ABILITY-BIASED TECHNOLOGICAL TRANSITION, WAGE INEQUALITY, AND ECONOMIC GROWTH*

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This paper develops a growth model characterized by ability-biased technological transition in which the evolution of technology, education attainment, and wage inequality is consistent with the observed pattern in the United States and other advanced countries over the past several decades. It argues that an increase in the rate of technological progress raises the return to ability and simultaneously generates an increase in wage inequality between and within groups of skilled and unskilled workers, an increase in average wages of skilled workers, a temporary decline in average wages of unskilled workers, an increase in education, and a productivity transitory slowdown.

I. INTRODUCTION

In the last two decades the United States, and other advanced countries, has experienced rapid technological progress along with fundamental changes in the pattern of wage inequality. The wage differential *between* skilled and unskilled labor has risen significantly despite the increase in the supply of skilled labor, the wage dispersion *within* the groups of skilled and unskilled labor has widened, and real wages of unskilled labor have declined.[1] The phenomenon of rapid technological change along with a rise in the skill premium, despite an increase in the supply of skilled labor, has recurred in several time intervals in the last century.

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[1] Katz and Murphy {1992} document this pattern of inequality in the United States, and Berman, Bound, and Machin {1998} document this pattern of inequality in the OECD. As to the change in the pace of technological progress, Autor, Katz, and Krueger {1998} show that the pace of relative demand shifts favoring more skilled workers is faster from 1970 to 1996 than from 1940 to 1970. They provide evidence that this reflects an increase in the rate of skill-biased technological change, although their study cannot separate whether this arises from an increase in the overall rate of technological change or from a shift in the direction of technological change.

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Over the period as a whole, however, wage inequality has evolved in a cyclical fashion.[2]

This paper develops a growth model, characterized by *ability-biased* technological transition, which accounts for the fundamental elements that have characterized the evolution of technology, education, and wage inequality in the United States and other advanced countries over the past several decades. The study argues that an increase in the rate of technological change raises the return to ability and generates simultaneously: a rise in the wage inequality between and within groups of skilled and unskilled workers, an increase in the average wage of skilled workers, a temporary decline in the average wage of unskilled workers, an increase in education attainment, and a potential coexistence of rising rates of technological progress and a transitory productivity slowdown that may have been observed in earlier parts of recent decades.

Earlier theoretical attempts to explain the recent empirical regularities have focused on the role of skill-biased technological change and globalization of markets in the increase of the wage differential between skilled and unskilled workers. These theories, however, have treated the groups of skilled and unskilled labor largely as homogeneous labor inputs and have therefore failed to account for the contemporary phenomenon of widening wage inequality within these groups.

The contemporaneous phenomena of persistent increase in the relative wages of skilled workers and the rise in the wage dispersion within the groups of skilled and unskilled workers, suggest that the heterogeneity of ability is central for the analysis of these empirical regularities. Furthermore, the coexistence of rapid technological change and the observed pattern of wage inequality suggests that the nature of the interaction between technological progress and the relative return to ability may provide the resolution for the puzzle as a whole. If rapid technological progress raises the relative return to ability, then wage inequality may rise within as well as across groups, provided that the average level of ability is higher among skilled individuals. In contrast, if technological progress would increase the return to education without affecting the return to ability, individuals with

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[2] Goldin and Katz {1999} and Autor, Katz, and Krueger {1998} show that wage inequality between groups declined in the United States from the 1900s until the 1940s, as well as in the 1970s, and increased in the 1950s, 1960s, 1980s, and 1990s. In the 1970s, however, overall wage inequality expanded.

a lower level of ability would find it beneficial to acquire education, and the ability dispersion would widen among educated individuals and would narrow among the uneducated. The wage inequality among the educated would therefore rise, but counterfactually, wage inequality among the uneducated would decline.

The conjecture regarding the centrality of the positive interaction between technological change and the return to ability for the understanding of the observed pattern of wage inequality is largely consistent with empirical evidence. Bartel and Sicherman {1999} find that the education premium associated with technological change is the result of an increase in demand for the innate ability or other unobservable characteristics of *more*-educated workers in the United States over the period 1979–1993. Murnane, Willett, and Levy {1995} argue that during the 1980s the return to cognitive skills had risen. Finally, Katz and Murphy {1992} and Juhn, Murphy, and Pierce {1993} provide evidence regarding the changing role of observed and unobserved components of skills in the determination of earnings in the United States in the past three decades. Their studies suggest that the premium to unobserved components of skills has increased steadily since 1970, and it preceded the increase in the return to education since 1980.

The relationship between technology and inequality has been the subject of intensive research in the last few years.[3] Galor and Tsiddon {1997}, Greenwood and Yorukoglu {1997}, and Caselli {1999} argue that the increase in the wage inequality *between* skilled and unskilled labor reflects the positive effect of technological revolution on the demand for skilled individuals and thus on the return to skilled labor. Further, Acemoglu {1998} suggests that an exogenous increase in the supply of educated individuals in the 1970s induced the development of a skill-biased production technology which has increased wage inequality. These papers do not focus, however, on the contemporary phenomenon of an increase in the wage inequality *within* groups.[4]

[3] Other recent explanations for the pattern of wage inequality that are not based on technological change include Acemoglu {1999}. In a search model in which the composition of jobs changes endogenously and causes reallocation of capital from unskilled to skilled workers, unemployment and between and within group inequality rises and wages of the unskilled fall.

[4] Galor and Tsiddon {1997} implicitly capture some of the patterns of within group inequality. Caselli {1999} informally suggests a mechanism that may account for some of the recent patterns of within-group inequality. Acemoglu {1998} extends his basic model and argues that in the absence of perfect mapping between education and skills, inequality within education groups increases as

This paper, in contrast, develops a growth model with *endogenous* determination of both technological change and the composition of the labor force in which *ability-biased* technological transition generates patterns of wage inequality that are consistent with those observed in the United States and other advanced countries over the past several decades. The evolution of the economy and its impact on wage inequality is based upon three central elements that appear consistent with empirical evidence. First, an increase in the rate of technological progress raises the rate of return to skills.[5] Second, the increase in the return to skills induces an increase in the supply of educated individuals.[6] Third, an increase in the level of human capital increases the rate of technological progress.[7] These three elements generate a dynamic path characterized by a positive feedback loop that permits a monotonic evolution of the rate of technological progress in a transition to a steady-state equilibrium with perpetual growth. The increase in the return to ability and education that stem from the increase in the rate of technological progress brings about a monotonic rise in wage inequality within as well as between groups along the transition to a steady-state equilibrium.

The supposition that the state of transition brought about by technological change positively affects the rate of return to ability is at the heart of the model.[8] Although the new technological level may reflect in the long run either a skill-biased or skill-saving technological change, it is argued that the transition to the new technological state is mostly skill (ability)-biased in the short run.[9] In particular, it is assumed that the level of technology has

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well. In contrast, Aghion, Howitt, and Violante {1999} focus on within-group inequality rather than on between-group inequality. Moreover, an additional aspect of the recent patterns of inequality, i.e., the decline in the wages of unskilled workers, is captured only by Caselli {1999}.

[5] Goldin and Katz {1998} find evidence for technology-skill complementarity throughout the twentieth century. See Foster and Rosenzweig {1996} for evidence from the Green Revolution in India.

