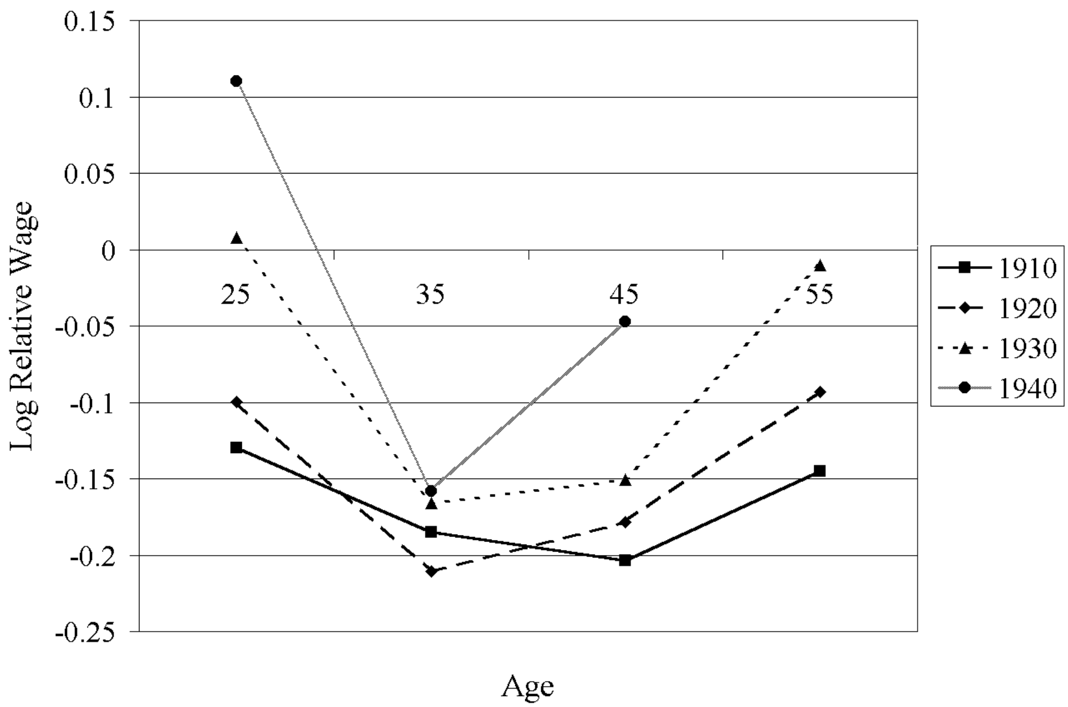

Figure 7: Unconditional log relative wage profile of US male teachers, relative to working male college graduates, by birth cohort.

a comparison between a cohort with thirty years of experience and one with twenty. The older cohort has a higher relative wage, due to its experience. As a result of our restriction, however, we infer that the older cohort is of higher relative quality. Effectively, we overstate the relative quality of the older cohort, and thus overstate the decline in relative quality from the older cohort to the younger cohort.

3.2.2 Data and Construction of Variables

The specification in equation 19 will be estimated by using annual earnings as the dependent variable, and including weeks worked as a regressor.[61] The data contain teachers, college professors, and other college graduates in the labor force. Here, college graduates are taken to be the group of skilled workers. An individual is classified as a schoolteacher if she reports being an elementary or high school teacher.[62] She is classified as a college professor if she reports being a college professor, dean, or instructor. Finally, a "college graduate" is defined as a worker with at least two years of college education.

The data are taken from the Integrated Public Use Microdata Samples. (Ruggles and Sobek 1997) This set contains microdata from decennial US Census microdata samples on annual earnings, occupation, age, years of schooling, number of weeks worked, labor force status, and family characteristics;[63] these data are available every 10 years, from 1940 to

[61]Annual earnings include all monetary earnings received as an employee. It will also include any wages earned in a secondary occupation other than the one reported. This may generate some bias in the estimation of occupation-specific parameters.

[62]Prior to the 1960 Census, it is impossible to distinguish between high school teachers and primary school teachers.

[63]Unfortunately, the Census data on earnings do not include fringe benefits, which represent a significant component of overall teacher compensation. However, it does not appear that teachers' benefits rose much more quickly than the benefits of other college graduates. Based on a very limited sample of teachers, Rothstein and Miles (1995) argue that fringe benefits rose by 5% annually for teachers, between 1967 and 1991. Over the same period, benefits rose at a 4% annual rate for the average worker, but benefits almost certainly rose significantly more quickly for college graduates. Therefore, there would appear to be little difference between the benefit growth for college graduates and that for teachers. Moreover, relative changes in fringe benefits would not explain the decline in the relative schooling of teachers.

