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Oliver Nikutowski:

Accelerated Technological Progress - An Explanation for Wage Dispersion and a Possible Solution to the Productivity Paradox

Accelerated Technological Progress - An Explanation for Wage Dispersion and a Possible Solution to the Productivity Paradox

Oliver Nikutowski*

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Abstract

Due to scarcity considerations an increase in the supply of college graduates should reduce the premium for this kind of qualification. Therefore it seems quite contradictory that a tremendous educational expansion in the USA is accompanied by rising wage dispersion (overall and between educational groups). A second seemingly paradox development, which occured simultaneously, is the reduction of the total factor productivity growth during the emergence of the computerage - the so called *productivity paradox*.

This contribution offers a simple unified solution to both of these puzzles and explains the educational expansion by assuming accelerated technological progress: An increase in the speed of technological progress raises the economic value of prospective periods and therefore works in favor of time-consuming higher qualifications. The resulting educational expansion firstly goes along with a composition effect which leads to wage dispersion. Secondly the additional absence from the labor market of some more able individuals, due to the longer qualification, as well as an increasing share of individuals who choose a less productive qualification may lead to a transitory slowdown of the productivity growth rate.

1 Introduction

The educational expansion is a widespread phenomenon which takes place in almost all industrialized and developing economies since a couple of decades. In the USA the number and the share of college graduates increased more or less continously at least since the 1940ies (see e.g. AUTOR, KATZ AND KRUEGER, 1998). From the market perspective one would expect such a development to lead to a reduction of the college premium because of the decreased scarcity of college workers. But after a decade of wage compression in the 1940ies the distribution of wages in the USA for men as well as for women began to become more unequal - albeit slowly at first. Figure 1 illustrates the more pronounced increase of the wage dispersion since the 1970ies by showing the development of the first, fifth and ninth decentile of the wage distribution among fulltime working men in the USA. Although the college premium behaved more cyclically than e.g. the D9-D1-Ratio, its general upward sloping trend is one of the most important contributors to the overall wage dispersion[1].

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[1] In general one distinguishes between price, composition and residual components which together determine the development of the wage distribution over time. One of the most often used decomposition techniques is the one by JUHN, MURPHY AND PIERCE (1993). Some more recent techniques stem from DINARDO, FORTIN AND LEMIEUX (1996), MACHADO AND MATA (2005) and AUTOR, KATZ AND KEARNEY (2005). The college and the experience premium are the most important price components.
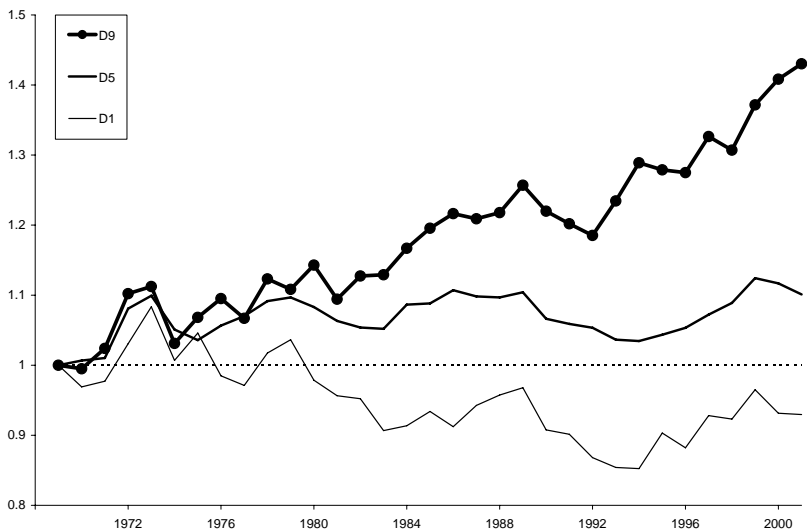
Figure 1: The development of the first (D1), the fifth (D5) and the ninth (D9) decentile of the US wage distribution among fulltime working men since 1969; Source: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplements (own calculations based on Table P-38 and Table IE-2)

Many explanations for the increased U.S. wage dispersion were proposed. Four of the most prominent candidates are i) the real reduction of minimum wages since the late 1960ies, ii) the decreased union density since the 1970ies, iii) the increased market integration with relatively low qualified economies especially since the 1970ies and iv) the increased immigration of less qualified since the 1980ies[2]. In sharp contrast to what the public debate often suggests, the influence of the domestic forces seems to be of much greater influence than that of immigration and globalization[3]. Anyway, following medium estimations, even all four explanations taken together leave a major part of the overall rise in wage dispersion unexplained[4]. Therefore, increased demand for higher qualifications due to technological change became the prime candidate for explaining this remaining share.

In general the technological approaches can be divided into two major categories: theories of a continous skill-biased technological change and theories of accelerated technological progress favoring higher skills. Because of the residual character of nearly all technological explanations it seems quite difficult to opt for one of these two approaches on empirical grounds (if at all). But at least there is some suggestive empirical evidence in favor of the latter hypothesis.

The diffusion of computers at the workplace since the 1970ies, a growing premium for computer skills from that time on and a superior increase in the demand for high skilled workers in computerized industries in the 1970ies and 1980ies - a time in which almost all industries increased their skill intensity - seem to support the view of an increased speed of technological progress since the 1970ies. Perhaps even more compelling for this hypothesis are studies in which it is shown that equipment capital seems to be of relatively stronger complementarity to higher skills and that an accelerating

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[2] This timing is a rough and suggestive approximation. For a more detailed presentation see e.g. NIKUTOWSKI (2007).

