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Returns to Human Capital and Investment in New Technology

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Abstract

This paper presents a simple framework that illustrates the link between skill-based wage differentiation and human capital acquisition given skill-biased technical progress. The analysis points to the economic costs resulting from labor market and income redistribution policies that prevent the skill premium from playing its role in fostering human capital accumulation and the adoption of new technologies. The study compares key economic indicators among Canada, France, Germany, the United Kingdom, and the United States. Differences in wage differentiation and investment in new technologies among these countries could be related to policies affecting labor markets; such practices may reflect social choices.

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Contents

I. Introduction

The sharp acceleration in output and labor productivity growth in the United States in the latter half of the 1990s has been attributed to a surge in technological innovations and the adoption of new technologies across the economy. The fact that the U.S. economy has been a leading innovator and has adopted many of the technological changes that took place more rapidly than other major industrial countries has been credited in part to the high degree of flexibility in U.S. product and labor markets. The flexibility in the U.S. labor market, in particular, has been singled out as a potentially important factor since it has allowed firms to more easily reorganize work processes to take full advantage of the productivity–enhancing features of the new technologies. However, there is another avenue through which labor market flexibility has contributed to the strong U.S. productivity performance. This flexibility has allowed a substantial differential between the wages of skilled and unskilled workers (referred here as the wage premium) to develop. With the change in technology having a significant skill bias, the demand for skilled workers has increased, bidding up the wage premium, and in turn, the supply of skilled workers has increased and further stimulated investment in new technologies.

As skill-biased technological change emerges as the main paradigm explaining the interaction between labor markets and investment in new technologies, it is more appropriate to think of the behavior of the relative wage of skilled and unskilled workers as the outcome of a race between technological change and increases in educational attainment. The positive feedback loop between investment in new technologies and human capital investment generates thus a positive growth path for the whole economy and can explain the changes in the wage premium, the relative demand for skilled workers, and the dynamics of technological progress.[2]

Given the evidence on skill-biased technological progress, we ask how certain policies or institutional arrangements limiting the wage premium and/or fostering investment in human capital could affect the growth process of an economy. Using a simple theoretical model, we illustrate the link between the wage premium, the acquisition of skill (investment in human capital) and investment in technologies. Following the basic framework of Blankenau (1999), the model allows explicitly for the existence of skill-biased technology change and for a positive feedback loop between investment in human and physical capital. The model is used to illustrate the negative effects of policies that serve to limit the wage premium (and returns to human capital) and how these effects may be partially offset by measures to subsidize education.

In the 1990s, the United States experienced a substantial increase in the wage premium and rising employment of skilled workers in both absolute and relative terms. The increase in the wage premium was reflected in a significant widening in the income distribution (pre-tax basis)

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[2] Galor and Moav (2000), Acemoglu (1998), Krusell, Ohanian, Rios-Rull and Violante (2002) develop theoretical models explaining the implications of the positive link between investment in human capital and investment in new technologies.

in the United States. The major industrial countries (with the exception of the United Kingdom) did not experience similar widening in their income distributions, suggesting that these countries did not see a substantial increase in their wage premiums and in human capital investment, contributing to the slower pace of adoption of new technologies in most of these countries. The more limited differentiation in wages in these countries is related to economic policies and/or institutional arrangements affecting labor market behavior; such practices to some extent may reflect social choices and cultural differences.

The subsidization of education costs (a key feature of the education system in all countries) can have a positive impact on skills acquisition and economic growth offsetting some of the effects of limitations in wage differentiation. However, education costs tend to be small in relation to the opportunity cost of wages foregone during the period of skill acquisition.

We illustrate our analysis by presenting stylized facts for the United States and by comparing key indicators with four other developed economies: the United Kingdom, Canada, Germany, and France. We present evidence that the U.S. economy in the 1990s has experienced a process of rapid technical innovation, an increase in skill premia and employment of skilled workers, and higher output and productivity growth. The international comparison focuses on income inequality and investment in new technologies. In the 1990s, the United States had higher income dispersion that was accompanied by stronger investment in technology and higher growth in output and productivity than the rest of the developed countries considered.

The paper is organized as follows. Section II develops a simple model of wage differentiation in the context of skill-biased technological progress. After describing the theoretical framework, we consider the effect of policies that reduce the skill premium. Section III summarizes evidence on the rise in the skill premium in the United States over the last two decades associated with the development of new technologies. In section IV, we compare stylized facts for the Unites States with those of other developed countries. Section V concludes.

II. A Simple Model of Wage Differentiation Based on Skill

A simple theoretical model can be used to illustrate the dynamic interplay between technological progress, the wage premium, and investment in human capital. In the model, individual workers face a choice between supplying unskilled labor or investing in education in order to supply skilled labor at a higher wage. Skilled labor commands a higher wage because of its higher marginal productivity. The choice of whether to acquire skills is dependent on the cost of education and the wage premium for skilled labor; a fall (rise) in education costs will increase (decrease) investment in human capital and an increase (decrease) in the wage premium will raise (reduce) human capital investment. With the assumption that technological changes tends to be (at least in its initial phases) skill-biased such that higher skilled labor becomes more productive relative to lesser skilled labor, the model can illustrate a positive link between investment in human capital and technological progress. An improvement in technology increases the demand for skilled labor, leading to a rise in the wage premium and stimulating investment in human capital. Positive spillover effects arise as a growing pool of skilled workers fosters conditions conducive to the diffusion of technology across the sectors of the economy and spurring further innovation

Individuals' preferences and choice of higher education

Individuals are heterogeneous in terms of their ability $i \in [0,1]$ to acquire education. People live for two periods: in the first period, they can acquire higher education and work, while in the second, they retire and consume their savings. Agents are endowed with one unit of unskilled labor, which they supply inelastically. Individuals can choose to become skilled workers by acquiring higher education at a cost $g(i)$. We assume a cost function that is increasing on i, the individual's type, implying that individuals with small i are more efficient to acquire new skills.

The education cost represents the time spent acquiring skills and so corresponds to the opportunity cost of forgone earnings for workers. The choice of higher education in the model is similar to that of high-school graduates who have to decide whether to enter the labor force as unskilled workers or to pursue college in order to acquire better skills. We could also think of this choice in terms of on-the-job training where workers give up a fraction of wage earnings to acquire job-specific skills.[3]

The choice of acquiring education is the main decision that individuals make, as it allows to differentiate skilled workers from unskilled ones. Only people with education have access to high-skill jobs. As high-skill jobs are more productive, they command a higher wage. Given that individuals with low i face lower education costs, they are more likely to acquire education and so enjoy a wage premium. The choice to obtain education would depend on the trade-off between the foregone earnings resulting from the time spent acquiring skills and the gains from such training reflected in the wage premium. Individual i would choose to obtain higher education if $w_{s,t} - g(i)w_{s,t} \geq w_{u,t}$, where $w_{s,t}$ and $w_{u,t}$ correspond to the skilled and unskilled wages in period t, respectively, and $g(i)w_{s,t}$ represents the education cost of foregone earnings.

The monotonic property of the education cost function implies that there exists a marginal worker m_t who is indifferent between acquiring education or remaining an unskilled worker: $w_{s,t}(1 - g(m_t)) = w_{u,t}$. Defining the wage premium as the ratio of skilled wage to unskilled wage, we have that $\pi_t \equiv \frac{w_{s,t}}{w_{u,t}} = \frac{1}{1 - g(m_t)}$. The wage premium determines the decision of the marginal individual to obtain higher education.

[3] This view is compatible with learning-by-doing theories which explain the wage profile of young workers.

More important, the wage premium has a direct effect on the aggregate supply of both skilled and unskilled workers. Given that workers are uniformly distributed with respect to the ability factor, m_t represents the fraction of the workers who choose to become skilled. The total supply of skilled labor in period t includes the total fraction of skilled workers minus the total time forgone in higher education: $s_t = m_t - \int_0^{m_t} g(z)dz \equiv m_t - G(m_t)$. For unskilled workers, the total supply is equivalent to the fraction of unskilled workers: $u_t = 1 - m_t$.

Production technology

In this economy, aggregate output results from a production function characterized by labor-augmenting technological progress[4]: $Y_t = F(K_t, A_t L_t) \equiv A_t L_t f(k_t)$ where k_t corresponds to aggregate capital per efficiency unit of labor, A_t refers to the level of technological progress and L_t represents total labor input. The non-standard feature of this production function is that we consider total labor as resulting from an aggregating function of skilled and unskilled labor inputs: $L_t = s_t^{\alpha} u_t^{1-\alpha}$ where $\alpha \in (1/2, 1)$ represents the relative contribution of skilled and unskilled labor in total production, and skilled workers have higher productivity. We assume that labor markets are competitive, and so the marginal product of skilled and unskilled labor determines their total demand.[5] We have that the wage premium defined by the ratio of skilled wage to unskilled wage determines the relative demand for skilled and unskilled workers:
$\pi_t \equiv \frac{w_{s,t}}{w_{u,t}} = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{u_t}{s_t}\right)$.

Equilibrium relations

Market clearing in both the labor and capital markets determine the equilibrium conditions for each of the variables in this economy. To simplify the analysis, we assume that the economy

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[4] The function F has the standard properties of the Neoclassical production functions, that is, $F(K, AL)$ is increasing, concave in both arguments, and homogeneous of degree one. We can thus rewrite it as: $Y_t = A_t L_t f(k_t)$, where $f(\cdot)$ is increasing and concave and $k_t = \frac{K_t}{A_t L_t}$.

[5] Given wages $w_{s,t}$ and $w_{u,t}$, we have that $w_{s,t} = \frac{\partial F_t}{\partial s_t} = \alpha \frac{A_t L_t F'_{AL}}{s_t}$ and
$w_{u,t} = \frac{\partial F_t}{\partial u_t} = (1-\alpha) \frac{A_t L_t F'_{AL}}{u_t}$

operates in a perfectly competitive world where international capital movements are unrestricted, implying that the rate of return on capital r is given. This assumption allows us to pin down the aggregate capital per labor unit as a function of r.[6] In the case of labor markets, both supply and demand relations for skilled and unskilled labor depend on the wage premium. Equating labor supply and labor demand, we obtain the following relationship for the wage premium.

$$\pi_t = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{1-m_t}{m_t - G(m_t)}\right) = \frac{1}{1-g(m_t)} \tag{1}$$

A solution to this equation allows us to derive the equilibrium wage premium $\bar{\pi}$ as a function of the deep parameters: the relative importance of skill in the production function, given by parameter α, and the education cost function $g(m_t)$.