[6] See Freeman {1975}, Mincer {1994}, and Kane {1994}.

[7] This link is commonly used in growth theory. It was first proposed by Nelson and Phelps {1966}. It is supported by empirical evidence (e.g., Doms, Dunne, and Troske {1997}).

[8] This argument is raised in the seminal papers by Nelson and Phelps {1966} and Schultz {1975}. See the recent paper by Rubinstein and Tsiddon {1999} as well.

[9] If technological changes are skill-biased in the long run, then the effect will be enhanced, while if technology is skill-saving, then the effect will be diluted. In the current paper technological transition is ability-(skill)-biased only in the short run, but it may be either skill-biased or unskill-biased in the long run. This mechanism is related to that explored by Acemoglu {1998}, where an increase in the supply of skilled workers causes technologies to be more skill-biased in the long run. Goldin and Katz {1998} provide evidence regarding technology-skill comple-

no effect on the relative demand for skilled workers, whereas a faster *rate of* technological progress raises the relative demand for skilled labor.

Individuals' levels of human capital are determined by their ability and education, as well as by the technological environment. Technological progress is assumed to reduce the adaptability of existing human capital for the new technological environment. Able individuals, however, have a comparative advantage in adapting to the new technology (i.e., their learning cost is smaller). Individuals are subjected to two opposing effects due to technological progress. On the one hand, the level of human capital of each individual is diminished due to the transition from the existing technological state to a superior one—the "erosion effect." On the other hand, each individual operates with a superior level of technology—the "productivity effect." Further, an increase in the rate of technological progress raises the return to skilled labor decreases the threshold level of ability above which individuals would choose to become skilled workers. It increases the number of skilled workers, decreases the number of unskilled workers, and decreases the average ability in both groups. Hence in addition to the "erosion effect" and the "productivity effect," technological progress has a "composition effect."

A sufficiently large increase in the rate of technological progress generates, due to the erosion effect, a slowdown in the growth rate in Total Factor Productivity (TFP) in the short run. However, once the *rate* of technological progress reaches a steady state, the erosion effect is constant, whereas the productivity effect grows at a higher constant rate.

The predictions of the basic model are consistent with the evolution of wage inequality and the number of college graduates in the United States economy over the past several decades. The economy converges to a steady-state equilibrium with a positive growth rate of output per worker supported by a positive endogenous rate of technological progress. In the transition to the steady state, the rate of technological progress increases monotonically, wage inequality within and between groups increases, the average wage of skilled workers increases despite the increase in their number, and the average wage of unskilled workers may decline, despite the decline in their relative supply. The rise in the

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mentarity which is consistent with our short-run view of the skill-bias of technological change as well as the long-run view.

wage dispersion within a group and the rise in wages of skilled workers follows from the rise in the return to ability. The former due to the heterogeneity in ability within a group, and the latter due to the fact that in equilibrium the average level of ability is higher among skilled workers. Further, consistent with the slowdown in the growth of wage inequality in the United States in the 1990s {Autor, Katz, and Krueger 1998}, as the economy converges to the steady-state equilibrium, the rise in the rate of technological progress diminishes, and the increase in the wage inequality subsides.

The introduction of institutional changes into the basic model permits the analysis to be consistent with those episodes in which a decline in wage inequality was associated with an increase in the fraction of skilled individuals in the labor force. In the presence of capital markets imperfections, investment in human capital is suboptimal. If economic development is associated with institutional changes which reduce the effectiveness of imperfections in capital markets (e.g., the high school movement of 1910 to 1940 in the United States and the expansion in financial aid to higher education in the United States from the 1960s to the early 1970s), they may generate a decrease in wage inequality between groups along with an increase in education attainment. In particular, if the decline in the degree of credit market imperfections is sufficiently large, the increase in the supply of skilled workers would dominate the demand effect induced by the increase in the rate of technological change, and wage inequality between skilled and unskilled workers would decrease.

A cyclical evolution of the wage inequality between skilled and unskilled labor, despite the monotonic increase in the supply of skilled labor, would emerge from the effect of growth on institutional changes.[10] The pattern of increased wage inequality due to the acceleration in the rate of technological progress would be interrupted occasionally due to the feedback from growth to capital markets that would increase the supply of skilled workers and temporarily decrease wage inequality between skilled and unskilled labor. This dynamic process would repeat itself and, consistent with empirical evidence, would generate cyclicality in

[10] Galor and Tsiddon {1997}, in contrast, argue that the cyclical evolution of the wage differential between skilled and unskilled workers is due to the cyclical nature of technological progress (i.e., inventions followed by innovations). An alternative mechanism is explored by Eicher {1996}.

the wage differential between skilled and unskilled labor along with a monotonic increase in the number of skilled workers.

II. THE BASIC STRUCTURE OF THE MODEL

Consider a small, open, overlapping-generations economy that operates in a perfectly competitive world where international capital movements are unrestricted and economic activity extends over infinite discrete time. In every period the economy produces a single homogeneous good that can be used for either consumption or investment.[11] The good is produced by physical capital and a composite labor input (measured in efficiency units) that consists of skilled labor and unskilled labor. The supply of all factors of production is endogenously determined. The number of efficiency units of skilled and unskilled labor in every period is determined by occupational choices of the fixed number of individuals within a generation, as well as by the state of technology. The stock of physical capital in every period is given by the sum of the economy's aggregate saving net of international lending.

A. Production of Final Output

Production occurs according to a neoclassical, constant-returns-to-scale, production technology that is subject to technological progress. The output produced at time t, Y_t, is

$$Y_t = F(K_t, A_t H_t) \equiv A_t H_t f(k_t); \qquad k_t \equiv K_t/(A_t H_t), \tag{1}$$

where K_t and H_t are the quantities of physical capital and efficiency units of the composite labor input employed in production at time t, and A_t is the technological level at time t, where A_0 is historically given. $f(k_t)$ is strictly monotonic increasing, strictly concave satisfying the boundary conditions that assure the existence of an interior solution to the producers' profit-maximization problem.

Producers operate in a perfectly competitive environment. Given the wage rate per efficiency unit of labor and the rate of return to capital at time t, w_t, and r_t, respectively, producers choose the level of employment of capital, K_t, and the composite labor input, H_t, so as to maximize profits. The producers' inverse

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[11] The focus on a single industry in this context is justified by empirical evidence which suggests that the increase in demand for skills comes from changes within industries and not between industries {Autor, Katz, and Krueger 1998}.

demand for factors of production is therefore

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(2)\qquad \begin{aligned} r_t &= f'(k_t); \\ w_t &= A_t\{f(k_t) - f'(k_t)k_t\} \equiv A_t w(k_t). \end{aligned}
$$

B. The Internal Structure of the Composite Labor Input

The composite labor input H_t is a weighted sum of the number of efficiency units of skilled labor, h_t, and unskilled labor l_t employed in production at time t:[12]

$$
(3)\qquad H_t = \beta h_t + l_t(1 - \delta g_t),
$$

where $\beta > 1$, and $0 < \delta g_t < 1$ is the reduction in the *aggregate* weight given to efficiency units of unskilled labor due to the rate of technological progress from period $t - 1$ to period t, $g_t \equiv (A_t - A_{t-1})/A_{t-1}$. It is assumed that[13]

$$
(\text{A1})\qquad 0 < g_t < 1.
$$

δ is therefore assumed to be in the open interval (0,1).