[3] See e.g. KRUGMAN AND LAWRENCE (1993) or TOPEL (1997).

[4] For the influence of the real reductions of the minimum wage see e.g. BLACKBURN, BLOOM AND FREEMAN (1990), HORRIGAN AND MINCY (1993), MISHEL AND BERNSTEIN (1994), CARD AND KRUEGER (1995), DINARDO, FORTIN AND LEMIEUX (1996), or TEULING (2003). For the influence of the reduced union density see particularly CARD, LEMIEUX AND RIDDELL (2003). For the influence of immigration see e.g. GROSSMAN (1982), CARD (1990), ALTONJI AND CARD (1991), LALONDE AND TOPEL (1991), BORJAS, FREEMAN AND KATZ (1997), or BORJAS (1999). For the influence of globalization see e.g. BORJAS, FREEMAN AND KATZ (1992), KATZ AND MURPHY (1992), LAWRENCE ET AL. (1993), KRUGMAN AND LAWRENCE (1993), FEENSTRA AND HANSON (1995), or SLAUGHTER (2000).

decline in the relative price of this kind of capital can be observed since the 1970ies. Additionally, estimations of the elasticity of substitution between high and low skilled within an assumed one sector CES-type economy are only consistent with the observed educational expansion and with the observed degree of wage dispersion if the speed of a skill-biased technological change had increased since 1970. Furthermore, it is argued that the increased share of the residual or within group inequality since the 1970ies may at least in part be interpreted as a rise in the price for unobserved skills and therefore may reflect accelerated technological progress favoring these skills[5].

No matter how convincingly these observations may point to accelerated technological progress, another stylized fact appears highly contradictive - the productivity slowdown since the late 1960ies. Following AGHION AND HOWITT (2005) the (hodrick-prescott-filtered) growth rate of the total factor productivity fluctuates around two per cent between the early 1950ies and the mid 1960ies. Thereafter it began to decrease and came close to zero in the mid 1970ies. Since then it has risen - slowly but steadily - but has only reached its initial level of two per cent at the turn of the millennium. The simultaneous emergence of computerization and the invention of lots of new products, services and technologies on the one hand and the productivity slowdown on the other hand is often referred to as the *productivity paradox*[6].

In the following I present a simple model, in which accelerated technological progress explains why the educational expansion may have occured, why it went along with wage dispersion between educational groups and how a transitory productivity slowdown fits into the picture. The core mechanism bears on the fact that higher education is more time-consuming: By increasing the productivity of prospective periods, accelerated technological progess works in favor of the more time-consuming qualification and leads to increased wage dispersion due to a composition effect - while the additional absence from the labor market of some more able individuals, due to longer education, as well as an increasing share of individuals who choose a less productive qualification may explain the productivity paradox.

The next section describes the model, its basic assumptions and the comparative statics of accelerated technological progress. The third section offers some simulations which reconstruct the US experiences since the 1970ies. The fourth section discusses in short some additional empirical and theoretical considerations before a final section concludes.

2 The Model

Generations, Ability Distribution and Educational Choice

To capture the dynamic element of increasing wage dispersion a two generation OLG model is assumed. That is, in every period t the economy is populated by one young and one old generation - in every period a new generation emerges, the old leaves and the young becomes the old. It is assumed that all generations are equal in their economically relevant characteristics including their size. Therefore the time index is suppressed subsequently if not essential for understanding. Every generation consists of a continuum of individuals with mass one, who only differ in their innate ability. More specifically an individual ability $a_i > 0$ is assumed, which is equally distributed among the interval $[\underline{a}; \overline{a}]$ in every generation. The only decision an individual has to make occurs in its first period and concerns the educational choice $e_i \in \{H; L\}$: either one chooses to become a college graduate, $e_i = H$, or one becomes a non-college worker, $e_i = L$. The later on discussed cost-benefit-structure ensures, that the more able individuals have a higher college affinity. That is, only individuals with an ability above a critical value $a^* \in [\underline{a}; \overline{a}]$ decide to become college graduates:

$$e_i^* = \left\{ \begin{array}{l} H, \text{ für } a_i \geq a^* \\ L, \text{ für } a_i < a^* \end{array} \right. . \tag{1}$$

Correspondingly the college share, α, is given by

$$\alpha = \frac{\overline{a} - a^*}{\overline{a} - \underline{a}}. \tag{2}$$

The average ability of college and non-college workers follow as

$$
\begin{align}
a_L &= 0,5 \cdot (\overline{a} + \underline{a}) - 0,5 \cdot \alpha \cdot (\overline{a} - \underline{a}) \tag{3} \\
a_H &= \overline{a} - 0,5 \cdot \alpha \cdot (\overline{a} - \underline{a}). \tag{4}
\end{align}
$$