1990. Educational cohorts are constructed by birth year, where a cohort is defined as a group of individuals born in a given 10-year interval; throughout the analysis, we refer to a cohort by using the first year of the interval. For example, the 1900 cohort represents individuals born from 1900 to 1909. The experience variable is constructed as $(Age - 6 - Sch)$, where Sch represents the highest school grade completed.[64] Individuals are then divided into five-year experience groups, but all individuals with more than thirty years of experience are considered to be in the same experience group.[65] This experience measure is not as accurate for women as it is for men, because women often take time out of the labor force for child-rearing. To account for this difference, the female regressions include the number of children born, *chborn*, as an independent variable.[66]

According to equation 20, estimating the average value of skill V_c^j requires the calculation of $\overline{Sch}_j^c$, the average years of schooling for occupation j within cohort c.[67] This is measured as the average schooling of a cohort for the years in which all cohort members are between the ages of 30 and 60.[68] The calculation is limited to workers over age 30, because younger workers may not have finished receiving their education. Observations for workers in their 60s are discarded, because these observations often differ wildly from those at other ages. It is quite likely that those still in the labor force during their 60s are not representative of

[64]For example, completion of grade twelve is measured as $Sch = 12$, while completion of two years of college is measured as $Sch = 14$.

[65]Since the cohort and experience dummies are based on intervals of years, there will no longer be *exact* linear dependence between cohort, period, and experience. However, it is still not appropriate to estimate the model without an additional restriction, because in such a case, the coefficients β_4^{cj}, β_5^{tj}, and β_6^{xj} would be separately identified solely by the imposition of measurement error. The resulting set of point estimates would thus be no better than another set which differed by a linear term.

[66]It should be noted that the regressions for men and women will be run separately.

[67]Any calculation of the cohort educational average suffers from the problem of "educational drift," as a result of which older workers are more likely to overreport their education. It does not appear that this drift greatly affects the relative wage estimates, which were largely insensitive to several different methods of calculating $\bar{Y}_j^c$, such as computing the average for all cohorts at a single, fixed age.

[68]To construct this, we begin by computing the cohort's average education within each year. Next, we keep only the years in which all members of the cohort are between the ages of 30 and 60. Finally, we compute an unconditional average over these remaining years.

their cohort; more educated workers should be likely to stay in the work force longer.

3.2.3 Measuring the Relative Human Capital of Schoolteachers

This section presents the estimated change in the relative quality of schoolteachers. The theoretical model in this paper predicts that the quality of schoolteachers should decline, both relative to the average worker, and relative to the average skilled worker. The latter claim, of a decline relative to skilled workers, is the stronger of the two. Therefore, we will attempt to test this claim, by measuring the quality of teachers, relative to college graduates. To estimate the relative quality, the regression framework of equation 19 is used. Within this framework, workers will be split up into two occupational groups: schoolteachers, for whom $j = tch$, and college graduates, for whom $j = col$.[69] The fitted values from these regressions will be used to calculate for each cohort, $V_c^{tch} - V_c^{col}$, which represents the relative value of schoolteachers' skill, when compared with college graduates. Note that V_c^{tch} and V_c^{col} are defined according to equation 20.

The model is first estimated by assuming that the relative demand for teacher quantity is perfectly elastic. This yields an initial estimate of the change in the relative quality of teachers, or $V_c^{tch} - V_c^{col}$. To check these estimates, we then estimate lower and upper bounds on the change in $V_c^{tch} - V_c^{col}$, by exploiting the shape of the relative earnings profile for teachers. The results of the perfect elasticity restrictions are depicted by the solid line in Figure 8 for female teachers, and by the solid line in Figure 9 for male teachers. In each figure, the dashed lines represent the lower and upper bounds. The coefficient estimates themselves, and their associated t-statistics, are reported in the first four columns of Table 3, found at the end of this paper. The perfect elasticity restrictions produce an estimated

[69]Since we are not yet concerned with the wages of college professors, workers will be classified into only two occupational groups.