A. Equilibrium with Exogenous Growth

We consider first an exogenous growth path such that the technological level increases at a constant rate $x \equiv A_t/A_{t-1} - 1$. Having assumed a production function characterized by labor-augmenting technological progress, we have that output and capital follow a balanced-growth path at rate x. On the other hand, labor demand remains independent of technological progress as the relative demand for skilled and unskilled workers is still determined by the wage premium π_t. Similarly, individuals' education choice depends on the skilled and unskilled wage differential and so is not affected by the rate of technological progress. Correspondingly, the solution to the wage premium in equation (1) above characterizes the relative equilibrium demand for skilled and unskilled labor in the context of the exogenous growth path of the economy. The following result presents the basic properties of the labor market equilibrium.

Result 1: *The fraction of skilled workers, determined by the marginal worker with ability m choosing to acquire education, represents a unique function $\bar{m}(\alpha, g)$ such that $\bar{m}$ is increasing in α (the relative productivity parameter of skilled labor) and decreasing in g (the cost of education).*[7]

This result simply shows that an increase in skilled labor productivity leads to a higher number of skilled workers in the economy while an increase in education costs leads to a decrease in the relative number of skilled labor. As a corollary, the equilibrium wage premium goes up as

[6] Equating the marginal product of capital to the international interest rate, we have:

$$\frac{\partial Y_t}{\partial K_t} = f'(k_t) = r$$

[7] The proofs of all results are shown in the appendix.

skilled labor productivity and education costs increase. Another important feature of this basic framework is that we assume an exogenous technological progress that explains the constant growth path of output and investment without affecting the labor market outcomes. In other words, the individuals' education choice does not alter the growth profile of the economy.

B. Endogenous Skill-Biased Technological Progress

We now extend the model to link output dynamics to investment in human capital. We introduce two crucial assumptions to establish the dynamic interplay between technological progress, output growth, and labor market outcomes. First, we consider skill-biased technological change, whereby the technological progress has a direct impact on the relative productivity of labor factors. Second, we take into account the positive link between investment in human capital and technical progress.

The main thrust of skill-biased technological progress is that the introduction of new technologies has a higher impact on the productivity of skilled workers than on that of unskilled ones. While a higher level of technology benefits both types of workers, we allow changes in the rate of technological growth to have a net positive effect on skilled workers relative to unskilled workers. We have thus a positive relation between the rate of technological progress and the relative labor productivity parameter: $\alpha(x_t)$, where x_t is the rate of technological progress.[8]

We also consider a link by which higher investment in human capital (a higher fraction of skill workers) leads to a higher rate of technological progress. The positive spillover effect of a larger concentration of skilled labor generates better conditions for the fostering of knowledge and the creation and diffusion of ideas leading to more productive technology.[9] Hence, we assume that a higher share of skilled workers in one period leads to a higher rate of technical progress in the next period: $x_{t+1} = \Gamma(s_t)$.[10]

These two key assumptions on skill-biased technological change and the spillover effects of human capital on development provide the building blocks to characterize the dynamic equilibrium of the economy. In particular, we want to determine whether a steady-state growth path exists for this economy and if so, what the properties of such an equilibrium path are.

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[8] We assume that $\alpha(x_t)$ is an increasing and weakly concave function bounded by unity.

[9] Our assumption is also consistent with Acemoglu (1998)'s view that a high proportion of skilled workers implies a larger market size for skill-complementary technologies and encourages faster upgrading of productivity of skilled workers.

[10] We assume that $\Gamma(.)$ is an increasing, concave, and continuous function.

Result 2: *There exists a unique steady-state technological progress growth path $\bar{x}$ so that the economy converges monotonically to it. As a corollary the dynamics of technological progress $\{x_t\}$ is positively related to the evolution of the wage premium and the fraction of skilled labor.*

The existence of a unique steady-state growth path for technological change suggests that the dynamics of output and capital stock converge to a steady state growth path determined by $\bar{x}$. Similarly, the wage premium and labor allocation outcome also converge to a steady-state variable determined by steady-state level of the relative skilled labor productivity parameter $\alpha(\bar{x})$.

More interesting, the dynamic evolution of key variables in the economy depends on the changes in technological progress relative to its steady-state level. A temporary shock to technological change would have a temporary effect on the evolution of the wage premium and human capital investment, as the economy converges back to its initial steady-state growth rate (first panel in Figure 1). As the adjustment process unwinds, the wage premium and the relative supply of skilled workers come back to their initial levels after having risen due the positive technological shock. Correspondingly, temporary changes in technological progress are related to a cyclical pattern in the behavior of the wage premium. In contrast, a permanent positive shock to technological change implies a steady convergence of output growth to a higher permanent level, entailing a monotonic increase in the wage premium and investment in human capital (second panel in Figure 1).

C. The Effect of Income Redistribution and Education Subsidies

The model can help illustrate the impact of policies or institutional arrangements that serve to limit the differential in wage across groups of workers with different skill levels. In particular, we consider the effects of policies that reduce the skill premium. To the extent that these policies affect the incentives to human capital investment (through for example a reallocation of income between skilled and unskilled worker), they have a direct effect on the education choices of individuals and the growth path of the economy.

We consider a direct lump sum transfer to unskilled workers financed by an income tax on skilled workers.[11] This type of policy tries to replicate the effect of a range of policies that serve to cap the skill premium. Alternatively, the introduction of an income tax (especially one with very progressive marginal rates) is expected to reduce the skill premium. In lowering the incentives to acquire education, policies capping the wage premium have a negative impact on human capital investment and economic output growth.

[11] The results are not specific to a particular mechanism used to cap the skill premium. We consider here a common income redistribution policy that shifts income from those well-off (according to earnings) to those in need (on a per-capita basis).

To offset the effects of policies limiting the wage differential, human capital investment can be promoted through education subsidies. However, education costs tend to be small in relation to foregone wages during the training period. Moreover, how education subsidies are financed may limit their intended benefits on a an economy-wide basis. We consider two possibilities for the financing of the education subsidy. First, we allow for a net positive income transfer to skilled workers with high education costs by taxing all workers skilled and unskilled. The second option considers a tax on skilled workers only; it involves a net income transfer from skilled workers with low education cost to skilled workers with high education cost. Education subsidies would encourage skill acquisition and so would have a positive impact on human capital investment and output growth. Nonetheless, the impact of these policies is limited.

We summarize the main implications from these policy options in the next two results. [12] All policies considered take into account a same-period balanced budget constraint.[13]

Result 3: *Let subscript {0} denote the no-policy, baseline case while subscript {1} represent the income redistribution policy (with no education subsidy). We find that* $\bar{x}_1 < \bar{x}_0$; $\bar{\pi}_1 < \bar{\pi}_0$*; and* $\bar{m}_1 < \bar{m}_0$. *Output growth, after-tax wage premium, and investment in human capital decrease relative to the baseline case.*

The first pane in Figure 2 illustrates the main implication from income redistribution implying a capping of the wage premium. A direct lump sum transfer to unskilled workers financed by a tax on skilled workers leads to a lower output growth equilibrium together with lower investment in human capital. This policy is equivalent to having a negative shock on the relative productivity of skilled workers, as it reduces incentives to acquire education by lowering the after-tax/transfer wage premium. The welfare implications remain uncertain given that income disparity is lower (i.e. unskilled workers are better off in relative terms), but total output is lower. Depending on the magnitude of transfers, it is possible that all individuals are worse off in absolute terms given the low incentives to further invest in human capital.

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[12] A formal presentation of policies is developed in the appendix.

[13] Here we do not investigate optimal size issues for the education subsidy, which would require using an inter-temporal budget constraint and a government welfare function to bring in intergenerational preferences. Although human capital in this framework is an input fully consumed in the one period when individual are active workers (i.e. human capital has a depreciation rate of 100 percent), the existence of cross-generation externalities, implied by $x_{t+1} = \Gamma(s_t)$, may determine an optimal budget deficit. Nonetheless, given that we ask the narrower question of what would be the effect of an education subsidy on skill acquisition and growth, the use of a budget balance for every period does not alter the qualitative implications of the results.

Result 4: *Let subscripts {2} and {3} denote the policy options to subsidize investment in human capital; the first one represents the case of a broad tax base (comprising an income tax on all workers), while the second corresponds to the case of income taxation on only skilled workers. We obtain that, for the same per-capita education subsidy,* $\bar{x}_2 > \bar{x}_3 > \bar{x}_0$; *and* $\overline{m}_2 > \overline{m}_3 > \overline{m}_0$.

In contrast to the case of policies capping the skill premium, education subsidies lead to higher growth and investment in human capital. Under education subsidies that are financed with a broad tax base (including both skilled and unskilled workers), case $\{2\}$, there is more human capital accumulation and growth than in the baseline case $\{0\}$ and the case of taxation on just skilled workers $\{3\}$. For both instances of a broad or narrow tax base, more individuals, at the margin, choose to acquire skills because the after tax/subsidy return to skills increases and compensates workers with higher education costs. Since human capital investment is the main element driving dynamics under skilled-biased technological progress, the education subsidy policies have a positive impact on the dynamics of productivity and output growth.

The net return to skills rises significantly more in case $\{2\}$ than in $\{3\}$ since the broader tax base allows a lower tax rate and shifts up the marginal high-cost worker for whom it pays to acquire skills. In fact, as the third panel in Figure 2 shows, case $\{3\}$ increases growth and human capital marginally from the baseline case compared to case $\{2\}$. The main difference between these cases is that, at the margin, individuals in $\{2\}$ not only face lower education costs due to the subsidy, but more important, they obtain a higher after-tax return to investment in human capital. The broad tax base case replicates, to a good extent, the opposite of case $\{1\}$, i.e. a redistribution of income from the unskilled to the skilled. In this context, education subsidy policies are effective in fostering human capital accumulation and higher growth in as much as they increase the after tax/subsidy return to education, and in so doing at least partially offsetting policies capping the skill premium.

Figure 3 shows output growth relative to the baseline for different tax and subsidy scenarios. The first panel points out the increasing negative effect of a higher tax rate on output growth in the context of income redistribution policies, case $\{1\}$; this implies an increasing income tax elasticity of output. In contrast, while the net effect of education subsidies on output growth is positive, the marginal impact of higher tax rates on output growth is significantly lower.[14] The second panel shows the relative output growth gain from the two education subsidy schemes considered. For case $\{3\}$, the marginal effect of subsidies on growth is lower than the marginal effect for case $\{2\}$, even though the profile of the latter decreases as the subsidy increases.