This formalization of the effect of an increase in the rate of technological progress on the composite labor input is designed to capture the spirit of the fundamental observation that technological progress is skill-biased in the short run. Whereas the technological level A_t has no effect on the relative demand for skilled workers, the *rate* of technological progress, g_t, determines the relative *demand* for skilled labor. For a given wage ratio, an increase in the rate of technological progress would generate a substitution of skilled for unskilled workers.[14] This is a novel formalization in which the change in the rate of technological

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[12] The introduction of imperfect substitution between skilled and unskilled labor would not change the qualitative analysis. It would, however, make the analysis complex and less transparent.

[13] As will become apparent, Assumption (A1), which places restrictions on the magnitude of the rate of growth, is used as long as technological progress is exogenous. Once technological progress is endogenized, Assumption (A1) is replaced by Assumption (A2) which restricts the magnitude of the exogenous parameter γ.

[14] Formally, technological change erodes the *aggregate* stock of human capital, H_t, although aggregate output may increase due to the productivity effect captured by the rise in the technological parameter A_t. In the absence of changes in the rate of technological progress, skilled and unskilled labor have a constant weight in the composite labor input. A temporary increase in the rate of technological progress, however, temporarily increases the relative weight given to skilled labor and diminishes the aggregate number of efficiency units of labor. As the rate of technological progress returns to the previous state, the aggregate number of efficiency units increases, reflecting the adjustment of labor to the new technological state.

progress endogenously determines the shares of skilled and unskilled labor in production.

C. Factor Prices

Suppose that the world rental-rate is stationary at a level $\bar{r}$. Since the small economy permits unrestricted international lending and borrowing, its rental rate is stationary as well at the rate $\bar{r}$.[15] Namely, $r_t = \bar{r}$. Consequently, the ratio of capital to efficiency units of labor in every period t, k_t, is stationary at a level $f'^{-1}(\bar{r}) \equiv \bar{k}$, and the wage rate per efficiency unit of the composite labor input is $w_t = A_t w(\bar{k}) \equiv \bar{w}A_t$. As follows from (3), each efficiency unit of skilled labor generates β efficiency units of the composite labor input, whereas each efficiency unit of unskilled labor generates $(1 - \delta g_t)$ units of composite labor input. Hence, the wages per efficiency unit of skilled and unskilled labor in period t, w_t^s, and w_t^u, respectively, are

$$\begin{aligned} w_t^s &= \beta \bar{w} A_t; \\ w_t^u &= \bar{w}(1 - \delta g_t)A_t. \end{aligned} \tag{4}$$

D. Individuals

In each period a generation is born. It consists of a continuum of individuals of measure 1. Individuals, within as well as across generations, are identical in their nonaltruistic preferences. They may differ, however, in their cognitive ability and thus in their education and their level of human capital. Ability is distributed uniformly over the unit interval.[16]

Individuals live for two periods. In the first period, individuals who choose to become skilled workers acquire education and work, whereas those who choose to become unskilled workers join the labor force directly. The resulting wage income is allocated between consumption and saving. In the second period, individuals retire consuming their entire savings. Individuals' preferences are defined over consumption in the two periods of their lives.

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[15] The removal of the simplifying assumption of a small open economy with perfect capital mobility would not affect our analysis qualitatively. As will become apparent, occupational choice and wage inequality are independent of the interest rate.

[16] As will become apparent, the qualitative effect of technological change on within-group inequality is independent of the distribution of ability in society as long as the distribution is continuous. The effect on between-group inequality, however, may be sensitive to the choice of distribution.

They are represented by a utility function that is strictly monotonically increasing, strictly quasi concave, and satisfies the conventional boundaries conditions that assure the existence of an interior solution for the utility maximization problem.

Members of generation t face an occupational choice in the first period of their life. Individuals who choose to become skilled workers devote a fraction $0 < \tau < 1$ of their unit time-endowment (in either the form of formal education or on-the-job-training) to the formation of human capital. They supply a fraction $1 - \tau$, of their potential efficiency units of skilled labor earning the competitive market wage w_t^s per efficiency unit of skill supplied. Individuals who choose to become unskilled supply their entire time endowment, earning the competitive market wage w_t^u per efficiency unit of unskilled labor.[17]

Ability, Technological Change, and Human Capital. The level of human capital of skilled and unskilled workers is determined by their ability as well as by the technological environment. Technological progress changes the nature of occupations and reduces the adaptability of existing human capital for the new technological environment. That is, human capital is technology specific, and technological progress that takes the form of creative destruction erodes some of the existing stock of human capital. Therefore, in the presence of technological progress, the applicability of the level of human capital that can be absorbed from the existing technological environment erodes, and individuals devote time (on the job) for learning the new technology.

Consistent with empirical evidence, the time required for learning the new technology diminishes with the level of ability and increases with the rate of technological change.[18] Hence, following the insight of Nelson and Phelps {1966} and Schultz {1975} discussed above, technological progress increases the return to ability. The efficiency units of labor of a member i of generation t depends positively on individual i's ability, a_t^i, negatively on the rate of technological change, g_t, and positively on the complementarity of the rate of technological change and ability.

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[17] In every point in time within a period skilled and unskilled workers are jointly employed. That is, the time cost of education is uniformly distributed over the period.

[18] Bartel and Sicherman {1998} show that at a higher rate of technological change, low skilled nonproduction workers receive significantly more training than high skilled nonproduction workers, and the proportion of individuals receiving training increases.

Suppose that the number of efficiency units of labor that a member i of generation t supplies as an unskilled worker, l_t^i, has a simple linear representation:[19]

$$l_t^i = l(a_t^i, g_t) = 1 - (1 - a_t^i)g_t. \tag{5}$$

The number of efficiency units of unskilled workers is subject to depreciation due to technological progress, and ability lessens the adverse effect of technological change. $\{(1 - a_t^i)g_t\}$ is therefore the fraction of the working time of an unskilled worker devoted to learning the new technology on the job. Individuals who choose to become unskilled workers are endowed with one efficiency unit of labor, regardless of ability. That is, the level of ability of unskilled workers would not be rewarded in a stationary technological environment.

Suppose that the number of efficiency units of labor that a member i of generation t supplies as a skilled worker has a simple linear representation:[20]

$$h_t^i = h(a_t^i, g_t) = (1 - \tau)\{a_t^i - (1 - a_t^i)g_t\}. \tag{6}$$

Individual i's level of human capital depends therefore on two components: a_t^i captures the direct positive effect of ability, whereas $\{(1 - a_t^i)g_t\}$ captures the depreciation due to technological progress.[21] In particular, unlike unskilled workers, the level of ability of skilled workers is rewarded even in a stationary technological environment.

Consistent with Schultz's observations, technological progress complements ability in the formation of human capital. That is, ability lessens the adverse effect of technological change. The higher the rate of technological progress the higher the return to ability. Individuals are subjected to two opposing effects due to technological progress. On the one hand, the potential number of efficiency units of labor is diminished due to the transition from the existing technological state to a superior one—the erosion

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[19] Assumption A1 (i.e., $0 < g_t < 1$) assures that regardless of ability, the number of efficiency units of any individual as an unskilled worker is strictly positive.