Productivity, Wages and Educational Signaling

As KATZ AND AUTOR (1999, p. 1465) put it, one of the relatively timeless qualitative features of the wage structure is the steeper wage profile of college graduates compared to that of non-college workers. Figure 2 illustrates the meaning of such a steeper wage profile by showing the stylized development of the income of college and non college workers over time. Essentially figure 2 reflects, that a relatively bigger share of the income of college workers is earned in later periods as result of a former period of investment. To capture this regularity we make the simplifying assumption, that individuals who decide to become college workers are productive only in their second period, while non-college workers participate in the production process in both periods (correspondingly the college education in the following is also referred to as off-the-job training and the non-college education as on-the-job training). Further it is assumed that there is a single good y in the economy, which price is normalized to one. The individual productivity $y_{i,e,p,t}$ reflects the individual output of this single good and depends on the innate ability $a_i \in [\underline{a}; \overline{a}]$, the educational choice $e_i \in \{H; L\}$, the seniority $p \in \{1; 2\}$ and the state of the art τ at time t. More precisely it is assumed

$$
\begin{align}
y_{i,L,1,t} &= \tau_t \cdot a_i \tag{5} \\
y_{i,L,2,t+1} &= \tau_{t+1} \cdot l \cdot a_i \tag{6} \\
y_{i,H,1,t} &= 0 \tag{7} \\
y_{i,H,2,t+1} &= \tau_{t+1} \cdot h \cdot a_i, \tag{8}
\end{align}
$$

where $l, h > 1$ represent the growth rates of the individual productivity due to on-the-job and off-the-job training. The multiplicative connection between these training parameters and the individual ability a_i expresses that college education leads to a higher absolute productivity increase for the more able individuals, while it leaves the relative productivity advance unchanged. That is, the productivity relation of two individuals is independent of the educational choice as long as both individuals decide in favor of the same qualification. The alternative formulation of an additive educational component seems less adequate, because this would characterize education as an equalizing moment per se (see e.g. the discussion in BOOTH AND ZOEGA, 2000). An analogous argument can be made for the multiplicative formulation of the technological parameter τ_t.

In our model technological progress is parameterized as an exogenous increase in the general productivity level τ :

$$\tau_{t+1} = s_{t+1} \cdot \tau_t, \tag{9}$$

where s_{t+1} reflects the speed of technological progess (so that $A_{t+1} = s_{t+1}/s_t - 1$ defines the acceleration rate of technological progress).

With observable individual productivity $y_{i,e,p,t}$ all individuals would be paid according to their marginal product and the training incentives would be efficient. Deviating from this we assume, that firms can only observe the educational status and the age of the individuals. Furthermore we assume
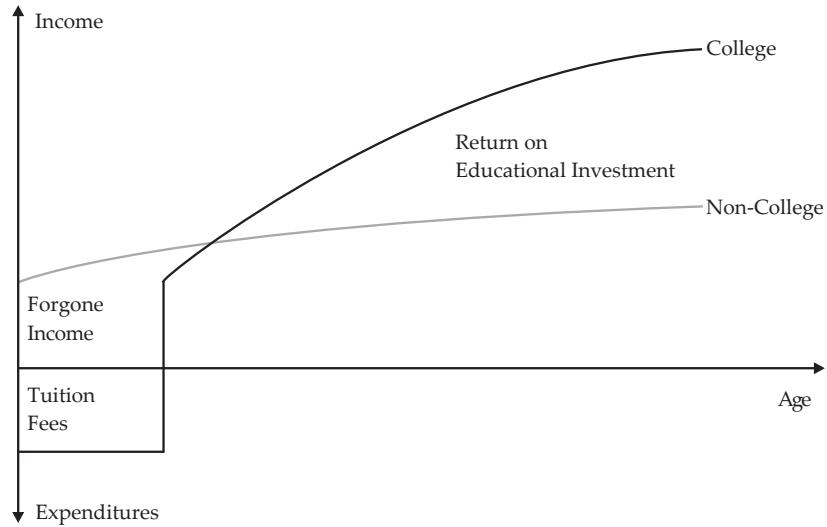
Figure 2: Stylized income profiles of college and non-college workers (an akin illustration can be found in EHRENBERG AND SMITH, 1994)

that there is no other signaling chanel than the educational choice to produce credible information on the individual productivity. Consequently wages are exclusively conditioned on the age, the qualification and the technological status quo. Except for this intransperancy, labor markets are assumed to be competitive, such that the market generates the following pooling wages

$$w_{L,1,t} = \tau_t \cdot a_L \tag{10}$$

$$w_{L,2,t+1} = \tau_{t+1} \cdot l \cdot a_L \tag{11}$$

$$w_{H,1,t} = 0 \tag{12}$$

$$w_{H,2,t+1} = \tau_{t+1} \cdot h \cdot a_H, \tag{13}$$

where a_L and a_H represent the public information on the average ability within both qualification groups. Such a specific wage mechanism asks for some additional explanations.

From a technical point of view the above wage schedule may be justified by the existence of two different technologies which are compatible only with one kind of qualification. This would explain why the productivity is measured on different educational levels. In addition, to justify pooling wages within educational groups, prohibitive high screening costs with respect to the individual productivity have to be assumed. These rather strong assumptions are made to open an *educational signaling chanel* which may explain real wage reductions for the low qualified as they have been observed since the 1970ies (see figure 1) and which gives rise to interesting policy implications as well. But even with marginal product remuneration the subsequently presented mechanism leads to wage dispersion and enables accelerated technological progress to lead to a temporary productivity slowdown.

To establish the signaling effect it would have been sufficient to assume that wages depend in part on the average ability of the workforce. This assumption, however, appears barely restrictive but is in line with the observation of wage compression within occupational (see e.g. FRANK, 1984) and within educational groups (see e.g. MOURRE, 2005). The literature also offers many theoretical explanations for wage compression: An advantage of group performance pay and of compressed wage structures within firms is the cost reduction due to lower *influence activity* (MILGROM AND ROBERTS, 1992) and *sabotage* (LAZEAR, 1989) of the workforce. The fact that the individual satisfaction with the wage one gets depends on what people with the same occupational and educational background earn (FREY AND BENZ, 2001), can also encourage wage compression. Furthermore it is often argued that

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wage compression meets the fairness-preferences of the workforce, increases cooperation, and therefore leads to higher productivity (LEVINE, 1991). Perhaps the most compelling argument in favor of group performance pay among educational groups is, that this remuneration scheme induces beneficial mutual monitoring within the workforce and therefore may enhance the overall performance (KANDEL AND LAZEAR, 1992). At least it seems reasonable to assume that more homogeneous employees have an informational advantage with respect to their colleagues' efforts.