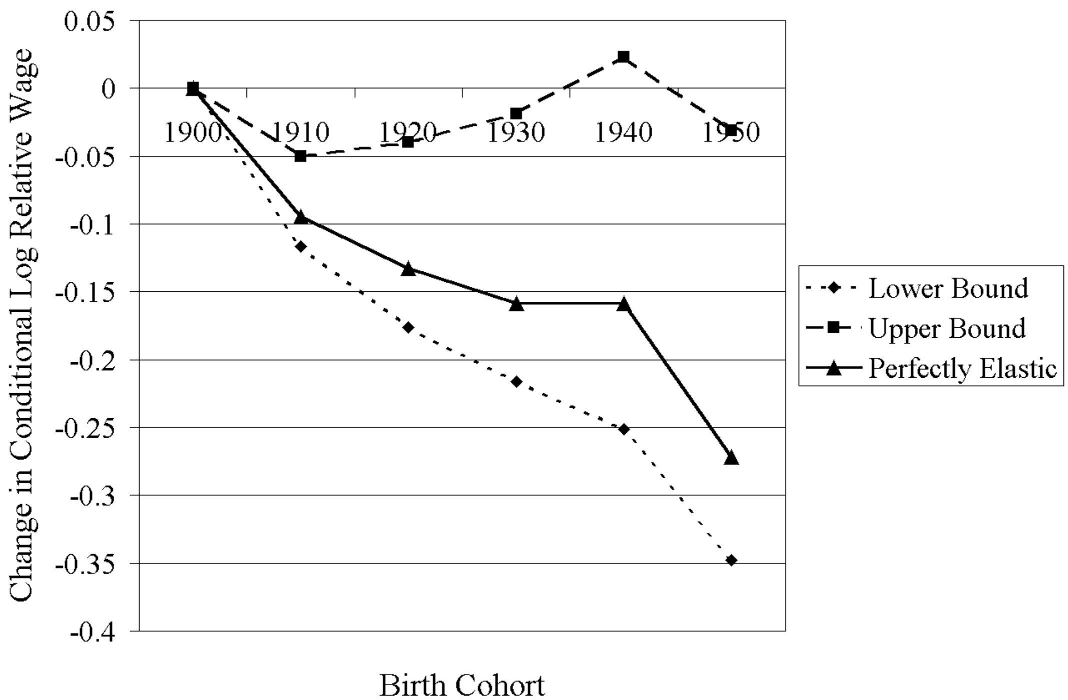

Figure 8: Estimated change in the value of human capital for US female schoolteachers, relative to working female college graduates, by birth cohort.

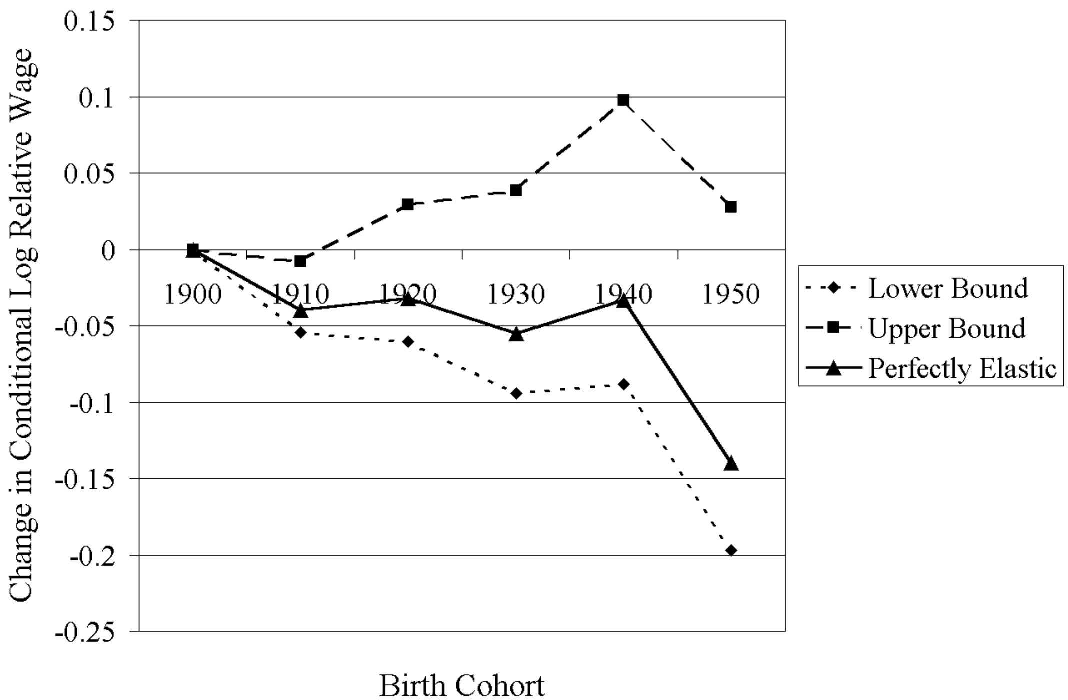

Figure 9: Estimated change in the value of human capital for US male schoolteachers, relative to working male college graduates, by birth cohort.

decline in relative quality of nearly fifteen percentage points for male schoolteachers, and of nearly thirty percentage points for female schoolteachers. In other words, the human capital of the average college graduate is estimated to have risen in value by much more than that of the average teacher, by fifteen percentage points more for males, and thirty percentage points more for females. This occurs over roughly two generations, from the 1900 birth cohort to the 1950 birth cohort, and it represents significant evidence in favor of the predicted decline in the relative human capital of schoolteachers.

It is not hard to understand why the predicted decline is larger for females. Over this time period, there was a significant expansion of labor force opportunities for skilled women outside teaching.[70] In the 1900 birth cohort, over 90% of college-educated women in the labor force were teachers, but by the 1950 cohort, this share had dipped to under 15%.[71] Therefore, one would expect a flight of the most skilled women out of teaching. This force should magnify the decline in relative quality for female teachers. Therefore, the relative decline for males should be taken as the benchmark effect of technical change alone. If the labor market for teachers were driven entirely by the expansion of opportunities for skilled women, and not by technical change, one would expect declining relative quality for female teachers, but rising relative quality for male teachers.[72] The presence of declines for male teachers provides evidence of technical change outside education, above and beyond expansion in female labor force opportunities.