[20] As will become apparent, in equilibrium individuals whose ability level would not assure a positive level of efficiency units as skilled workers would choose to become unskilled workers.

[21] $\{(1 - a_t^i)g_t\}/a_t^i$ is the fraction of working time devoted for learning the new technology on the job. As one would expect, this formulation implies that, for a given level of ability, the time cost of unskilled workers is smaller than that of skilled workers.

effect. On the other hand, each individual operates with a superior level of technology—the productivity effect. Moreover, once the *rate* of technological progress reaches a steady state, the erosion effect is constant, whereas the productivity effect and thus wages grow at a constant rate. For the economy as a whole, the productivity effect is dominating, and producers would find it beneficial to adopt the new technology. However, for some individuals the erosion effect may dominate, and their wages would decline due to technological change.[22]

Occupational Choice. Since skilled and unskilled workers coexist in the labor market, additional structure is added to the model so as to assure that in equilibrium the number of skilled and unskilled workers is positive. In particular, the time cost of education τ is required to be compensated by β—the added weight given to skilled workers in the production technology so as to assure that regardless of the rate of technological progress investment in human capital is profitable. Although $\beta(1 - \tau) \geq 1$ would be a sufficient (additional) condition for the existence of skilled workers in the economy, to simplify the exposition it is assumed that $\beta(1 - \tau) = 1$.[23]

A member i of generation t who chooses to become a skilled worker supplies h_t^i efficiency units of skilled labor. Given the wage rate per efficiency unit of skilled labor at time t, w_t^s, the individual's income, $I_t^{i,s}$, is therefore

$$I_t^{i,s} = w_t^s h_t^i = \overline{w}A_t\{a_t^i - (1 - a_t^i)g_t\} \equiv I^s(a_t^i, g_t, A_t), \tag{7}$$

where as depicted in Figure I, $\partial I^s(a_t^i, g_t, A_t)/\partial a_t^i = \overline{w}A_t\,\{1 + g_t\} > 0$, i.e., $I_t^{i,s}$ is an increasing linear function of a_t^i.

Similarly, the income of a member i of generation t who chooses to become an unskilled worker is

$$I_t^{i,u} = w_t^u l_t^i = (1 - \delta g_t)A_t\overline{w}\{1 - (1 - a_t^i)g_t\} \equiv I^u(a_t^i, g_t, A_t), \tag{8}$$

where, as depicted in Figure I, $\partial I^u(a_t^i, g_t, A_t)/\partial a_t^i = (1 - \delta g_t, A_t)\,\overline{w}g_t > 0$; i.e., $I_t^{i,u}$ is an increasing linear function of a_t^i.

As stated earlier, individuals' utility function is defined over first- and second-period consumption, and is strictly increasing in

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[22] The underlying assumption is that the new technology replaces the old technology. This outcome can be endogenized in several ways (e.g., intertemporal consideration of firms and cost of technology adoption that is convex in the distance of the technological frontier).

[23] The existence of unskilled workers in the economy follows directly from (A1), (5), and (6), for any $\beta > 0$.

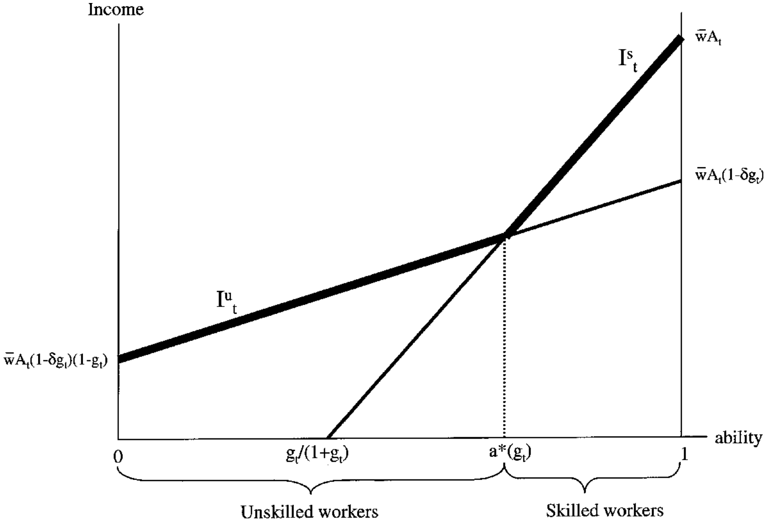

FIGURE I
The Threshold Level of Ability in Period t, a_t^*, and the Composition of the Labor Force, Given a Rate of Technological Progress g_t

both variables. Since individuals work only in the first period of their lives, maximization of first-period income is a necessary condition for maximization of utility. Individuals choose to become skilled workers if and only if, given their ability and the rate of technological progress, their income as skilled workers is higher than that as unskilled workers. That is, a member i of generation t whose ability level is a_t^i chooses to become a skilled worker if and only if $I^s(a_t^i, g_t, A_t) \geq I^u(a_t^i, g_t, A_t)$.

As follows from (7), (8), and (A1), there exists a unique, interior, threshold level of ability $0 < a_t^* < 1$. Individuals whose ability level is above this threshold would choose to become skilled workers, whereas individuals whose ability level is below it would choose to become unskilled workers. That is, $I^s(a_t^*, g_t, A_t) = I^u(a_t^*, g_t, A_t)$:

$$a_t^* = \frac{1 - \delta g_t + \delta g_t^2}{1 + \delta g_t^2} \equiv a^*(g_t), \tag{9}$$

where the steady-state threshold level of ability decreases monotonically in the rate of technological progress, i.e., $a^{*\prime}(g_t) < 0$, but is unaffected by the *level* of technology.

Figure I depicts the income of skilled and unskilled workers as a function of ability. As follows from (7) and (8), the return to ability is higher among skilled workers. The point of intersection of the two curves is the threshold level of ability, a_t^* above which individuals choose to become skilled workers.

E. The Composition of the Labor Force, Aggregate Output, and Income

In every period, given the threshold level of ability, the number of skilled and unskilled workers in the economy is uniquely determined. The number of unskilled workers at time t is a_t^*, whereas the number of skilled workers is $E_t \equiv 1 - a_t^*$.

The aggregate supply of efficiency units of skilled and unskilled labor is determined by the rate of technological progress via two channels. Indirectly, by its effect on the threshold ability level $a_t^* = a^*(g_t)$, which in turn determines the number of skilled and unskilled workers, and directly by its effects on the supply of efficiency units of skilled and unskilled workers.