To summarize, in the context of skill-biased technological progress, as formulated in the model, policies capping the skill premium imply considerable costs in terms forgone output growth,

[14] This observation is robust to various parameter specifications (i.e. education costs, growth function parameters).

while policies promoting investment in human capital lead to higher growth, but the extent of the these gains depend on how education subsidies are financed.

III. Skill Premium Dynamics and Stylized Facts for the United States

In the last 60 years, the wage premium in the United States between college-educated (used here as a proxy for "skilled" worker) and high school graduates (an "unskilled" proxy) has shifted dramatically.[15] In the 1940s, the premium fell significantly, before recovering in the 1950s and 1960s. The premium narrowed again in the 1970s, but it subsequently has risen sharply, increasing to an unprecedented level in the late 1990s (Figure 4). For heads of households, the premium has doubled in the last two decades, while for the work force as a whole it has increased by more than 50 percent (Figure 5).

At the same time, the supply of skilled workers has increase both absolutely and in relation to unskilled workers for both heads of households and all workers (Figure 6). This joint increase in the skill premium and the relative supply of skilled workers can be traced back to the very strong relative demand for skilled workers during the 1990s. Several studies point out that the prime cause of the increase in the skill premium is due to a shift in relative demand for skilled workers.[16]

This increase in the skill premium has coincided with a rapid acceleration in technological progress associated with the advent of the information technology revolution. Skill-biased technological change, associated with both new production technologies and organizational innovations, has emerged as the main paradigm explaining the interaction between labor markets and investment in new technology. Expenditure in new technologies in the United States has increased sharply in this period (Figure 7). In this context, several studies have assessed the power of several alternative explanations of the observed changes in wage premia and have found that the prime cause of the relative wage changes was a shift in the skill structure of labor demand brought about by skill-biased technological changes.[17]

IV. International Comparison

As a result of the rapid adoption of new technologies and reforms, the United States has enjoyed the highest rate of output growth in the last two decades among developed countries. It has also witnessed a significant acceleration in the rate of productivity growth in the second half of the 1990s. With the exception of Canada, all other countries have experienced tamer output growth and a slower rate of labor productivity gains. As discussed by Gust and Marquez (2000), while

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[15] See for example Katz (1999).

[16] See, for example, Autor, Katz and Krueger (1998), Katz (1999), Katz and Murphy (1992).

[17] See for example Bound and Johnson (1992).

capital deepening has played an important role to explain the increase in labor productivity, multifactor productivity growth appears to have played a preeminent role in accounting for divergences in labor productivity growth in the United States and other developed economies. They suggest that the more fundamental changes in the U.S. economy reflect the more advance diffusion of technological improvements, especially in the information technology sector.

Data on information technology investment during the 1990s show that as a share of GDP, such investment rose sharply in the 1990s in the United States, the United Kingdom and Canada, while it remained broadly unchanged in France and Germany (Figure 9). The United States has also led all the major industrial countries on private business expenditure in research and development (Figure 10). Machin and Van Reenen (1998) show evidence of a significant link between skill upgrading and research and development intensity for the five countries considered. While skill-biased technical change is a phenomenon present across the afore-mentioned countries, the upward shift in the demand of skilled labor during the 1990s has been particularly important in the United States, the United Kingdom, and Canada.[18]

The significant upward shift in the demand for skilled labor would translate into a rise in the wage premium before the supply of more skilled workers responds to wage changes. A substantial widening of the income distribution in the United States during the 1990s can be linked to the rise in the wage premium. In contrast, with the exception of the United Kingdom, income distribution was largely unchanged in other major countries. Measures of income inequality such as the ratio of incomes of the top to the bottom 20 percent of the population and the Gini coefficient reveal the widening income distribution for the United States and the United Kingdom (Figure 11). More formal evidence by Gottschalk and Smeeding (1997) points out that these two countries have exhibited the largest widening in income dispersion since the 1980s.

Even though consistent and comparable data on the wage premia among the sample countries is not available, movements in the wage premium can be inferred from changes in the income distribution. A widening in the income distribution would be expected to be associated, at least in part, with an increase in the wage premium, as illustrated by the behavior of the income distribution and the wage premium in the United States. Hence, given little change in income distribution in Canada, Germany, and France, there is little reason to suspect that wage premia in these countries have increased substantially. In fact, Fernandez (2000) shows that wage dispersion in Germany during 1980s and early 1990s is significantly smaller than in the case of the United States and the United Kingdom. Similarly, Murphy, Riddell, and Romer (1998) compare the low divergence in wage differentials between skilled and unskilled workers in Canada to the increase in the wage premium in the United States during the past two decades.

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[18] In the case of the United Kingdome, Prasad (2001) points out to evidence that rising wage dispersion is consistent with skill-biased technological progress. Similarly, Murphy, Riddell and Romer (1998) show evidence of relative demand shift for more-educated labor in the United States and Canada.

There may be a variety of institutional and policy explanations for the lower income disparity in some of these countries. Labor market institutions affect earnings inequality through wage-setting mechanisms, which reduce wage differentials by compressing pay within firms, across establishments and across industries. While in the United States, the United Kingdom, and Canada, wages are largely determined through decentralized markets, collective bargaining sets the pay of 92 percent of workers in France and 90 percent in Germany (OECD 1994, Table 5.8). In the United States, about a 20 percent of the rise in overall dispersion in wages during the 1980s and early 1990s can be attributed to the drop in unionization.[19] Minimum wages are also an important factor on earnings distribution. In France and Germany, the basic minimum wages remain significant as they represent about 60 percent of the average pay in manufacturing, compared to those in the United States, the United Kingdom, and Canada, where the minimum wages are about 40 percent. Several studies using U.S. data estimate that the decrease in the real minimum wage since 1979 have contributed between 10 to 30 percent to the increase in earnings inequality among all workers.[20] In the case of Germany, Prasad (2000) shows evidence that the low income disparity, both between and within skill groups, is attributable to institutional factors rather than market forces. Devroye and Freeman (2001) present evidence that the bulk of cross-country differences in income inequality occurs within skill groups; thus, differences in inequality lies not in the distribution of skills but in the countries' labor compensation systems. Some of this evidence would suggest that in times of skill-biased technological progress, the impact of institutional settings on price signals could represent a factor reducing incentives to investment in human capital and slowing the adoption of new technologies.

Education subsidies can also have an important effect on net returns to skill acquisition. Data on total government expenditure in higher education shows all of the major countries spend roughly comparable amounts, with the exception of Canada which spends significantly more than the others (Figure 12). Thus, although Canada has not experienced a comparable widening of income distribution as the United States and the United Kingdom have, its higher level of education spending may explain in part its more favorable performance in skill acquisition and adoption of new technologies in relation to most of the other major countries. Murphy, Riddle and Romer (1998) show that even though the relative demand for more educated labor has shifted out in Canada at the same rate as in the United States, the rate at which relative wages diverge has been significantly lower in Canada due to an increase in the relative supply of more-educated workers. Correspondingly, policies facilitating educational attainment and skill acquisition can have a significant effect on human capital accumulation, offsetting the undesired effect of income redistribution policies on skill-based technical progress and output growth.

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[19] See Freeman (1996) for a more detailed discussion.

[20] See DiNardo, Fortin and Lemieux (1994) and Card and Krueger (1995).

V. Conclusion

Our analysis provides a simple framework that illustrates the link between the wage premium, acquisition of skills and investment in new technologies. We show the economic costs in terms of foregone output growth resulting from policies or institutional arrangements that serve to limit the earning differentials across workers with different skill levels. Labor market institutions and income policies preventing the skill premium from playing its role, could constrain the complementarities between skills and new technologies, hence limiting their positive effect on output and productivity growth. Together with having the highest income disparity and investment in new technologies, the United States has enjoyed the highest average rate of output growth in the last two decades and the highest acceleration in labor productivity compared to France, Germany, the United Kingdom, and Canada. The more limited differentiation in wages in these countries could be related to economic policies and/or institutional arrangements affecting labor market behavior; such practices to some extent may reflect social choices and cultural differences. As in the case of Canada, which has experienced a similar shift in the demand for skilled labor to the United States, policies facilitating skill acquisition through education subsidies have helped offset, at least partially, the effect of policies capping the wage premium while maintaining the positive economic benefits of skill-biased technical progress.