[70] This expansion had observable impacts on the structure of teacher training in the US. As more skilled women chose occupations outside teaching, teacher-training colleges began to expand their offerings and to become full-fledged universities, particularly during the '50s and '60s. (Haberman and Stinnett 1973) Not coincidentally, these are the decades during which women began to migrate outside teaching in earnest.

[71] These figures are calculated by the author, using the data of Ruggles and Sobek (1997).

[72] Occupational desegregation would raise the price of skilled women, by raising the demand for their services. This would lower the quality of female teachers. However, it would *lower* the price of skilled men, who would face more competition in the non-educational labor market. As a result, occupational desegregation alone would lower the relative quality of female teachers, but raise the relative quality of male teachers.

The estimated bounds on the change in quality tell a qualitatively similar story. According to the estimated bounds, the relative human capital of male schoolteachers can have risen by only two percentage points at best, and may have declined by as much as twenty percentage points. The relative human capital of female schoolteachers has declined anywhere from two to thirty-five percentage points. It is important to note that the upper bounds on the change in relative quality are, for the most part, horizontal. At the very most, the relative quality of teachers has remained constant. Moreover, we have reason to believe that these are *strict* upper bounds, insofar as the estimates are biased upwards. Even the use of overly favorable assumptions does not produce estimated increases in the relative quality of teachers.

3.2.4 Measuring the Relative Quality of College Professors

Similar methods will be used to estimate the change in the human capital of college professors relative to teachers. The basic regression framework specified in equation 19 will still be used, but in this section, workers will be divided into three occupational groups: college professors, schoolteachers, and other college graduates. The change in the relative human capital of professors can be written as the change in $V_c^{prf} - V_c^{tch}$; the theory predicts that this quantity rises over time. An assumption of perfectly elastic labor supply will yield one estimate of the change in this quantity, while an assumption about the relative wage profile of college professors will yield a lower bound on the increase in $V_c^{prf} - V_c^{tch}$.

Suppose that the labor supply functions for schoolteachers and for college professors are perfectly elastic, conditional on a fixed level of relative human capital. In this case, there will be no price effects on the relative wages of schoolteachers or of college professors. In terms of equation 19, $\beta_5^{t,tch}$ and $\beta_5^{t,prf}$ will be uniformly zero for all time periods t. Just as in the estimation of teacher quality, this estimate can be checked against a lower bound. We can construct a lower bound on the change in relative quality, if we assume that the relative wage profiles of professors are upward sloping. This assumption makes theoretical sense if one regards tenure as a form of income insurance for older professors.[73] Such insurance for older professors would have to be financed by pay cuts for younger professors and would thus appear to result in rising relative wage profiles for professors, compared to other college graduates.[74] This idea is consistent with patterns in the Census data, according to Figure 10. This figure is constructed just like Figure 7, except that it depicts the log wage of male college professors relative to the log wage of other college-educated male workers. As a cohort ages, the wages of male professors on average tend to rise relative to the wages of male college-educated workers.[75]

To construct a lower bound, we impose the restriction that the relative wage profile of professors, compared to college graduates, is flat after twenty-five years of experience, even though it appears to be rising. To see how this works, consider a comparison between a cohort with thirty-five years experience and one with twenty-five. The older cohort has higher relative wages because of its experience; as a result of the restriction, however, this will be attributed to its higher quality. As a result, the restriction overstates the decline in the quality of college professors relative to college graduates, by making older cohorts look better than they are. This results in a lower bound on changes in $V_c^{prf} - V_c^{col}$. Moreover, we have already shown how to derive an upper bound on $V_c^{tch} - V_c^{col}$, by assuming that the relative wage profiles of teachers are flat early in their careers. Taking the difference of these two bounds results in a lower bound on $(V_c^{prf} - V_c^{col}) - (V_c^{tch} - V_c^{col}) = V_c^{prf} - V_c^{tch}$. This

[73]Siow (1998) makes this case more specifically by arguing that, as a result of their high degree of specialization, professors need income insurance against the possibility that their skills may become obsolete.

[74]This conclusion relies on the fact that tenure is very uncommon outside the academy.

[75]The corresponding figure for females, available from the author, shows similar patterns.