The Cost-Benefit-Structure

More important for our model - than pooling wages - is the already indicated assumption that in every single generation there is no on-the-job trained worker who has a higher abiltiy than any college worker. That is, we assume that the more able an individual is, the higher is his college affinity. There are at least three theoretical justifications for this quite intuitive assumption: Firstly a higher ability may not only reflect a higher productivity, but may also go along with a higher learning aptitude and therefore with higher returns on human capital investments. Secondly more able people may simply prefer higher education or the handling of more abstract tasks, which may require this kind of education. Following the very detailed empirical analysis of HECKMAN, LOCHNER AND TODD (2005) there seems to be strong evidence in favor of this second motive. They come to the conclusion (p. 121) that

> "Psychic costs play a very important role. More able people have lower psychic costs of attending college."

Also the third consideration may be subsumed under the label of "psychic costs": A higher time preference rate of the less able individuals together with a costly transfer of tomorow's income into today's consumption (due to a higher interest rate on borrowing than on lending) should lead to a higher college affinity of more able individuals (figure 3 illustrates this argument for two individuals with different abilities $\bar{a} > \underline{a}$).
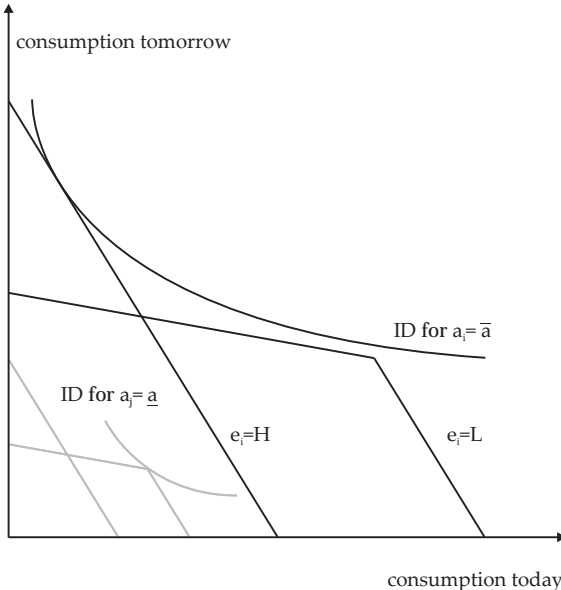

Figure 3: A negative correlation of ability and education costs due to i) imperfect capital markets and ii) higher time preference rates for the less able individuals. The kinked budget lines refer to on-the-job training and reflect higher interest rates on borrowing than on lending.

Instead of formalizing one of these arguments explicitly, the higher college afinity of the more able individuals is captured by assuming a discountfactor $c(\alpha)$ in the utility function of the marginal agent:

$$U_e(\alpha) = \begin{cases} W_L(\alpha), & \text{if} \quad e = L \\ c(\alpha) \cdot W_H(\alpha), & \text{if} \quad e = H \end{cases}, \tag{14}$$

where W_L and W_H represent the present value of the life time income of the low and the high qualified and where the properties of the discountfunction $c(\alpha)$

$$c'(\alpha) < 0; \quad \lim_{\alpha \to 0} c(\alpha) = \infty; \quad c(1) = 0$$

ensure that the share of college workers, α, only consists of the most able individuals. To keep the notation as easy as possible, not only the time preference rate but also the interest rate is assumed to be zero. With $(9) - (13)$ this implies

$$W_L = (1 + s \cdot l) \cdot a_L \cdot \tau_t \tag{15}$$
$$W_H = s \cdot h \cdot a_H \cdot \tau_t. \tag{16}$$

Equilibrium and Welfare Analysis

The setup discussed so far already allows for some equilibrium considerations and welfare analysis. An equilibrium college share, $\alpha^\star$, is reached, when everybody's behavior is rational given the decision of all other agents. That is, the marginal agent has to be indifferent between both kind of qualifications:

$$U_H(\alpha^*) = U_L(\alpha^*)$$
$$\Leftrightarrow$$
$$s \cdot h \cdot \tau_t \cdot a_H(\alpha^*) \cdot c(\alpha^*) = (1 + s \cdot l) \cdot \tau_t \cdot a_L(\alpha^*). \tag{17}$$

Equation (17) potentially defines multiple equilibria, but the properties of the discountfunction $c(\alpha)$ eliminate corner solutions and force at least one interior and stable solution $0 < \alpha^\star < 1$ to exist[7]. Stability requires $\frac{\partial U_H}{\partial \alpha} < \frac{\partial U_L}{\partial \alpha}$ in the point of intersection $U_H(\alpha^*) = U_L(\alpha^*)$. Otherwise, small deviations from α^* would lead away from the equilibrium. Due to $U_H(\alpha = 1) = 0$, $\lim_{\alpha \to 0} U_H = \infty$, $U_L(\alpha = 1) > 0$, $U_L(\alpha = 0) < \infty$ and due to the assumption of steady differentiability of U_L and U_H at least one point of intersection $U_H(\alpha^*) = U_L(\alpha^*)$ with this property exists. The existence of further equilibria first of all depends on the functional form of the discountfunction.