The aggregate efficiency units of skilled labor, h_t, and unskilled labor, l_t, at time t, is

$$\begin{aligned} h_t &= \int_{a_t^*}^{1} (1-\tau)\{a_t^i - (1-a_t^i)g_t\}\, da_t^i \equiv h(g_t), \\ l_t &= \int_0^{a_t^*} \{1 - (1-a_t^i)g_t\}\, da_t^i \equiv l(g_t). \end{aligned} \tag{10}$$

The level of the composite labor input, as follows from (3), is therefore

$$H_t = \beta h(g_t) + l(g_t)(1 - \delta g_t) \equiv H(g_t). \tag{11}$$

As follows from, (7), (8), and (9), the average income at time t of skilled individuals, $\tilde{I}_t^s$, and unskilled individuals, $\tilde{I}_t^u$, is

$$\begin{aligned} \tilde{I}_t^s &= \frac{I^s(a_t^*, g_t, A_t) + I^s(1, g_t, A_t)}{2} \\ &= \frac{\overline{w}A_t(2 - \delta g_t + \delta g_t^2)}{2(1 + \delta g_t^2)} \equiv \tilde{I}^s(g_t, A_t); \end{aligned} \tag{12}$$

$$\tilde{I}^u_t = \frac{I^u(0,g_t,A_t) + I^u(a^*_t,g_t,A_t)}{2} \tag{13}$$

$$= \frac{\overline{w}A_t(1 - \delta g_t)(2 - g_t + (1 - g_t)\delta g_t^2)}{2(1 + \delta g_t^2)} \equiv \tilde{I}^u(g_t,A_t).$$

The domestic output per worker produced at time t, y^d_t, given (1) and (11), is

$$y^d_t = A_t H(g_t) f(\overline{k}) \equiv y(g_t,A_t). \tag{14}$$

III. EXOGENOUS TECHNOLOGICAL PROGRESS

This section analyzes the evolution of the economy as a whole. It focuses on three central elements: the effect of the rate of technological progress on (i) the return to skilled and unskilled workers, (ii) the composition of the labor force and wage inequality, and the effect of the composition of the labor force on the rate of technological progress. In order to distinguish between the short-run effects and the long-run effects, the analysis is conducted in two stages. First, technological progress is supposed to be exogenous and its impact on the composition of the labor force, the average income in each group and income inequality within and between groups is thoroughly examined. Second, the rate of technological progress is endogenized, and the joint evolution of technological progress and wage inequality is characterized.

This section demonstrates that exogenous changes in the rate of technological progress affect wage inequality. In particular, in accordance with the pattern of wage inequality during the 1980s and the 1990s in the United States, as long as the rate of technological progress increases between two subsequent periods, wage inequality within and across groups increases, the average wage of skilled workers increases, and the average wage of unskilled workers may decline.

A. Education, Average Wages, and Output

Technological change affects the average income of skilled and unskilled workers via three channels. First, for a given composition of the labor force, the rise in the level of technology affects income of each group positively. Second for a given composition of the labor force, the rate of technological change affects the income of each group negatively via the erosion effect. Third, the rate of technological progress alters the composition of ability within each of the groups. An increase in the rate of technological change decreases the threshold level of ability above which individuals chose to become skilled workers. The number of skilled workers increases, the number of unskilled workers decreases, and the average ability decreases in both groups. Income in each of the groups is therefore affected negatively, although due to the optimal adjustment in the composition of the labor force the average income in the economy as a whole is affected positively.

For a stationary rate of technological progress, $\bar{g} > 0$ changes in income are only due to the first effect discussed above. The erosion effect is constant, and so is the composition of the labor force. As follow from (9), (12), (13), and (14) and as depicted in Figure II, for a given rate of technological progress $\bar{g} > 0$, the threshold ability is constant at a steady-state level, $\bar{a}^* \equiv a^*(\bar{g})$, the number of skilled individuals is constant at a steady-state level, $\bar{E} = 1 - a^*(\bar{g})$, the average income of skilled and unskilled workers and output per worker increase monotonically, and their growth rate is equal to the rate of technological progress $\bar{g}$.

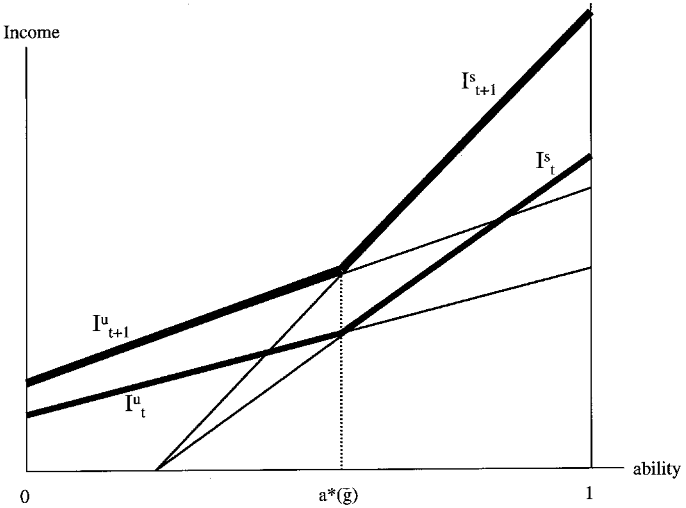

FIGURE II
The Threshold Level of Ability, the Composition of the Labor Force, and the Income of Skilled and Unskilled Workers in a Steady State Equilibrium with a Constant Rate of Technological Progress, $\bar{g}$

PROPOSITION 1 (The effect of the path of technological progress on average wages). Under (A1),

(a) The average income of skilled workers increases from period t to period $t + 1$, regardless of the time path of the positive rate of technological progress.

(b) The average income of unskilled workers decreases from period t to period $t + 1$ for some time path of the rate of technological progress $\{g_t, g_{t+1}\}$.

Proof.

(a) Let $\hat{I}^s_{t+1} \equiv \hat{I}^s(g_t, g_{t+1}, A_t) \equiv \tilde{I}^s(g_{t+1}, A_t(1 + g_{t+1})) - \tilde{I}^s(g_t, A_t)$ denote the difference in the average income of skilled workers between periods $t + 1$ and t. As follows from (12), (A1), and $\delta \in (0,1)$, $\hat{I}^s(0, g_{t+1}, A_t) > 0$, $\partial \hat{I}^s_{t+1}/\partial g_t > 0$, and hence, $\hat{I}^s(g_t, g_{t+1}, A_t) > 0$.

(b) Let $\hat{I}^u_{t+1} \equiv \hat{I}^u(g_t, g_{t+1}, A_t) \equiv \tilde{I}^u(g_{t+1}, A_t(1 + g_{t+1})) - \tilde{I}^u(g_t, A_t)$ denote the difference in the average income of unskilled workers between periods $t + 1$ and t. As follows from (13), (A1), and $\delta \in (0,1)$, for the extreme range of the time path of the rate of technological change, i.e., $\{g_t, g_{t+1}\} = \{0,1\}$, $\hat{I}^u_{t+1} \equiv \hat{I}^u(0,1,A_t) < 0$. Hence, it follows from the continuity of $\tilde{I}^u(g_t, A_t)$ in $g_t \in \{0,1\}$ that $\hat{I}^u_{t+1}$ is strictly negative for some feasible range $\{g_t, g_{t+1}\}$ in the open interval (0,1). □

Hence, since $E_t \equiv 1 - a^*_t$, Proposition 1 implies that for monotonically increasing rates of technological change the average wage of skilled workers increases despite the increase in their number, whereas the average wage of unskilled workers may decline, despite the decline in their relative supply. The rise in the average wage of skilled workers is due to the rise in the return to (heterogeneous) ability despite the decline in the average ability within the group, whereas the potential decline in the average wage of unskilled workers is due to the erosion effect and the reduction in the average level of ability within the group.

B. Productivity Slowdown

The predictions of the model reconcile the coexistence of acceleration in the rate of technological progress and a productivity slowdown that may have been observed in earlier parts of recent decades. As is established in Galor and Moav {1998}, a sufficiently large increase in the rate of technological progress generates a productivity slowdown in the short run. In the long run, however, the growth rate of productivity is higher than existed initially.