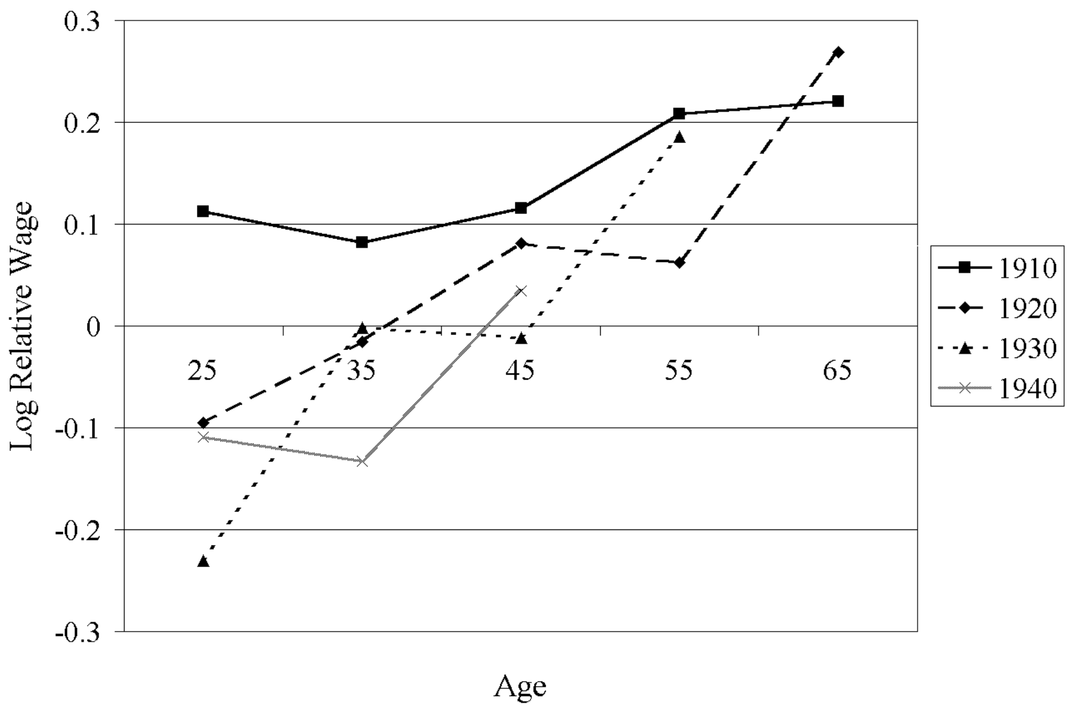

Figure 10: Unconditional log relative wage profile of US male college professors, relative to working male college graduates, by birth cohort.

yields a lower bound on changes in the quality of professors relative to teachers.

The results of the perfect elasticity restrictions are depicted by the solid line in Figure 11 for female professors, and by the solid line in Figure 12 for male professors. The lower bounds are depicted by the dashed lines in the figures. The associated coefficient estimates are reported in the first four columns of Table 4, found at the end of this paper.

According to the perfect elasticity restrictions, from the 1900 to 1950 birth cohorts, the relative quality of college professors is estimated to have risen by more than twenty percentage points for males and more than thirty percentage points for females. This represents a substantial rise in college professor quality relative to schoolteacher quality, as predicted by the theory. Once again, the decline in teacher quality is larger for women than for men. This is consistent with rising female labor force opportunities outside teaching, and it suggests that the estimates for males should be treated as the benchmark effects of technical change. Moreover, the figures show that the lower bounds are essentially horizontal. The relative quality of male college professors cannot have fallen by more than four percentage points, while the relative quality of female college professors has risen by at least ten percentage points. Even assumptions which heavily favor the quality of teachers do not produce large estimated increases in the relative quality of teachers. This is powerful evidence that the data cannot support increases in the relative quality of teachers.

4 Conclusions

This paper has presented the following key idea: innovation raises the productivity of skilled workers outside education, but not the productivity of skilled teachers. This has several implications. First, the skill of non-teachers, who benefit from innovation, will grow more rapidly than the skill of teachers. Second, the increased demand for skill outside teaching