But even without additional assumptions on $c(\alpha)$ it is easy to see that every equilibrium college share α^* is inefficiently high. To show this we first calculate the socially optimal college share α^S: If wages would equal the marginal productivity the educational choice would be undistorted. The present value of the lifetime income would exclusively depend on the individual productivity:

$$W_L = y_{i,L,1,t} + y_{i,L,2,t+1} \tag{18}$$
$$W_H = y_{i,H,2,t+1}. \tag{19}$$

Together with (5) - (9), (14), (18) and (19) the equilibrium condition $U_H(\alpha^S) = U_L(\alpha^S)$ implicitly defines the socially optimal college share:

$$s \cdot h \cdot \tau_t \cdot c(\alpha^S) = (1 + s \cdot l) \cdot \tau_t. \tag{20}$$

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[7] The convexity of the discountfunction would ensure uniqueness of the interior stable solution. In the following illustrations this case is assumed, but all subsequent conclusions refer to the more the general case.

From (17) and (20) we get

$$\frac{c\left(\alpha^{*}\right)}{c\left(\alpha^{S}\right)} \;\; = \;\; \frac{a_{L}\left(\alpha^{*}\right)}{a_{H}\left(\alpha^{*}\right)} < 1 \tag{21}$$

implying

$$\alpha^{*} > \alpha^{S}. \tag{22}$$

The intuition to this result is simple: Due to average wages individuals with an inferior ability in each group exert a negative externality on those individuals with a superior ability and vice versa. This leads to a distortion in favor of the college degree, because by choosing this kind of qualification one disposes of the negative externality of the least able. Additionally those high qualified with an ability below the average are subsidized by the most able. Therefore the high qualified with the lowest ability decide to become college workers not because it pays for itself, but because of this additional distortions.

This result can be illustrated graphically by rearranging (17) to

$$\frac{W_{H}}{W_{L}} = \frac{1}{c\left(\alpha\right)}. \tag{23}$$

The right hand side reflects the cost factor or the utility discount connected with the college education, while the left hand side of the equation corresponds to the *realized* monetary advantage of being a college worker. As long as $\frac{W_{H}}{W_{L}} \geq \frac{1}{c(\alpha)}$ the marginal agent will favor off-the-job training. The *socially relevant* return on education, $\frac{y_{i,H,1,t}+y_{i,H,2,t+1}}{y_{i,L,1,t}+y_{i,L,2,t+1}}$, equals $\frac{s \cdot h}{1+s \cdot l}$ and is lower than the realized return $\frac{W_{H}}{W_{L}}$, which explains the inefficient high college share (see figure 4). Tution fees or progressive taxes appear as natural devices to overcome this distortion.
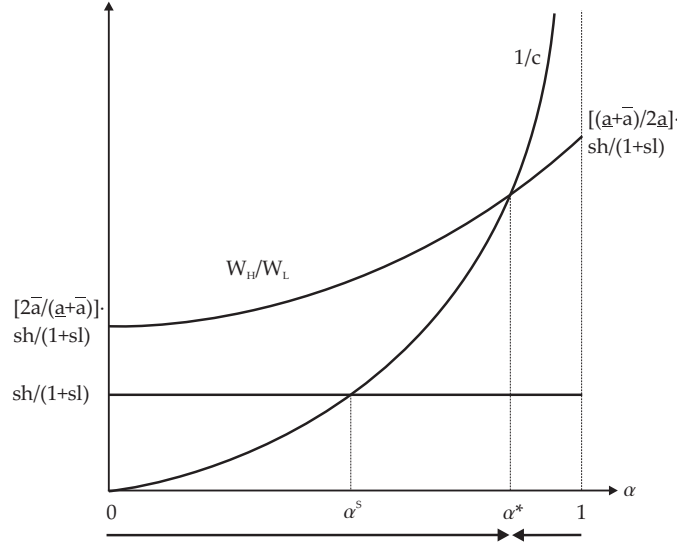

Figure 4: Realized and socially optimal college share

Comparative Statics of Accelerated Technological Progress

Given the equilibrium considerations of the last section the consequences of accelerated technological progress can be calculated. Implicit differentiation of (17) allows to evaluate the influence of increased speed of technological progress s on the college share α:
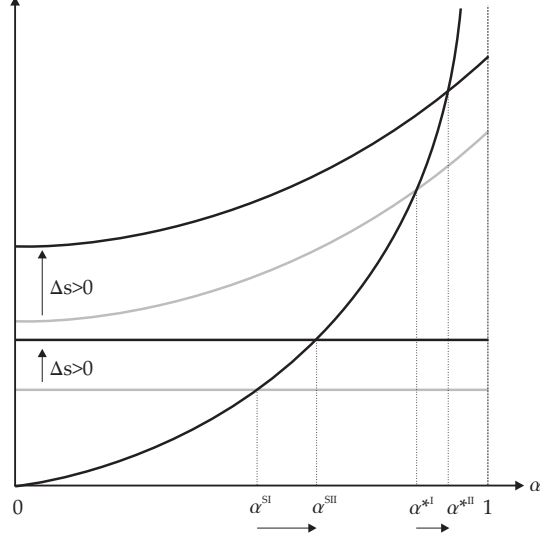
Figure 5: Accelerated technological progress increases the realized and the social college share

$$\frac{\partial \alpha^*}{\partial s} = -\frac{\frac{\partial U_H}{\partial s} - \frac{\partial U_L}{\partial s}}{\frac{\partial U_H}{\partial \alpha^*} - \frac{\partial U_L}{\partial \alpha^*}}. \tag{24}$$