Due to the erosion effect, for a sufficiently large increase in the rate of technological progress, the growth rate in Total Factor Productivity (TFP) as measured by the Solow Residual declines. However, once the *rate* of technological progress reaches a steady state, the erosion effect is constant, whereas the productivity effect grows at a constant rate. TFP therefore grows in the long run at a higher constant rate.

C. Wage Inequality

This section analyzes the effect of an exogenous rate of technological progress on income inequality: within the group of skilled workers, within the group of unskilled workers, and between skilled and unskilled workers. Income inequality between skilled and unskilled workers is naturally defined as the ratio between the average wage of skilled and unskilled workers. As follows from (12) and (13), income inequality *between* skilled and unskilled workers, $\sigma_t^{s/u}$, is

$$(15)\qquad \sigma_t^{s/u} \equiv \frac{\tilde{I}^s(g_t,A_t)}{\tilde{I}^u(g_t,A_t)} = \frac{2 - \delta g_t + \delta g_t^2}{(1 - \delta g_t)(2 - g_t + (1 - g_t)\delta g_t^2)} \equiv \sigma^{s/u}(g_t).$$

Income inequality within the groups of skilled and unskilled workers is defined as the ratio of the top to bottom earners within the group. This appears as a natural choice given the assumption that ability is distributed uniformly, and income is linear in ability within each group.[24] As follows from (7)–(9), income inequality *within* skilled workers, σ_t^s, and *within* unskilled workers, σ_t^u, is

$$(16)\qquad \sigma_t^s \equiv \frac{I^s(1,g_t,A_t)}{I^s(a^*,g_t,A_t)} = \frac{1 + \delta g_t^2}{1 - \delta g_t} \equiv \sigma^s(g_t).$$

$$(17)\qquad \sigma_t^u \equiv \frac{I^u(a^*,g_t,A_t)}{I^u(0,g_t,A_t)} = \frac{1}{(1 - g_t)(1 + \delta g_t^2)} \equiv \sigma^u(g_t).$$

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[24] It should be noted that a Gini Index of inequality is monotonically increasing in our measure of inequality. If wages, $x \sim U\{x^L,x^H\}$, then the Gini index is $(x^H - x^L)/3(x^H + x^L) = \{(x^H/x^L) - 1\}/3\{x^H/x^L) + 1$, which is monotonically increasing in our index: x^H/x^L.

PROPOSITION 2 (The effect of changes in the rate of technological progress on inequality). Under (A1), an increase (decrease) in the rate of technological progress in period *t* increases (decreases)

(a) Income inequality between skilled and unskilled workers in period *t*.
(b) Income inequality within skilled workers in period *t*.
(c) Income inequality within unskilled workers in period *t*.

Proof. Follows from the differentiation of (15), (16), and (17) with respect to g_t. □

As follows from (15), (16), and (17), $\sigma^{s/u}$, σ^s, and σ^u are functions of a single variable—g_t, and they are time independent. Moreover, as established in Proposition 2, the functions are monotonically increasing in g_t. Hence the corollary follows.

COROLLARY (The effect of the time path of technological progress on wage inequality). Under (A1), an increase (decrease) in the rate of technological progress from period *t* to period $t + 1$ increases (decreases) income inequality between and within groups from period *t* to period $t + 1$.

Hence, as depicted in Figure III, if the rate of technological

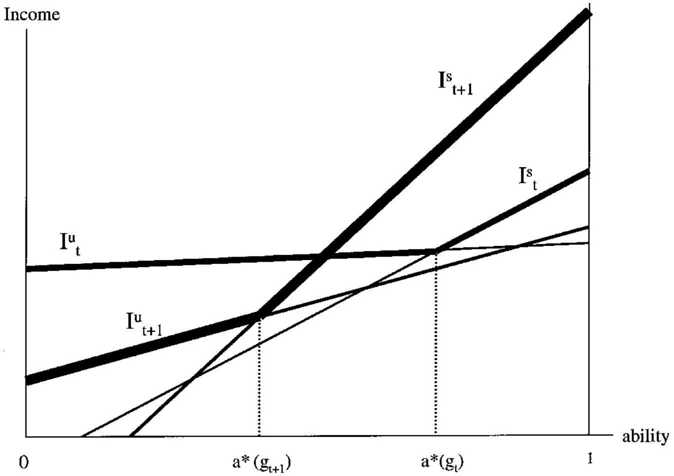

FIGURE III
The Effect of an Increase in the Rate of Technological Progress over Time on the Composition of the Labor Force and Wage Inequality within and between Groups

progress increases monotonically, wage inequality within and between groups increases, the average wage of skilled workers increases despite the increase in their number, and the average wage of unskilled workers may decline, despite the decline in their relative supply. The rise in the wage dispersion within a group is due to the rise in the return to (heterogeneous) ability, whereas the rise in the return to skills, despite the increase in the supply of skills follows since cognitive ability is nonpurchasable.

Since the threshold level of ability above which individuals choose to become skilled workers is independent of the distribution of ability, the qualitative effect of an increase in the rate of technological change on the composition of ability within groups and hence on wage inequality within groups is independent of the distribution of ability. The qualitative effect of technological change on wage inequality between groups may alter, however, if the additional mass of individuals who choose to become skilled workers due to the decline in the threshold level of ability is relatively large. The sensitivity to alternative distributions is mitigated, however, if the adverse effect of technological transition on the demand for unskilled workers is large (i.e., δ is large).

IV. ENDOGENOUS TECHNOLOGICAL PROGRESS

This section analyzes the evolution of the economy in the presence of an endogenous technological change. The evolution of the economy and its impact on wage inequality is based upon three central elements that appear consistent with empirical evidence. First, an increase in the rate of technological change raises the rate of return to skills. Second, the increase in the return to skills induces an increase in the supply of educated individuals. Third, an increase in the level of human capital increases the rate of technological progress. These three elements generate a dynamic path characterized by a positive feedback loop that permits a monotonic increase in the rate of technological progress in a transition to a steady-state equilibrium with perpetual growth. The increase in the return to ability and education that stems from the increase in the rate of technological progress brings about a monotonic rise in wage inequality within as well as between groups along the transition to a steady-state equilibrium.

Suppose that g_{t+1} is a positive (linear) function of the number of skilled workers in period t, or equivalently a positive (linear) function of the proportion of skilled worker in the economy.[25] That is, $g_{t+1} = \gamma E_t$, where $\gamma > 0$. Since $E_t = 1 - a_t^*$, (9) implies that the dynamic system is governed by a one-dimensional, first-order nonlinear difference equation that is time independent:

$$g_{t+1} = \gamma E_t = \gamma(1 - a^*(g_t)) = \frac{\gamma \delta g_t}{1 + \delta g_t^2} \equiv \phi(g_t), \tag{18}$$

where since $\delta \in (0,1)$ it follows from (A1) that $\phi(0) = 0$, $\phi'(g_t) > 0$, and $\phi''(g_t) < 0$.