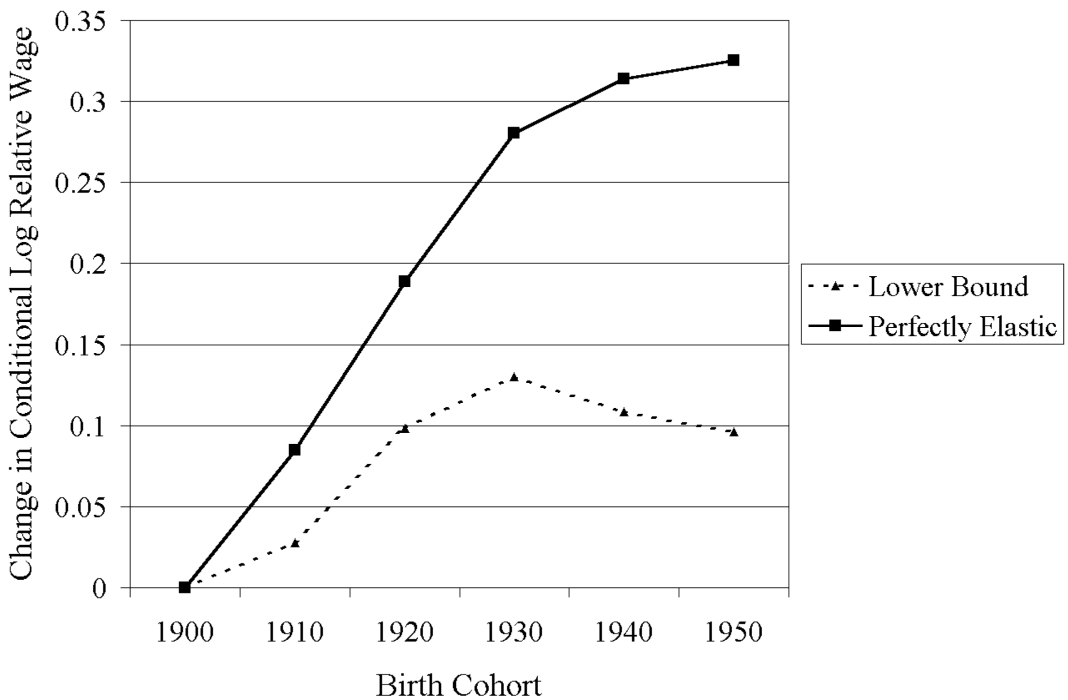

Figure 11: Estimated change in the value of human capital for US female college professors, relative to female schoolteachers, by birth cohort.

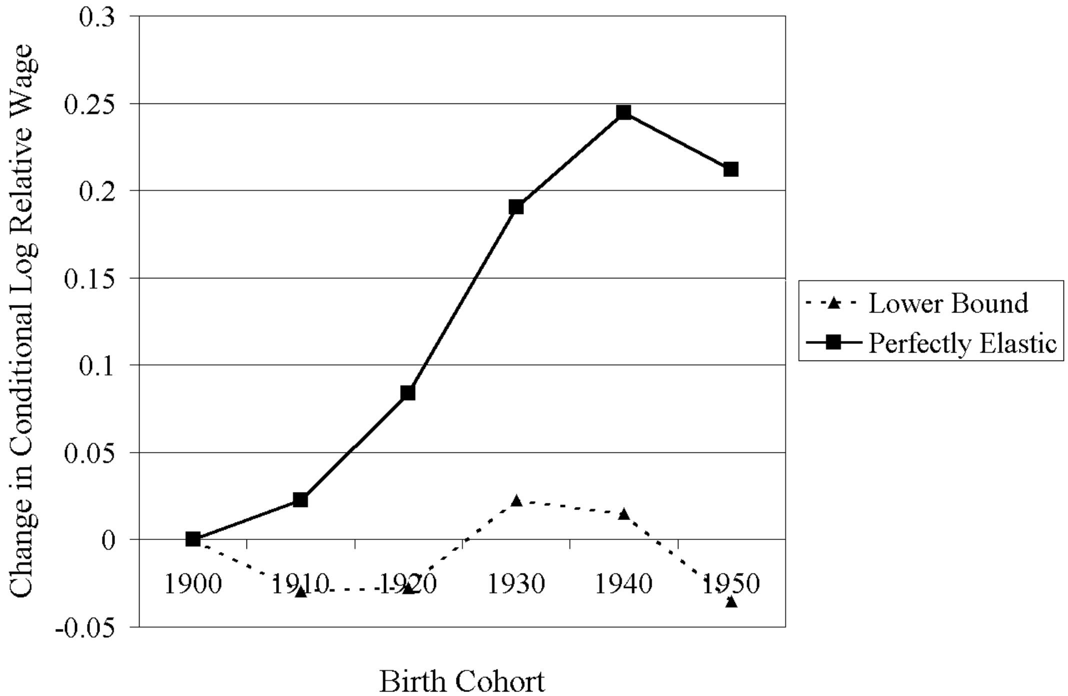

Figure 12: Estimated change in the value of human capital for US male college professors, relative to male schoolteachers, by birth cohort.

bids up its price. This reduces teacher quality and raises teacher *quantity*, which becomes relatively cheaper than quality. This helps explain why advanced countries experience the growth in primary school teacher-student ratios apparent in Table 1, while experiencing reductions in relative teacher quality. Furthermore, it explains why the relative quality of professors, whose specialized knowledge improves with innovation, has not fallen as well. Finally, the rising price of skilled teachers raises the cost of producing primary education and results in a shift towards college education. This prediction is consistent with apparent increases in primary educational costs: US primary school spending per student has nearly doubled since 1970, while student achievement has remained constant or fallen slightly.[76] It is also consistent with the finding that countries with higher rates of college participation, and thus higher demand for skill, exhibit *less* primary school achievement. (Simon and Woo 1995)

This paper has also tackled the important empirical question of how US teacher quality has changed; the evidence for teacher quality appears consistent with the predictions of the paper. First, along a variety of different dimensions, it appears that the relative schooling of teachers has declined considerably compared to other workers of all stripes. Second, during the twentieth century, the human capital of schoolteachers appears to have declined in value relative to college professors and college graduates. At the very least, the human capital of schoolteachers has not risen in value relative to those two groups. Moreover, over the past century, the human capital of male schoolteachers may have fallen by about fifteen or twenty percentage points, relative to male college graduates or male college professors. The human

[76]The spending data are reported in Hanushek and Rivkin (1997). Betts (1996) reports that SAT scores fell from 1970 to 1990, even though the proportion of 18 year-olds taking the test fell slightly as well. For a survey of the more general literature on the link between spending and student achievement, see Hanushek (1996). The link between school inputs and the eventual wages of graduates is less clear. Betts (1995) argues that there is little link between schooling inputs and the wages of workers. Card and Krueger (1992) argue for the opposite view.

capital of female schoolteachers may have fallen by roughly thirty percentage points relative to the same two groups.