It is easy to show that this expression is positive for all stable equilibria, which implies that the college share increases with the speed of technological progress: From (3), (4), and (10) - (14) follows, that $\frac{\partial U_H}{\partial \alpha^*}, \frac{\partial U_L}{\partial \alpha^*} < 0$. Stability requires $\frac{\partial U_H}{\partial \alpha} < \frac{\partial U_L}{\partial \alpha}$, so that it is only left to show, that $\frac{\partial U_H}{\partial s} - \frac{\partial U_L}{\partial s} > 0$. The equilibrium condition $U_H(\alpha^*) = U_L(\alpha^*)$ can be expressed as

$$sA = B + sC \tag{25}$$

with $A = h \cdot \tau_t \cdot a_H \cdot c > 0$, $B = \tau_t \cdot a_L > 0$ and $C = l \cdot \tau_t \cdot a_L > 0$. Obviously it follows $\frac{\partial U_H}{\partial s} = A > C = \frac{\partial U_L}{\partial s}$ and consequently $\frac{\partial \alpha^*}{\partial s} > 0$ is true for all stable equilibria. Not only the realized, but also the socially optimal college share increases with the speed of technological progress as follows from $\partial \left(\frac{y_{i,H,1,t} + y_{i,H,2,t+1}}{y_{i,L,1,t} + y_{i,L,2,t+1}} \right) / \partial s > 0$ (see figure 5).

The intuition to this result is again very simple: While on-the-job trained individuals participate in the production process in both periods, off-the-job trained individuals are productive only in the second period. Because technological progress increases the relative importance of prospective periods it works in favor of the more time-consuming college education.

Furthermore accelerated progress increases the dispersion of lifetime incomes $\frac{W_H}{W_L}$ (as figure 5 obviously reflects) as well as the wage dispersion within the second period. To show the latter we define this kind of wage dispersion as $\omega \equiv \frac{w_{H,2,t+1}}{w_{L,2,t+1}} = \frac{h \cdot a_H}{l \cdot a_L}$ which leads to

$$\frac{\partial \omega}{\partial s} = \frac{h}{l} \cdot \left(\frac{\frac{\partial a_L}{\partial \alpha} \cdot \frac{\partial \alpha}{\partial s} \cdot a_L - \frac{\partial a_H}{\partial \alpha} \cdot \frac{\partial \alpha}{\partial s} \cdot a_H}{(a_L)^2} \right).$$

Due to equations (3) and (4) we know that $\frac{\partial a_L}{\partial \alpha} = \frac{\partial a_H}{\partial \alpha} < 0$, which directly gives

$$\frac{\partial \omega}{\partial s} = \frac{h}{l} \cdot \left(\frac{\frac{\partial a_L}{\partial \alpha} \cdot \frac{\partial \alpha}{\partial s} \cdot (a_L - a_H)}{(a_L)^2} \right) > 0. \tag{26}$$

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A composition effect explains this result: The increased college share due to accelerated technological progress reflects that the former most able on-the-job trained workers now decide to become off-the-job trained college workers. Therefore an increase in the speed of technological progress decreases the average ability in both qualification groups. Although (or perhaps more appropriate *because*) this reduction of the average ability is identical in both qualification groups (compare equations (3) and (4) which give $\frac{\partial a_L}{\partial \alpha} = \frac{\partial a_H}{\partial \alpha} < 0$ and $a_H - a_L = \frac{1}{2}(\bar{a} - \underline{a}) = const.$ correspondingly), its relative importance is higher for the group of non-college workers - because of their general lower (average) ability - and therefore leads to wage dispersion.

3 Reconstructing the US experiences

Our model not only offers a possible explanation for the increased share of college workers and for the increased U.S. wage dispersion, but is also consistent with the productivity slowdown and the real wage reductions at the lower end of the wage distribution since the 1970ies.

There are two effects which may explain how accelerated technological progress, which purely increases the productivity of both types of qualification, may lead to a transitory reduction of the productivity growth rate[8]: Firstly an increase in the college share may result in additional first-period-absence from the labor market of individuals whose productivity would have been above average if they had decided to be non-college workers - that is, if they had chosen to be productive in the first period already. Secondly off-the-job training may be less productive than on-the-job training ($h < l$). In this case an increase in the share of college workers tends to reduce the average productivity also in the second period. If one or both of these effects are strong enough, an increase in the speed of technological progress leads to a transitory productivity slowdown. Additionally the assumption of wage compression within educational groups allows for real wage reductions on an individual level despite the general increasing productivity due to technological progress[9].

The following simulation illustrates these effects simultaneously and thereby reconstructs the US experiences qualitatively within a time horizon of nine periods ($t \in [1;9]$). We assume rational expectations[10], use $\underline{a} = 0,01$; $\bar{a} = 1$; $h = 1,2$ and $l = 1,7$ as parameter constellation, and apply $c = 1 - 0,635 \cdot \exp\left\{1 - \alpha^{-1}\right\}$ as discontfunction for the marginal agent. Furthermore we assume a constant speed of technological progress in the first four periods, $s_t = 1,01$ for $t \in [1;4]$, followed by two periods of (exogenous) accelerated technological progress, $s_5 = 1,012$ and $s_6 = 1,014$, followed by constant technological progress at the higher level thereafter, $s_t = 1,014$ for $t \in [7;9]$. The black squares in the top left of figure 5 reflect this technological timing. Due to rational expectations the accelerating technological progress in the fifth period increases the share of individuals who choose the college education in the fourth period (from less than 41% to over 42% - as can be seen in the bottom left of figure 5, where the development of the college share is illustrated for the periods 2 to 6). Correspondingly the acceleration in the sixth period explains the increase of the college share in the fifth period to over 45%. From this period on the college share stays constant because s_t is assumed to stay constant afterwards.