Hence, the evolution of the rate of technological progress is governed by a strictly increasing, strictly concave function, $\phi(g_t)$. The existence of a positive steady-state equilibrium in the rate of technological progress requires further restrictions on the value of the parameter γ. That is,

$$1/\delta < \gamma < 1 + 1/\delta. \tag{A2}$$

LEMMA 1 (Existence of a stable positive steady-state growth rate). If (A2) is satisfied, then there exists a unique steady-state equilibrium in the rate of technological progress $\bar{g} \in (0,1)$. The economy converges monotonically to $\bar{g}$ for all $g_0 \in (0,1)$.

Proof. Since $\phi(g_t)$ is a strictly increasing, strictly concave function of g_t, and since $\phi(0) = 0$, the existence of a unique, globally stable, steady-state equilibrium in the open interval (0,1) is established since $\phi'(0) = \gamma\delta > 1$ and $\phi(1) = \gamma\delta/(1 + \delta) < 1$ as follows from (A2) and (18). □

REMARK. As follows from Lemma 1, (A2) implies (A1). Hence an assumption on the magnitude of the exogenous variable γ replaces the assumption on the endogenous variable g_t.

Hence, for a given A_0, the sequence $\{g_t\}_{t=0}^{\infty}$ fully determines the time path of output per worker, average incomes of skilled and unskilled workers, and wage inequality within and across groups. The economy converges to a steady-state equilibrium with a positive growth rate of output per worker supported by a positive endogenous rate of technological progress. As long as the initial rate of technological progress is lower than its steady-state level, in the transition to the steady state the rate of technological progress increases monotonically. Hence, as summarized in the

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[25] The second interpretation permits endogenous growth *without* scale effect. That is, if population size increases, it has no effect on the economy's growth rate.

following proposition, wage inequality within and between groups increases, the average wage of skilled workers increases despite the increase in their number, and the average wage of unskilled workers may decline, despite the decline in their relative supply.

PROPOSITION 3 (The effect of the endogenous path of technological progress on wages, inequality, and the composition of the labor force). If $g_0 < \overline{g}$, then along the transition of the rate of technological progress to a steady-state equilibrium, $\overline{g}$,

(a) Wage inequality within and between skilled and unskilled workers increases.
(b) The average wage of skilled workers increases despite the increase in their relative supply.
(c) The average wage of unskilled workers may decline, despite the decline in their relative supply.

Proof. (a)–(b). Since, as follows from (18), the rate of technological progress increases monotonically in the transition to the steady-state equilibrium, (a)–(b) are corollaries of (9), and Propositions 1 and 2.

(c) Since $\tilde{I}^u(g_t,A_t) > 0$ for all $g \in (0,1)$, and $\tilde{I}^u(\overline{g},A_t) = 0$ if $\{\delta = 1$ and $\gamma = 1 + 1/\delta$ (i.e., $\overline{g} = 1)\}$, then for any $g_0 < 1$ income of unskilled workers decreases in the transition to a steady-state equilibrium. Hence, it follows from the continuity of $\tilde{I}^u(g_t,A_t)$ in $g \in \{0,1\}$, and in $\delta \in \{0,1\}$, that $\tilde{I}^u(g_t,A_t)$ decreases in the transition to a steady state, for some feasible range $\delta \in (0,1)$ and $1/\delta < \gamma < 1 + 1/\delta$. □

These qualitative results are robust under a different specification of the rate of technological progress. Suppose that g_{t+1} is a function of the number of efficiency units of labor of skilled workers, h_t. This formulation would not alter the qualitative results as long as δ is sufficiently small. In particular, if $g_{t+1} = \lambda h_t$, there is a unique globally stable steady-state equilibrium if $1/\delta(1 - \tau) < \lambda < (1 + \delta)^2/(1 - \tau)\delta$. Furthermore, convergence to the steady state is monotonic for a sufficiently low δ.

As the economy converges to the steady-state equilibrium, the increase in the wage inequality subsides. The study suggests therefore that the slowdown in the growth of wage inequality in the United States in the 1990s {Autor, Katz, and Krueger 1998} reflects the slowdown in the rate of change of the rate of technological progress as the economy approaches the steady-state equilibrium.

A. Technological Shocks and Endogenous Adjustment

Suppose that the economy is in steady-state equilibrium with a constant endogenous rate of technological progress $\bar{g}$. Technological shock increases the rate of technological progress (in one or several periods). Subsequently, the rate of technological progress declines endogenously and converges back to the original steady-state equilibrium $\bar{g}$. As established in Proposition 2 and consistent with the cyclical pattern of wage inequality between groups documented earlier, major (exogenous) technological changes initially increase wage inequality between groups, but once the revolution is completed, the economy converges back to the original steady-state equilibrium, and inequality between groups declines to its preshock level. If one interprets the 1980s and the early 1990s as periods of *major* technological breakthroughs (that are independent of the level of education), the model predicts that wage inequality between and within groups would rise and then decline, TFP growth may initially decline, and the number of skilled workers would initially rise and then would be expected to decline.[26]

V. ECONOMIC GROWTH AND INSTITUTIONAL CHANGES

The introduction of institutional changes into the basic model permits the analysis to be consistent with those episodes in which a decline in wage inequality was associated with an increase in the fraction of skilled individuals in the labor force. In the presence of capital market imperfections, investment in human capital is suboptimal.[27] If economic development is associated with institutional changes that reduce the effectiveness of imperfections in capital markets (e.g., directly via the expansion in financial aid to higher education in the United States from the 1960s to the early 1970s, or indirectly via the high school movement in the United States of 1910 to 1940), they generate a decrease in wage inequality along with an increase in the number of college graduates.

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[26] As elaborated below, if, in contrast, the increase in technological change is an outcome of an exogenous increase in the supply of skilled workers in the 1970s, then the supply of skilled worker would be expected to increase monotonically toward its steady-state level.

[27] For example, in the presence of differences in the rates of interest for borrowers and lenders, as in Galor and Zeira {1993}, investment in human capital is persistently suboptimal.

Consider a modification of the basic model where individuals live three periods. In the first period of their lives, individuals invest in human capital, in the second they work, and in the third they are retired. In contrast to the basic model, the cost of education for members of generation $t - 1$ who would like to become skilled workers is an indivisible tuition payment equivalent to the cost associated with hiring a teacher with e efficiency units of a skilled worker. That is, $e\overline{w}A_{t-1}$. Moreover, for simplicity, education is free for those who intend to become unskilled workers. Individuals borrow the entire fund to finance the cost of their education, $e\overline{w}A_{t-1}$. The loan repayment of a member of generation $t - 1$, is therefore $e\overline{w}A_{t-1}(1 + \theta_t\overline{r})$ in the working period t, where $\theta_t > 1$ is the ratio of the interest rate for borrowers and lenders in period t.

Hence, a member i of generation $t - 1$ chooses to become a skilled worker if and only if

$$I^s(a_t^i,g_t,A_t) - e\overline{w}A_{t-1}(1 + \theta_t\overline{r}) \geq I^u(a_t^i,g_t,A_t); \tag{19}$$

that is, if and only if $(1 + g_t)\beta\{a_t^i - (1 - a_t^i)g_t\} - e(1 + \theta_t\overline{r}) \geq (1 - \delta g_t)(1 + g_t)\{1 - (1 - a_t^i)g_t\}$. Provided that the number of skilled workers in the economy is positive, i.e., provided that $\beta > (1 - \delta g_t) + e(1 + \theta_t r)/(1 + g_t)$, the threshold level of ability in period t, a_t^{**} is

$$a_t^{**} = a(g_t;\theta_t), \tag{20}$$

where $\partial a_t^{**}/\partial\theta_t > 0$ and $\partial a_t^{**}/\partial g_t < 0$. That is a_t^{**} depends negatively upon the rate of technological progress, g_t, and positively on the degree of imperfection, θ_t.