Although the relative quality of schoolteachers appears to be falling, the theory suggests that this does not compromise the position of today's students. Innovation simply alters the relative efficiency of various educational inputs. This causes resources to flow away from schoolteacher quality, and towards other, more productive uses *within* the educational system. This conclusion is consistent with the broad empirical evidence. Resources have not simply departed from the educational system.[77] The relative quality of schoolteachers has declined, but there has been simultaneous and dramatic growth in the teacher-student ratio. Moreover, the relative quality of professors has not suffered the same decline. These facts point to an important lesson: one cannot measure the quality of the educational system simply by measuring changes in one set of inputs, such as the quality of teachers. A decline in one set of educational inputs may be accompanied by growth in another set; similarly, a decline in output at one level of education may be accompanied by output growth at another level. The only reliable way to assess the quality of the educational system is to measure the quality of the workers who have graduated from it. This view would assign less importance to concerns about declining test scores at the primary school level. These declines may simply point to the rising cost of producing general human capital, and to the ongoing substitution away from primary school education.

Several extensions of this discussion seem to merit future analysis. First, we have not focused on the issue of gender in teaching. Beginning in the nineteenth century, teaching became one of the few occupations open to educated women. From 1860 onwards, women constituted a majority among US schoolteachers, and around the same time, women were

[77] Indeed, Hanushek and Rivkin (1997) point out that US spending per pupil has grown significantly over the past century.

entering teaching in various nations throughout the now-developed world.[78] During the twentieth-century, however, educated women began to enter many different occupations outside teaching. In 1940, over half of college-educated American women in the labor force were teachers, but by 1990 only one-tenth were teachers.[79] It seems important to understand the conditions which precipitated the entry of educated women into fields outside teaching, and to evaluate empirically their effects on the price of teachers and other skilled workers.

Second, analysis of an educational system with different types of students may reveal important implications for economic inequality. The discussion here has distinguished between unschooled workers and skilled graduates. More generally, however, one could assume that some students choose to go to college, and others do not. This would result in there being three levels of skill: unskilled workers, high school graduates, and college graduates. The key feature of such a model would be that only college-bound students benefit when resources flow away from primary education and towards higher education. Increasing investment in higher education may thus continually worsen inequality between college graduates and high school graduates. This inequality may worsen further as the proportion of college-bound students rises, and the system becomes more heavily geared toward college-bound students.

Third, moving beyond the field of education, it seems that one of the key ideas of this paper, that innovation favors specialized fields of knowledge, could apply to other occupations which are subdivided into generalists and specialists. Medicine appears to be such a field; primary care-givers use general medical knowledge to provide general medical treatment, while surgeons, radiologists, and other medical specialists may use more specialized knowledge to provide highly specialized medical services. If innovation favors medical specialists, the quality of such specialists should rise more quickly than that of primary care-givers. The

[78] See Clifford (1989).

[79] These statistics are calculated from US Census data.

empirical methods set forth here could be used to estimate changes in the quality of medical specialists relative to generalists. However, any application of the theory to US data would have to cope with the explosion in the quantity of medical specialists; the proportion of US doctors who are specialists has more than quadrupled, from seventeen percent in 1931 to more than eighty percent in 1980.[80] It seems necessary both to understand the dramatic growth in the quantity of specialists, and to investigate empirically the change in the relative quality of specialist physicians.

Finally, it seems important to understand in more detail the cross-country patterns summarized in Figure 1 and Table 1. The predictions of the theory should apply with more force to developed countries than to developing countries. Since technology will be much less advanced in developing countries, school systems there should invest more in relative schoolteacher quality, but less in higher education and schoolteacher quantity. It would be useful to investigate whether this prediction is consistent with observed cross-country patterns. At the very least, it seems that the patterns of relative wage decline are not consistently present in developing countries. (Schultz 1987) Moreover, while Figure 1 reveals intriguingly similar wage patterns among various developed countries, it does not attempt to estimate directly the changes in teacher quality for other developed countries. Such estimation is necessary in order to assess the prevalence of declining relative quality. It may well turn out that the advanced economies, which value schooling most highly, exhibit the sharpest declines in the relative quality of schoolteachers.

[80] See Noether (1983, p. 109). Intriguingly, other developed countries appear to have had different experiences.

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Table 1. The primary and secondary student-teacher ratio in selected industrialized countries.

	1950	1960	1970	1980	1990
Austria	21.07 [a]	21.08	20.83	13.05	9.19
Canada	28.57	24.99	20.92	15.73 [b]	14.63
Finland	24.67	23.35 [a]	20.13	15.61	.
France	27.98 [a]	26.14	20.00	20.69	13.70
Ireland	33.58	29.70	24.62	20.53	20.26
Italy	23.54	18.16	16.47	13.19	10.06
Japan [c]	31.15	27.78	21.81	20.75	18.35
Netherlands	30.83	29.12	23.31	19.28	15.98 [b]
Norway	24.30 [d]	19.07	15.60	14.02	11.07
United States	25.94	24.71 [e]	20.77	16.90	15.40 [f]

Sources: UNESCO (1966), UNESCO (1985), and UNESCO (1994).