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[8] Within the framework of our model the relative change of the average productivity (of all active workers of one period) over time appears as the appropriate measure for the productivity growth rate.

[9] The observed real wage reductions for the less qualified since the 1970ies appear puzzling from the perspective of the conventional skill-biased technological change approach: Assuming a CES production function $Y = [(l \cdot L)^\rho (h \cdot L)^\rho]^{\frac{1}{\rho}}$, where H and L reflect the share of high and low skilled (or college and non-college) workers and where h and l reflect the corresponding specific productivity parameters, a skill-biased increase in the technological progress, $\triangle h > 0$, leads to wage dispersion, but also increases the real wages of the less qualified (see e.g. ACEMOGLU, 2002). Because in our model the educational expansion reduces the average ability in both qualification groups, wage reductions are possible on average even with marginal productivity remuneration . But to arrive at real wage losses on an individual level one at least needs some degree of wage compression.

[10] This assumption seems appropriate for the pure mechanical illustration of the described effects, while some kind of adaptive expectations may be more realistic.
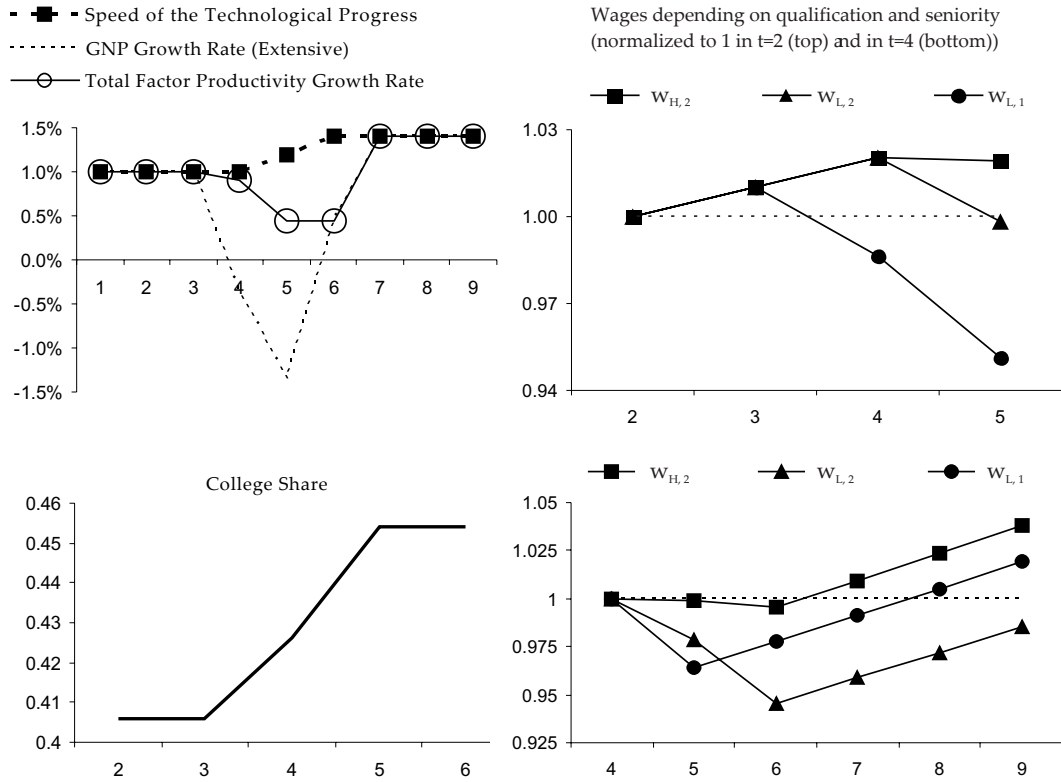
Figure 6: Reconstructing the US experiences: accelerated technological progress, productivity slow-down, educational expansion, wage dispersion and real wage losses for the low qualified

In our example this not only leads to a reduced productivity growth rate (illustrated by the white circles in the top left of figure 5), but also leads to an overall reduction of output in period 4 and 5 (illustrated by the dashed line in the top left of figure 5). This development can be explained by the above described effects: In $t = 4$ the productivity growth rate decreases only slightly, because relatively few additional individuals decide to become college workers and the productivity of these individuals would have been only slightly above the average productivity of the economy had they chosen to be productive in their first period already. In $t = 5$ the productivity slowdown is more pronounced, because i) again a higher additional share of above average productive individuals decided to be trained off-the-job and ii) a bigger share of the now elderly is less productive than they could have been had they decided in favor of the non-college education (because of $h < l$). The latter effect also explains why the productivity growth rate keeps roughly unchanged from $t = 5$ to $t = 6$: The increased share of college workers reduces the productivity growth in the sixth period. The first effect - the additional absence from the labor market of above average productive individuals due to the longer qualification - does not appear in the sixth period, because the share of the younger generation which decides to become college workers stays constant from period 5 onwards. So in period 4 only the first effect occurs, in period 5 both effects appear, in period 6 only the second effect is valid and from period 7 onwards both effects vanish leading to a productivity growth rate which equals the speed of technological progress (as was already the case in periods 1 to 3).