Hence, if economic development is associated with a reduction in the degree of imperfections in capital markets (i.e., a reduction in θ_t), it follows that the increase in the supply of skilled workers due to the increase in the rate of technological progress would be enhanced in the transition to a steady-state equilibrium. The level of inequality between skilled and unskilled workers, however, would be subjected to two opposing effects. The increase in the rate of technological progress raises inequality between groups. However, the reduction in imperfections increases the supply of skilled labor and reduces the average ability of both skilled and unskilled workers. Moreover, if skilled and unskilled workers are imperfect substitutes, inequality between groups declines.

The dynamic system in the presence of capital markets imperfections is depicted in Figure IV. Suppose that the degree of capital markets imperfections is initially θ^1. Modifying the analysis in Section IV, the economy converges along the map $\phi(g_t,\theta^1)$ to a steady-state equilibrium $\bar{g}(\theta^1)$. If along the transition to the steady-state equilibrium the economy experiences a discrete improvement in the degree of capital market imperfections from θ^1 to θ^2 (e.g., the enhancement of subsidy for college loans in the early 1970s), then the number of skilled workers increases. In the next period the rate of technological progress rises discretely, and the economy converges monotonically along the map $\phi(g_t,\theta^2)$ to a steady-state equilibrium $\bar{g}(\theta^2)$.

A. The Patterns of Wage Inequality in the 1970s

During the 1960s to the early 1970s, financial aid to higher education expanded in the United States. As observed by Autor, Katz, and Krueger {1998}, although the demand for college graduates in the United States has increased from the 1970s faster than previously, the college wage premium declined because of the large increase in supply of college graduates. In contrast, wage inequality within groups had increased over this period {Katz and Murphy 1992}.

As is apparent from the above analysis, if the decline in the degree of credit market imperfections is sufficiently large, the

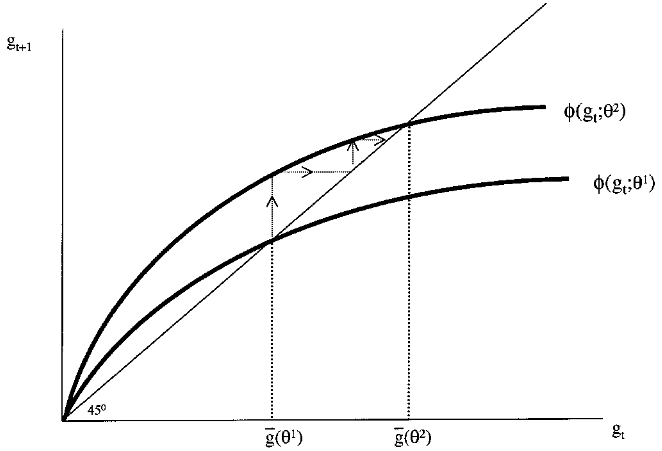

FIGURE IV
The Changes in the Evolution of the Rate of Technological Progress due to a Reduction in the Degree of Capital Markets Imperfections from θ^1 to θ^2

increase in the supply of skilled workers would dominate the demand effect induced by the increase in the rate of technological change, and wage inequality between skilled and unskilled workers would decrease. Moreover, wage inequality within groups and average wages of each group may follow the pattern observed in the 1970s. In particular, wage inequality within the group of skilled workers would increase unambiguously due to the increases in the heterogeneity in ability among skilled workers, whereas wage inequality within the group of unskilled workers would increase provided that the effect of technological progress on the return to ability dominates the composition effect.[28]

B. The Patterns of Wage Inequality in the Period 1910–1950

The United States experience of the high school movement of 1910 to 1940 can shed light on the patterns of wage inequality from 1910 to 1950. As established by Goldin and Katz {1999}, during this period wage inequality between and within groups had declined.[29] Unlike the experience of the 1970s, the improvement in the accessibility of schooling was primarily geographical in nature and consequently had no major effect on the composition of ability among skilled workers.

As is apparent from the analysis above, if the decline in the degree of credit market imperfections is sufficiently large, the increase in the supply of skilled workers would dominate the demand effect induced by the increase in the rate of technological change (e.g., the introduction of network electricity), and wage inequality between skilled and unskilled workers would decrease. Moreover, wage inequality within groups would follow the pattern observed in the period 1910–1950. Since the average ability among unskilled workers declines due to the outflow of the upper tail of the ability distribution, heterogeneity and wage inequality among unskilled workers decline. Further, the increase in the supply of ability among skilled workers reduces the return to ability and consequently decreases wage inequality within skilled workers.

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[28] Note that if the erosion effect with respect to unskilled labor is *sufficiently* small prior to the 1970s then the increase in the erosion effect since the 1970s would raise inequality within the group of unskilled workers unambiguously.

[29] This pattern of declining wage inequality within and between groups is consistent with the pattern observed in Europe in the period 1950–1980 {Freeman and Katz 1995}. The diverging pattern of within- and between-group inequality in the United States during the 1970s therefore appears to be the exception.

C. The Cyclical Pattern of Wage Inequality in the Last Century

The pattern of increased wage inequality due to the acceleration in the rate of technological progress would be interrupted occasionally due to a *discrete* feedback from growth to capital markets which would increase the supply of skilled workers and decrease temporarily wage inequality between skilled and unskilled labor. This dynamic process would repeat itself and, consistent with empirical evidence, would generate cyclicality in the wage differential between skilled and unskilled labor along with a monotonic increase in the number of skilled workers. As depicted in Figure IV, the increase in the number of skilled workers would reinforce the acceleration in the rate of technological progress and would enable wage inequality to increase once again. This process would repeat itself, and wage inequality would experience cyclical behavior despite the monotonic increase in the supply of skilled workers.

V. CONCLUDING REMARKS

This paper argues that ability-biased technological transition accounts for the evolution of technology, education attainment, and wage inequality as observed in the United States and other advanced countries over the past several decades. An increase in the rate of technological progress raises the return to ability and simultaneously generates a rise in the wage inequality between and within groups of skilled and unskilled workers, an increase in the average wage of skilled workers, a temporary decline in the average wage of unskilled workers, an increase in education attainment, and possibly a transitory productivity slowdown.[30]

The framework of analysis developed in this paper is suitable for the examination of the unexplored territory of the international spillovers of wage inequality. For instance, in the presence of imperfect technological diffusion, wage inequality among technological leaders is likely to be larger than among followers. Furthermore, institutional changes in a technological leader that

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[30] The proposed theory is indirectly supported by the apparent rise in the tuition differential between prestigious private universities and public universities in the United States since the 1970s. If enrollment in prestigious private colleges provides a signal about the ability of a student, and if tuition partially reflects the value of this signal, then a possible rise in the importance of ability since the 1970s would have increased the value of this signal, and tuition rates would be expected to rise in these private institutions more than in their public counterpart.

reduces the wage differential between skilled and unskilled labor and raises the rate of technological progress, would have an increasing effect on wage inequality among follower countries.

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