Figure 1. Output Growth Path and Convergence

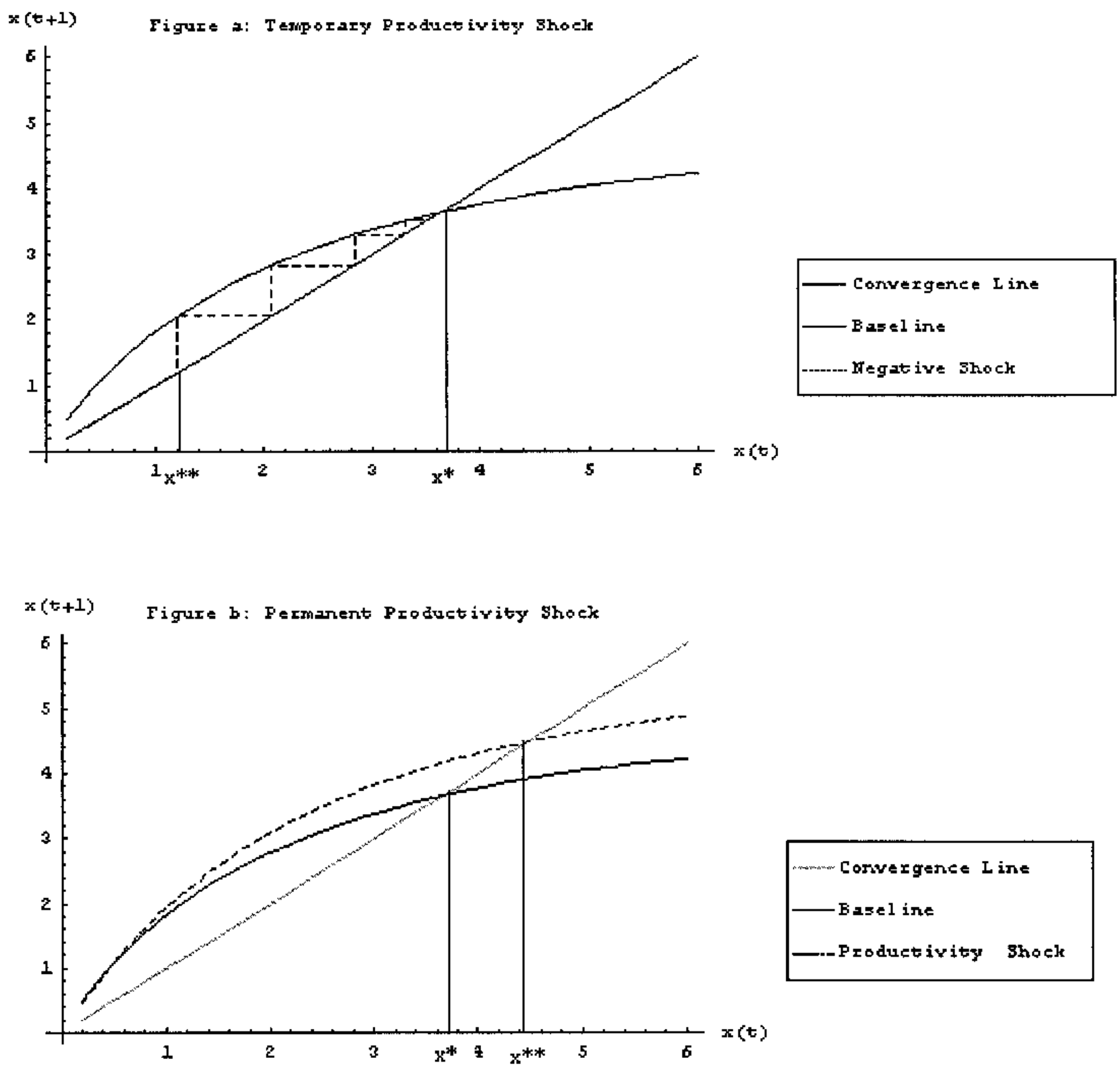


Figure 2. Output Growth Path under Different Income Transfer Policies

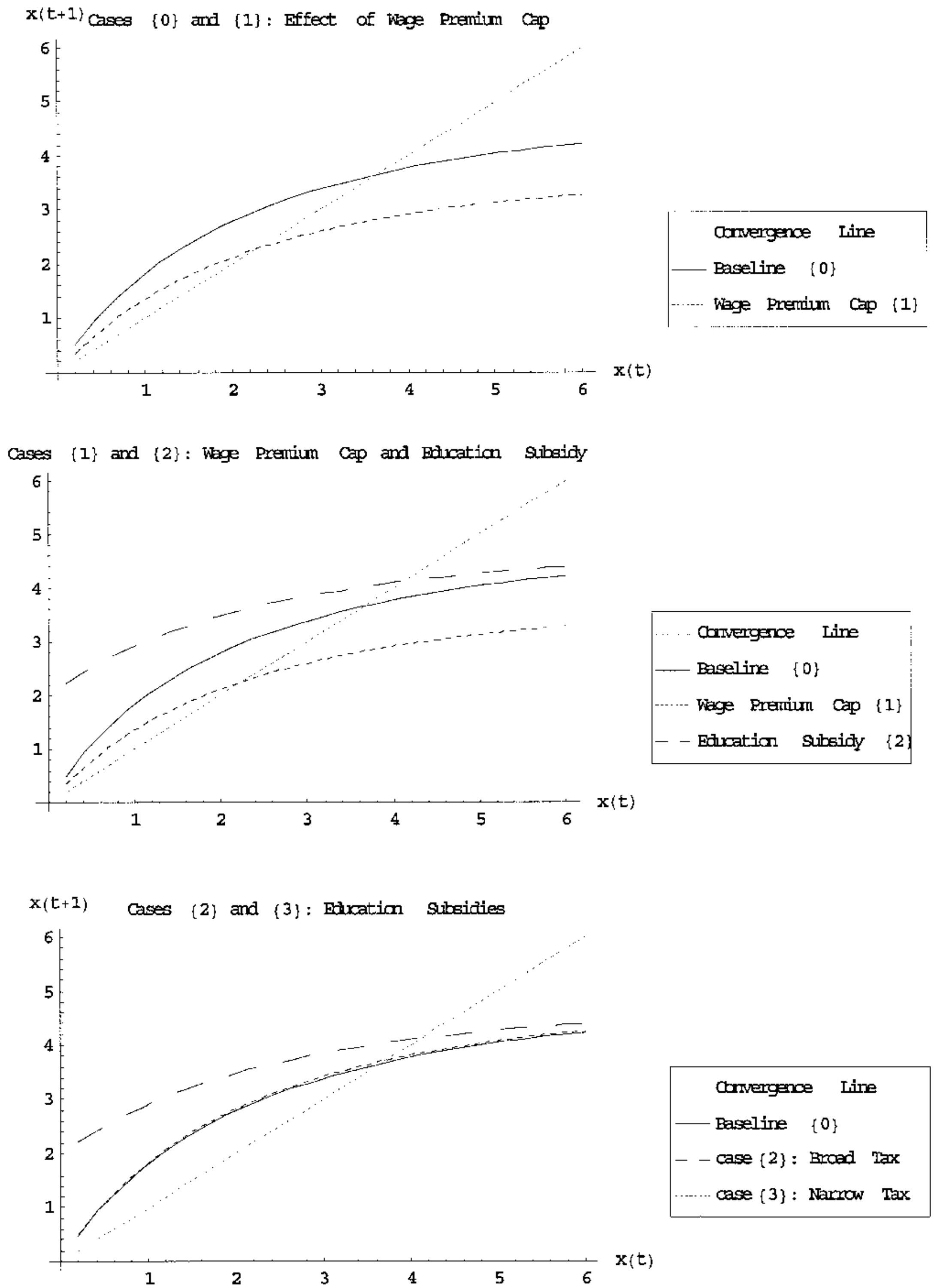
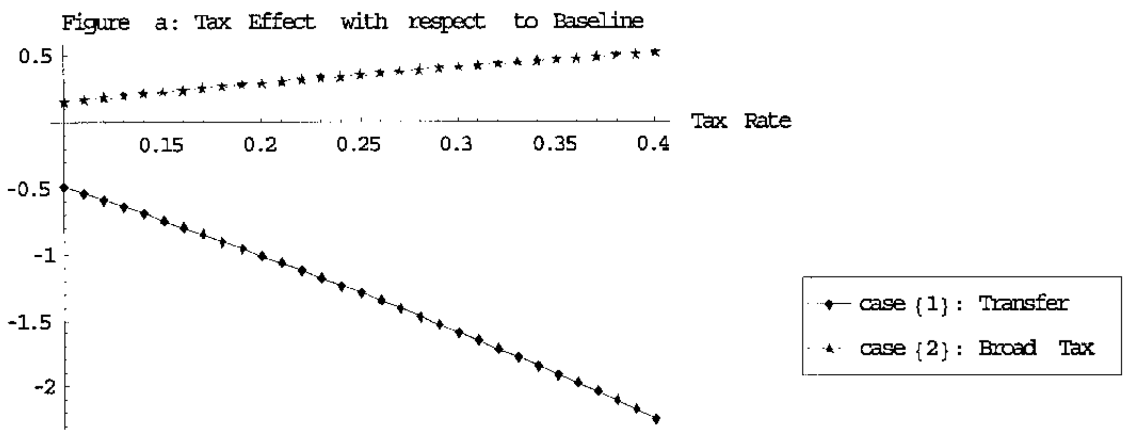