Beside the educational expansion and the reduced productivity growth rate our example also re-produces the US wage dynamics since the 1970ies (as shown in figure 1): While the wages of both educational groups rise with the rate of technological progress from period 2 to 3 the real wage is reduced for the non-college workers from period 3 to 4. This and the following developments are il-lustrated in the top right of figure 5, where $w_{H,2}$ stands for the wage of the elderly college workers, where $w_{L,2}$ stands for the wage of the elderly non-college workers and where $w_{L,1}$ stands for the wage

of the young non-college workers. All wages are normalized to 1 in period 2. The wage reduction for the young non-college workers in period 4 reflects a decreased average ability due to the increased college share of the young generation - caused by the technological acceleration in period 5. The wages of the old generation still increase with the rate of technological progress from period 3 to 4 because the college share of this generation is unaffected by the technological acceleration in period 5. The second period of technological acceleration (in $t = 6$) leads to a further increase of the college share in period 5 and therefore explains why the wages of the young non-college workers decline again. But also the wages of the older generation decrease and disperse in period 5 due to the increased college share in the previous period. Taken together, our example illustrates accelerated technological progress in periods 5 and 6, which leads to an educational expansion in periods 4 and 5, which goes along with a reduced productivity growth rate in period 4 to 6 and which leads to wage dispersion as well as wage reductions in periods 4 and 5.

From period 5 to 6 the wages of the older generation again decline (and disperse) due to the educational expansion, while the wages of the young non-college workers begin to rise in period 6 (with the rate of technological progress - compare the bottom right of figure 5). The latter happens because the college share of the young generation keeps constant from period 5 to 6 due to an unchanged speed of technological progress from period 6 to 7. Because the speed of technological progress also remains constant in the subsequent periods all wages increase equally with the rate of technological progress from the 6th period onwards.

4 Discussion

The above mechanism has particularly shown how accelerated technological progress may have contributed to (or even caused) the educational expansion, how this may have led to increased wage dispersion and that this development is consistent with a transitory productivity slowdown. At last some empirical and theoretical considerations should be addressed:

- **General Equilibrium**: Within a less partial framework than that presented, the appearance of the described effects should be expected to depend on some elasticities (e.g. within a one sector economy of the CES type the elasticity of substition would be a critical magnitude and assuming a two sector model would turn the relative price elasticity of demand into a crucial parameter).

- **Exogenous vs. endogenous technological progress**: The driving force of our model is an exogenous acceleration of the technological progress. As presented in the introduction there is some empirical evidence in favor of such an assumption. But also the endogenisation of the speed of the technological progress appears barely problematic: A higher college share may be the cause for the rising speed of the technological progress, which by itself gives rise to an increasing college share. Such a loop seems reasonable, but may appear somewhat contradictory to the pure signaling and consumption motive of education in the case of $h < l$.

- **Increased within group (or residual) wage inequality**: The perhaps most critical empirical observation for our model is that a major part of the wage dispersion since the 1970ies is due to an increase in the residual wage inequality (see e.g. KATZ AND MURPHY, 1992, or KATZ, LOVEMAN AND BLANCHFLOWER, 1993). Even in the shrinking group of non-college workers an increase of wage dispersion is observed, which could not be traced back to heterogenous characteristics. According to our model an increasing college share should lead to a more homogenous ability distribution in the group of non-college workers. But to point out that even an increasing college premium may go along with (additional) overeducation, the above model introduced a signaling chanel by assuming perfect wage compression within educational groups. With less perfect wage compression the increased homogeneity of the non-college workers would have led to declining within group wage inequality - that is the opposite of the described observation.

At least two arguments could be made against this kind of critique. Firstly, it is not yet clear if a theory for wage dispersion between educational groups also needs to explain the increased within group inequality: As is well known, the within group inequality set in earlier than the wage dispersion between groups did. Therefore e.g. KATZ, LOVEMAN AND BANCHFLOWER (1993, p. 36) come to the conclusion "that the general rise in within-group inequality and the rise in education premiums over the period 1963-87 are actually somewhat distinct phenomena." Secondly, empirical studies show that the overall wage dispersion does not seem to be caused by a single factor. The real reduction of the minimum wage(s) for example appears as one important contributor, which also may explain the rising within-group inequality of the low qualified.

5   Conclusion

In the last few decades the educational expansion should have led to wage dispersion in many economies due to a decreased scarcity of college workers. Especially in the USA quite the opposite happened: The overall wage inequality as well as the wage dispersion between educational groups has increased enormously since the 1970ies. Only a part of this development is explained by real minimum wage reductions, a shrinking union density, increased immigration of low qualified and increased market integration with less developed countries. Skill-biased technological change is one of the prime candidates for explaining the remaining share.

This contribution offered a special kind of skill-biased change hypothesis which stresses that accelerating technological progress increases the relative importance of prospective periods and therefore works in favor of the more time-consuming college education. It is shown that an increase of the speed of technological progess is not only a possible explanation for the educational expansion, but that it gives rise to dispersing life time incomes as well as to wage dispersion between educational groups. The additional absence from the labor market of some above average productive college workers as well as an increasing share of individuals who choose the less productive education also explains how accelerating technological progress may go along with a reduced productivity growth rate - the so called productivity paradox.

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