[a] Data point from 1955.

[b] Data point from 1985.

[c] Estimate includes students and teachers in vocational education.

[d] Estimate includes students and teachers in public vocational education.

[e] Data point from 1963.

[f] Data from Hanushek and Rivkin (1996).

Table 2. The student-teacher ratio in US higher education.

	FTE Faculty[a] (1000s)	FTE Students[a] (1000s)	Ratio of FTE Students to FTE Faculty[a]
1960	202	2954	14.62
1965	316	4671	14.78
1970	402	6737	16.76
1975	501	8480	16.93
1980	529	8819	16.67
1985	541	8943	16.53
1990[b]	629	9984	15.87
1995[b]	665	10286	15.47

SOURCES: 1990-5 data are from Andersen (1998). All other data are from Andersen et al (1989).

[a]"FTE" stands for Full-Time Equivalent.

[b]Due to revised survey methods, data after 1985 are not strictly comparable to earlier years.

Table 3. Regression estimates of teacher quality.[a]

	Perfectly Elastic				Lower Bound				Upper Bound			
	Males		Females		Males		Females		Males		Females	
	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
Years of Schooling	0.09	8.06	0.18	7.48	0.09	8.17	0.18	7.76	0.09	8.15	0.18	7.73
Exp5_10[b]	0.46	152	0.39	112	0.46	152	0.40	113	0.45	154	0.36	113
Exp10_15[b]	0.69	165	0.47	86.6	0.69	167	0.47	88	0.68	165	0.45	84
Exp15_20[b]	0.81	168	0.51	79.8	0.81	169	0.51	82	0.81	167	0.49	77
Exp20_25[b]	0.94	143	0.60	69.2	0.94	144	0.60	70	0.93	142	0.57	66
Exp25_30[b]	0.99	134	0.65	66.2	0.99	136	0.66	70	0.98	133	0.62	63
Exp30_[b]	0.97	99.6	0.68	52.4	0.98	103	0.70	58	0.96	99	0.64	49
Chborn[c]	.	.	-0.07	-67.0	.	.	-0.07	-67	.	.	-0.07	-67
Tch*Chborn[c]	.	.	0.03	12.4	.	.	0.03	13	.	.	0.02	11
Tch*Exp Dummies[d]	All				5_10, 10_15, 15_20, 20_				10_15, 15_20, 20_25, 25_30, 30_			
Tch*Period Dummies	None				All				All			
R-Squared	0.6506		0.6401		0.6507		0.6404		0.6505		0.6402	
Observations	688326		492971		688326		492971		688326		492971	

[a]The dependent variable is the log wage. All equations include Cohort, Teacher, Teacher*Cohort, and Period dummies.

[b]The variable ExpX_Y represents a dummy variable for a worker with experience in the interval [X,Y).

[c]Chborn represents the number of children a female worker has ever born.

[d]The row reports the experience intervals for which Tch*Exp dummies are included.

Table 4. Regression estimates of professor quality.[a]

	Perfectly Elastic				Lower Bound			
	Males		Females		Males		Females	
	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
Years of Schooling	0.08	6.67	0.14	5.58	0.08	6.76	0.14	5.74
Exp5_10[b]	0.46	151	0.39	112	0.45	153	0.36	112
Exp10_15[b]	0.69	163	0.47	85	0.68	163	0.44	83
Exp15_20[b]	0.81	166	0.50	79	0.81	166	0.48	76
Exp20_25[b]	0.94	140	0.60	68	0.93	140	0.57	65
Exp25_30[b]	0.99	132	0.64	65	0.98	132	0.61	62
Exp30_[b]	0.97	98	0.68	51	0.96	98	0.63	48
Chborn[c]	.	.	-0.07	-66	.	.	-0.07	-66
Tch*Chborn[c]	.	.	0.03	12	.	.	0.02	11
Prf*Chborn[c]	.	.	0.02	1.85	.	.	0.01	1.74
Tch*Exp Dummies[d]	All				10_15, 15_20, 20_25, 25_30, 30_			
Prf*Exp Dummies[d]	All				5_10, 10_15, 15_20, 20_25, 25_			
Tch*Period Dummies	None				All			
Prf*Period Dummies	None				All			
R-Squared	0.6517		0.6411		0.6516		0.6411	
Observations	688805		493395		688805		493395	

[a]The dependent variable is the log wage. All equations include Teacher and Professor dummies, Teacher*Cohort dummies, Professor*Cohort dummies, Cohort, and Period dummies.

[b]The variable ExpX_Y is one for a worker with experience in [X,Y).

[c]Chborn represents the number of children a female worker has ever born.

[d]The row reports the experience intervals for which Tch*Exp dummies are included.