Figure 3. Relative Growth Effect of Tax and Subsidies



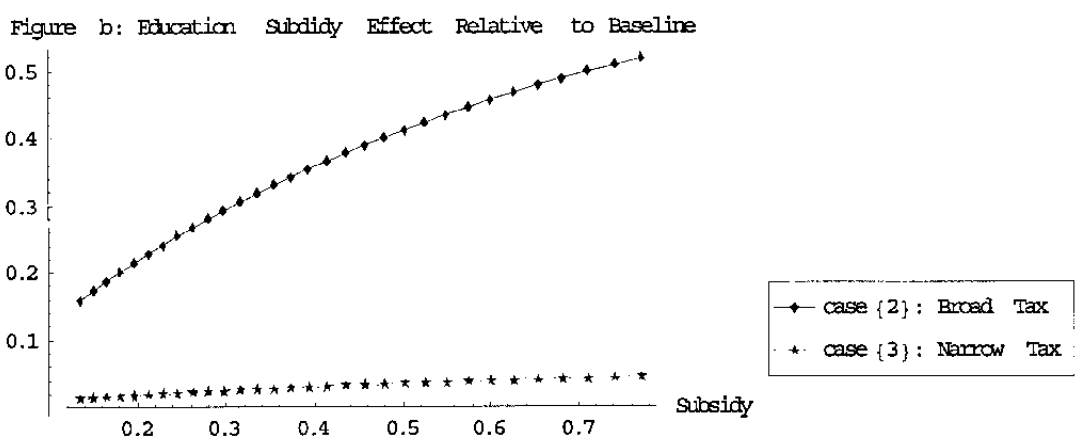
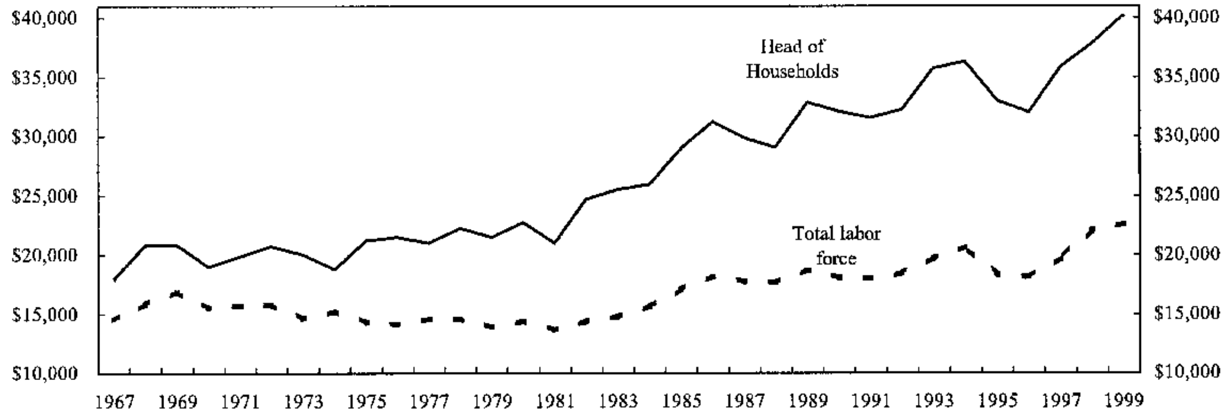
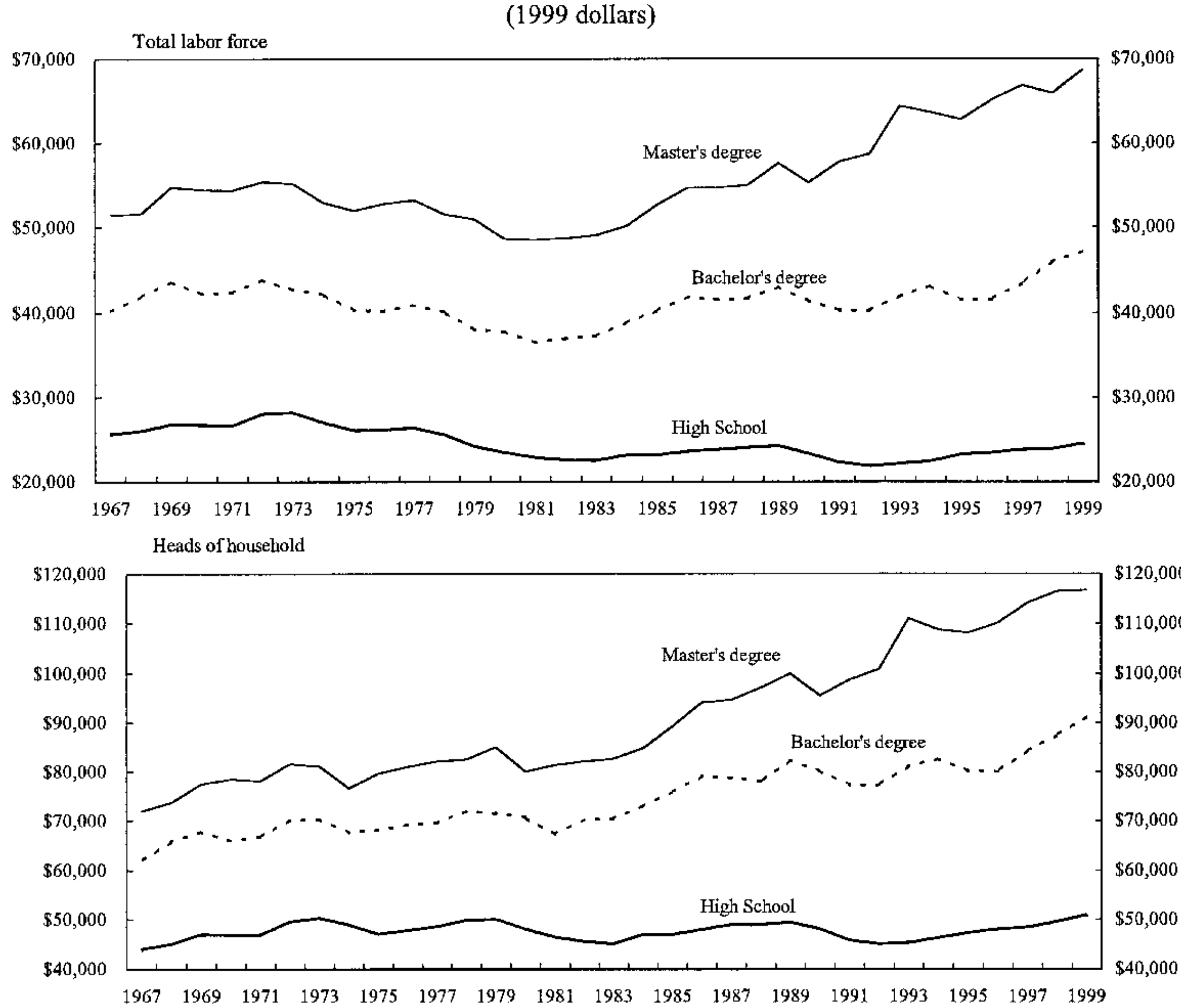


Figure 4. United States: Skill Premia[1]
(1999 dollars)



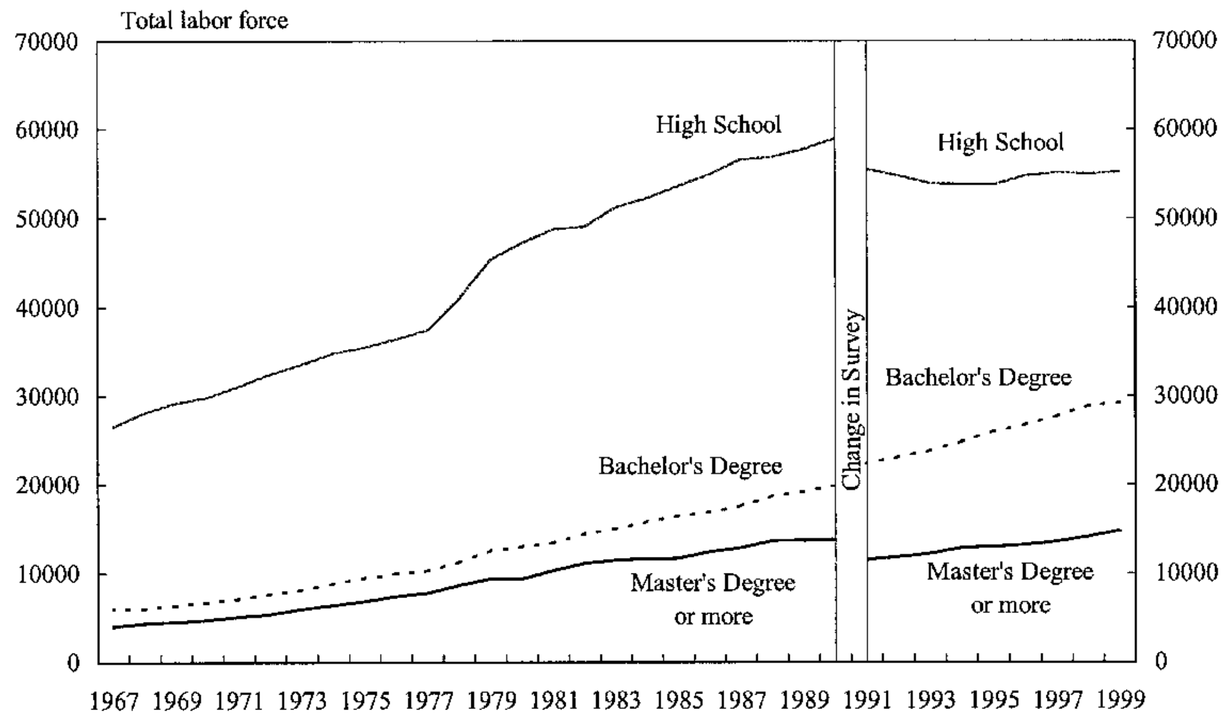
Source: U.S. Census Bureau. Current Population Survey.
1/ Wage differential between college and high school graduates.

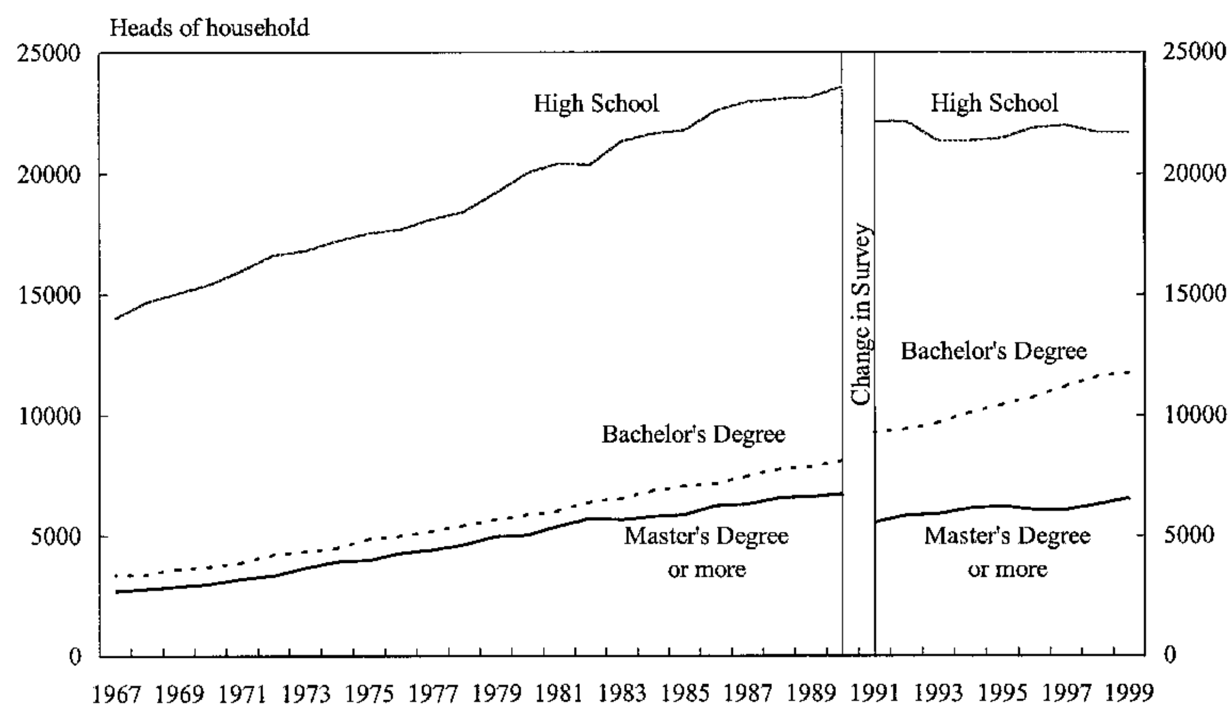
Figure 5. United States: Average Wages by Skill Level
(1999 dollars)



Source: U.S. Census Bureau. Current Population Survey.

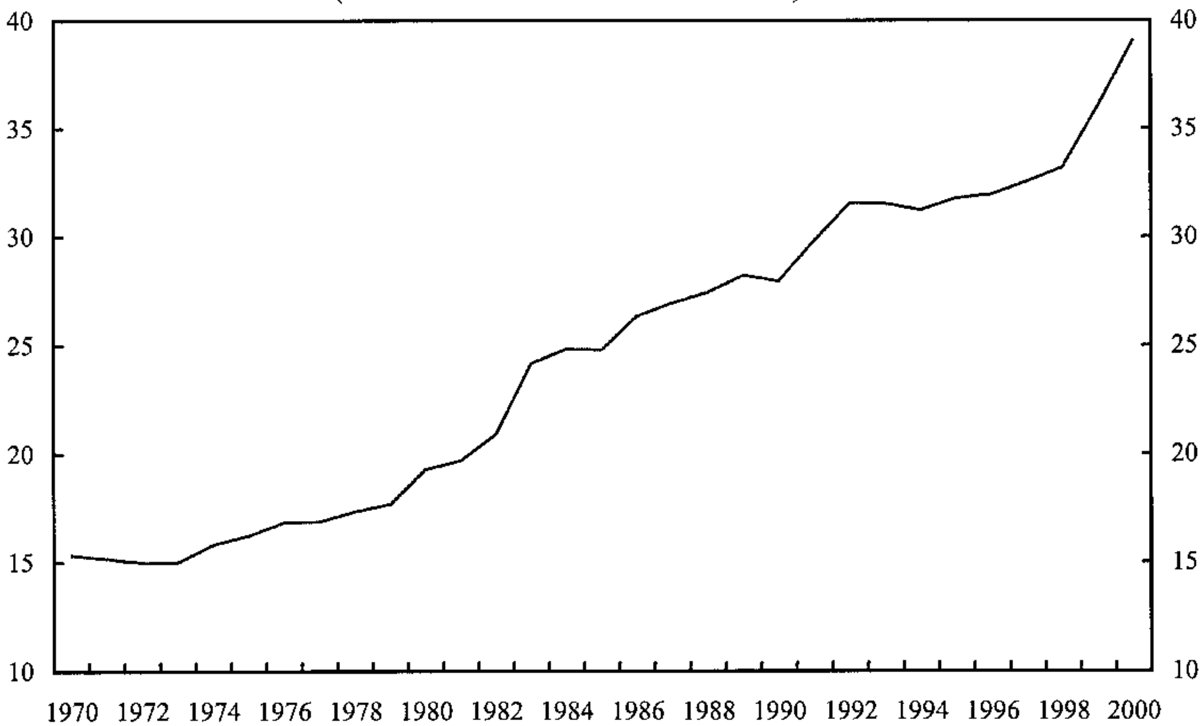
Figure 6. United States: Employment by Skill Level
(Thousands of people)





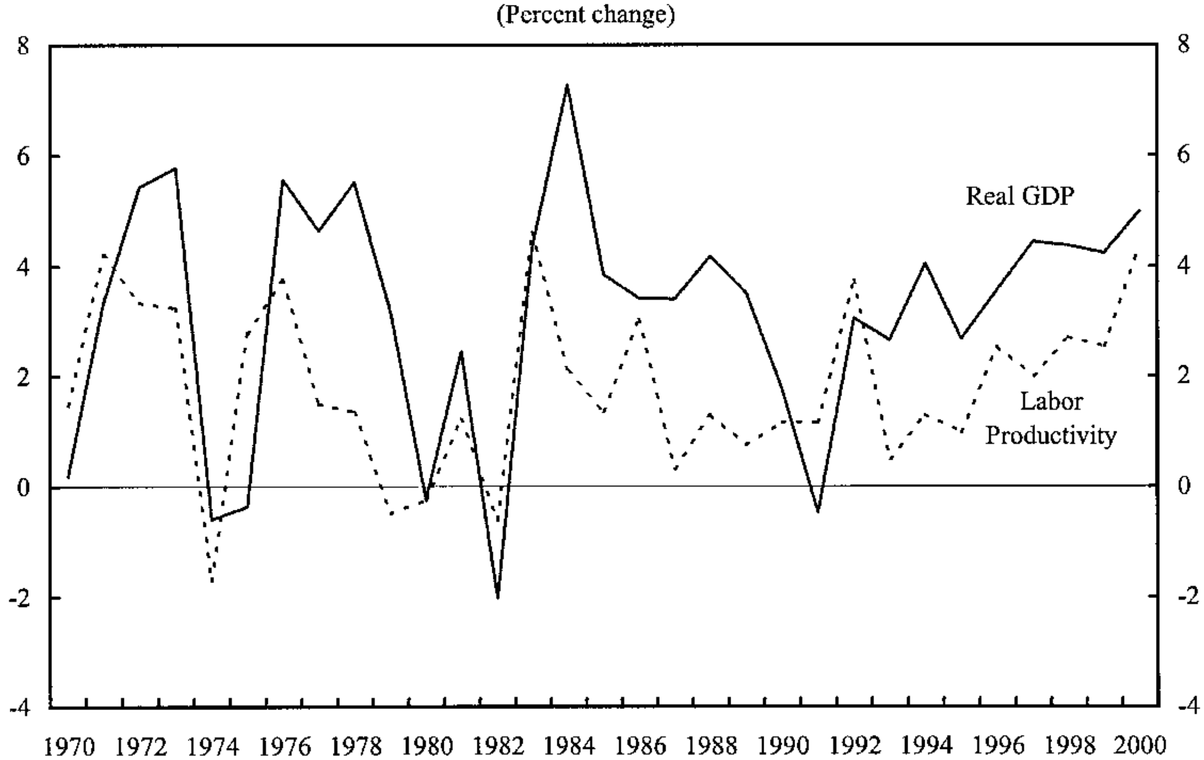
Source: U.S. Census Bureau. Current Population Survey.

Figure 7. United States: Investment in Information Technology
Equipment and Software
(Percent of nonresidential fixed investment)



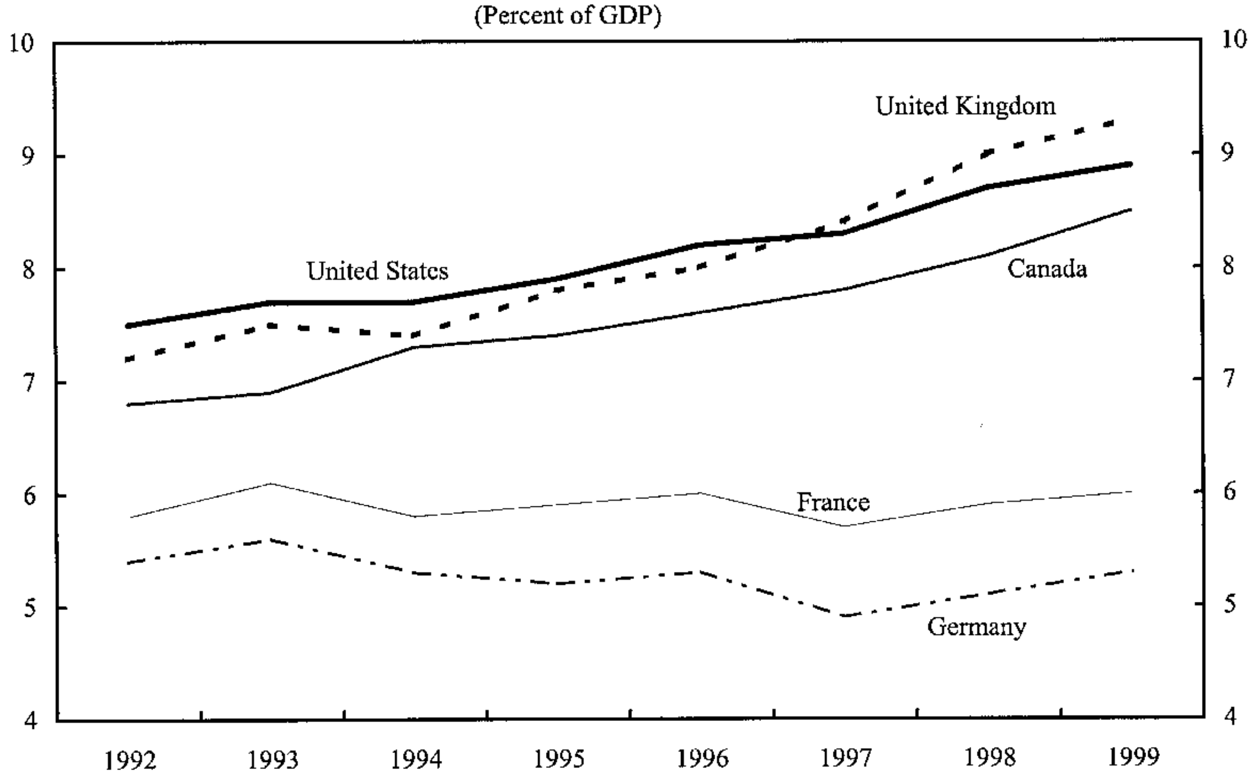
Source: U.S. Department of

Figure 8. United States: GDP and Labor Productivity Growth
(Percent change)



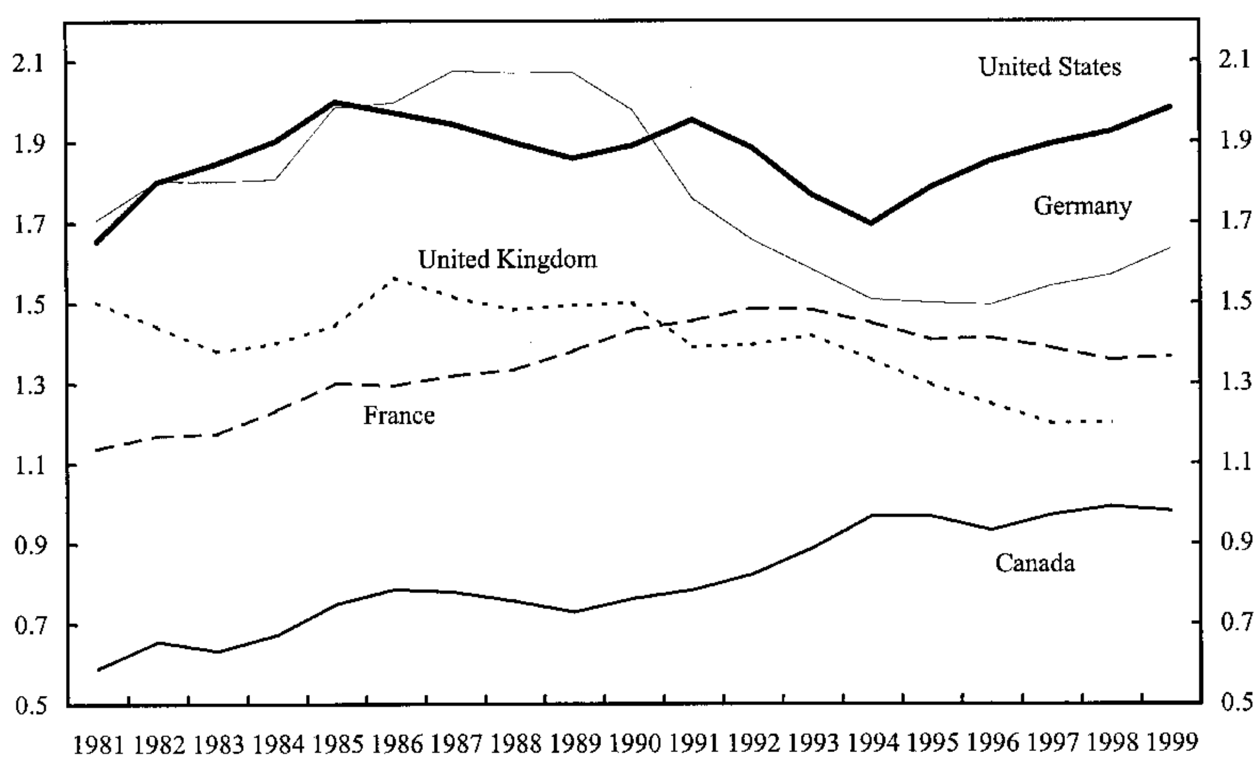
Sources: U.S. Department of Commerce, Bureau of Economic Analysis; and Bureau of Labor Statistics.

Figure 9. International Comparison: Information Technology Investment
(Percent of GDP)



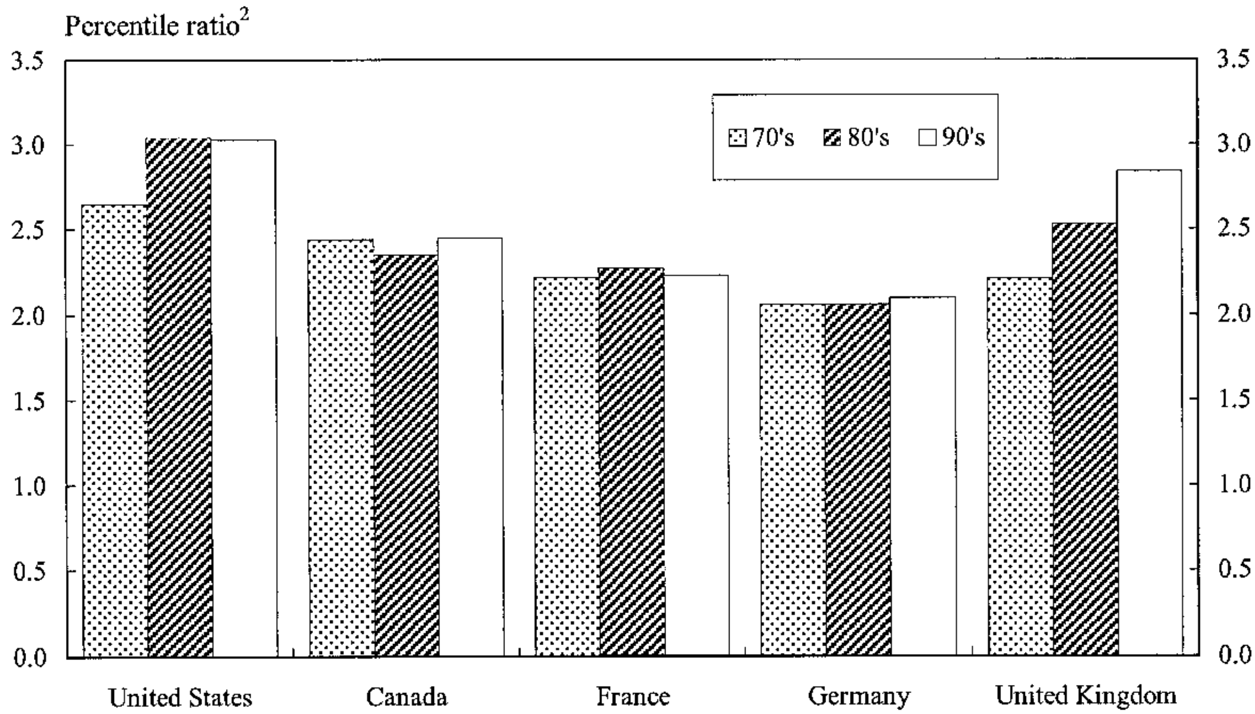
Source: WITSA/IDC.

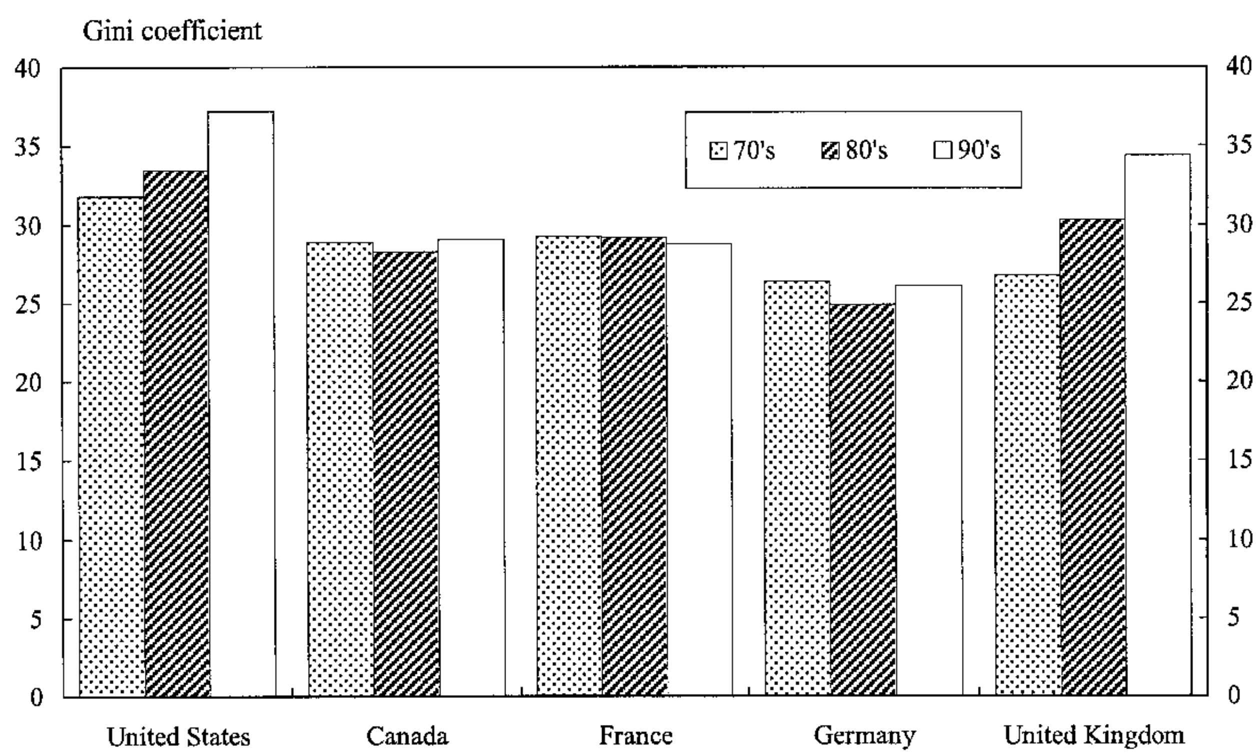
Figure 10. International Comparison: Private Business Expenditure on
Research and Development



Source: OECD.

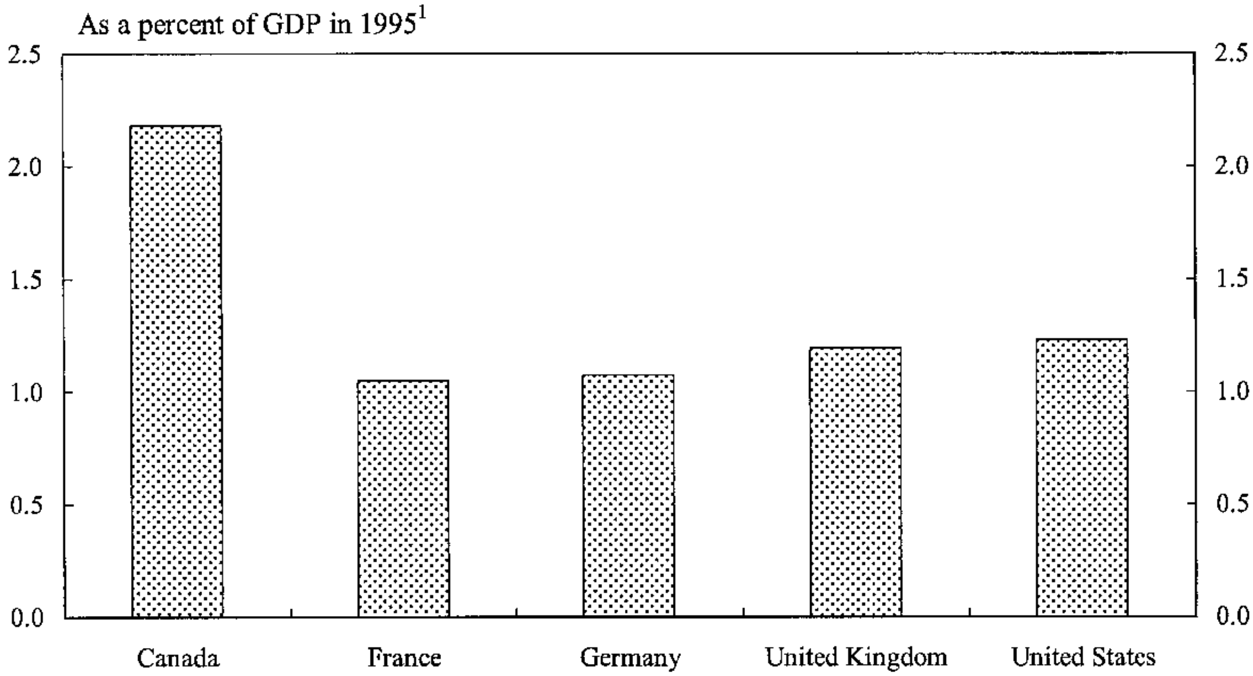
Figure 11. International Comparison: Income Distribution.[1]



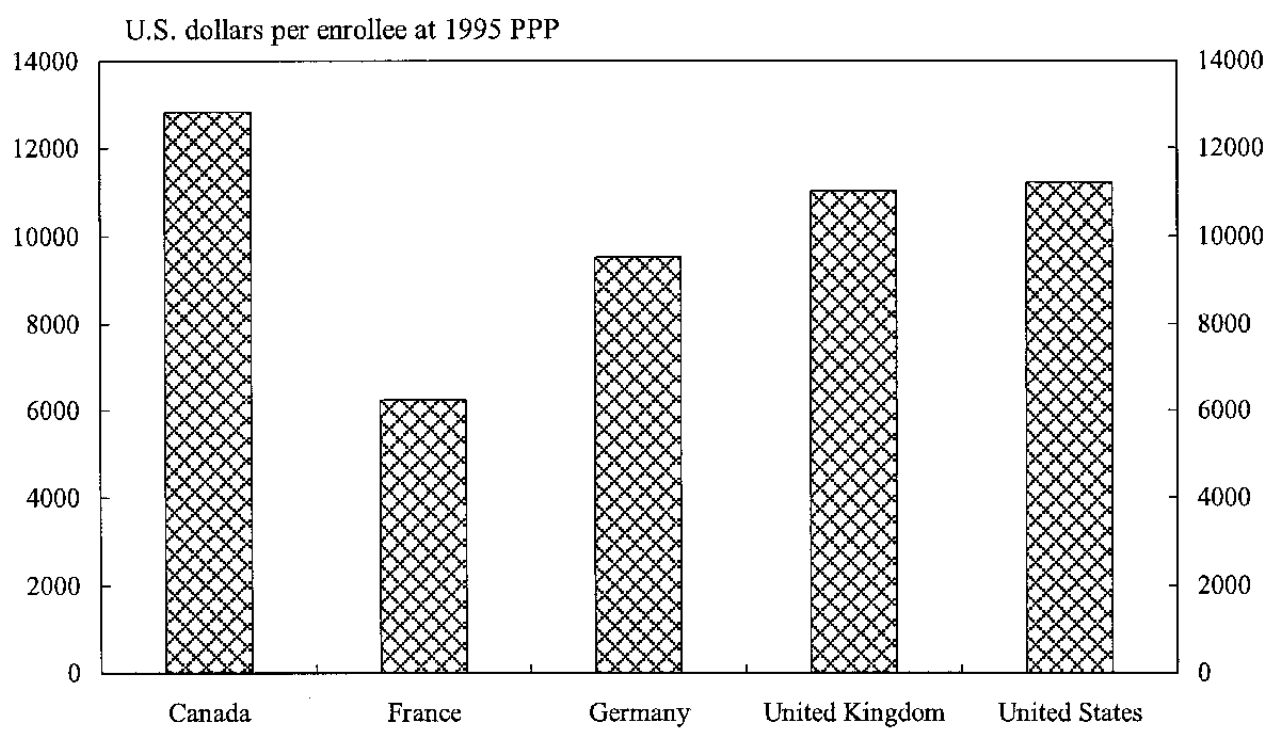


Source: Luxembourg Income Study (LIS Database).
1/ Based on pre-tax income.
2/ Ratio of the highest 20th percentile to the 20th lowest percentile.

Figure 12. International Comparison:
Total Government Expenditure for Higher Education



1/ Includes all spending for education beyond the secondary level.



Source: OECD.

The Model and Proofs of the Results

Basic structure of model

Preferences and choice of higher education

Heterogeneous individuals with ability i uniformly distributed over $[0,1]$ and a cost to acquire education $g(i)$ increasing in i.

Marginal Individual's decision to acquire education:
$w_{s,t}(1-g(m_t)) \geq w_{u,t} \Leftrightarrow \pi_t \equiv \frac{w_{s,t}}{w_{u,t}} = \frac{1}{1-g(m_t)}$ where $w_{s,t}$ and $w_{u,t}$ correspond to the skilled and unskilled wages in period t, and m_t is the marginal individual's ability.

Production technology

Production function with labor-augmenting technical progress: $Y_t = F(K_t, A_t L_t) \equiv A_t L_t f(k_t)$, where total labor is a function of skilled and unskilled labor inputs: $L_t = s_t^{\alpha} u_t^{1-\alpha}$ where $\alpha \in (\frac{1}{2},1)$.

Labor demand as a function of the wage premium: $\pi_t \equiv \frac{w_{s,t}}{w_{u,t}} = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{u_t}{s_t}\right)$.

Labor market equilibrium condition

$$\pi_t = \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{1-m_t}{m_t - G(m_t)}\right) = \frac{1}{1-g(m_t)}$$

The proofs of the results

Equilibrium with exogenous growth

Growth path such that the technological level increases at a constant rate: $x \equiv \frac{A_t}{A_{t-1}} - 1$.

Result 1: *The fraction of skilled workers, determined by the marginal worker with ability* m *choosing to acquire education, represents a unique function* $\overline{m}(\alpha, g)$ *such that* $\overline{m}$ *is increasing in* α *(the relative productivity parameter of skilled labor) and decreasing in* g *(the cost of education).*

Proof: Consider a linear education cost function $g(i) = \mu i$ where parameter $\mu \in (0,1)$. From the equilibrium equation (1), let a function $H(m)$ be such that:

$$H(m_t, \mu) = \frac{(1-m_t)(1-\mu m_t)}{m_t - \mu m^2/2} = \frac{1-\alpha_t}{\alpha_t} \tag{1}$$

We have then that $H(m_t, \mu)$ is continuous and decreasing in m_t with the following properties: $\lim_{m_t \to 0} H(m_t, \mu) = \infty$ and $\lim_{m_t \to 1} H(m_t, \mu) = 0$. So for any $\alpha_t \in (0,1)$, there exists a unique m_t such that $H(m_t, \mu) = \frac{1-\alpha_t}{\alpha_t}$. Given that $H(m_t \mu)$ is decreasing and continuous, m_t increases with α_t. The partial derivative of H with respect of μ is negative. So m_t is decreasing in μ. This proof also applies to a general specifications of $g(i)$ as long as the cost function is differentiable and $g(1) < 1$, as assumed.

Endogenous skill-biased technological growth

Skill-biased technological progress assumption: Let a positive relation between the rate of technological progress and the relative labor productivity parameter: $\alpha(x_t)$, where x_t is the rate of technical progress.

Growth-enhancing effect of human capital accumulation assumption: Let a higher share of skilled workers in one period lead to a higher rate of technical progress in the next period: $x_{t+1} = \Gamma(s_t)$.

Result 2: *There exists a unique steady-state growth path $\bar{x}$ so that the economy converges monotonically to it. As a corollary the dynamics of technological progress $\{x_t\}$ is positively related to the evolution of the wage premium and the fraction of skilled labor. We need to show that a transition function $F(x_t) = x_{t+1}$ exists such that it is monotonic increasing and concave.*

Proof: Given that we have assumed that the function $\Gamma(s_t)$ is increasing and weakly concave, we need to prove that $\overline{m}(\alpha_t, g)$ is concave as $s_t = \overline{m}(\alpha_t, g) - G(\overline{m}(\alpha_t, g))$ and $g(i)$ is weakly convex. From the specification above for the cost function, we have that $\overline{m}(\alpha, \mu) = \frac{\alpha\mu + 1 + \left((\alpha\mu)^2 + 1 - 2\alpha^2\mu\right)^{1/2}}{\mu + \mu\alpha}$. This is a weakly concave function on $\alpha(x_t)$ which in turn is strictly concave by assumption. This results implies that $F(x_t)$ is also concave. The wage premium is determined by $\pi = \frac{1}{1 - g(\overline{m}(\alpha, g))}$, while the fraction of skilled labor is given by $\overline{m}(\alpha, g)$. So these two variables are monotonically related to the evolution of output. □

The effect of income redistribution and education subsidies

The balance budget constraint: $w_s\tau_s s + w_u\tau_u u = \varepsilon G(m) + u\eta$, where τ_s, τ_u, η, and ε correspond to an income tax on skilled and unskilled workers, a lump sum transfer to unskilled labor and an education subsidy respectively.

Result 3: *Let subscript {0} denote the no-policy, baseline case while subscripts {1} represent the income redistribution policy (with no education subsidy). We find that* $\bar{x}_1 < \bar{x}_0$ *;* $\bar{\pi}_1 < \bar{\pi}_0$*; and* $\bar{m}_1 < \bar{m}_0$ *Output growth, after-tax wage premium and investment in human capital decrease relative to the baseline case.*

Proof: The policy of capping the skill premium assumes an income transfer from skilled workers to unskilled workers. This corresponds to having $(\tau_u, \varepsilon) = 0$ implying that the budget constraint is $w_s\tau_s = u\eta$. This leads to an equilibrium condition such that $H(m,\mu) = \dfrac{1-\alpha(1-\tau_s)}{\alpha(1-\tau_s)}$. It follows that the resulting investment in human capital $\bar{m}_1(\alpha, \mu, \tau_s)$ is smaller than the one derived from the neutral case $\bar{m}_0(\alpha, \mu)$. Because of the monotonicity of the transition function, we have that $\bar{x}_1 < \bar{x}_0$.

Result 4: *Let subscripts {2,3} denote the policy options to subsidize investment in human capital; the first one represents the case of a broad tax base (comprising an income tax on all workers), while the second corresponds to the case of income taxation on only skilled workers.*

Proof: We obtain that, for the same per-capita education subsidy, $\bar{x}_2 > \bar{x}_3 > \bar{x}_0$*; and* $\bar{m}_2 > \bar{m}_3 > \bar{m}_0$.

Policy experiment {2}: Consider an education subsidy financed by taxes on all agents: $\tau_s = \tau_u = \tau > 0$ such that $(w_s s + w_u u)^* \tau = \varepsilon G(m)$. The resulting equilibrium condition is:

$$H(m,\mu) = \frac{1-\alpha}{\alpha} - \left(\frac{1}{\alpha}\right)\left(\frac{\tau}{1-\tau}\right)\left(\frac{1-m}{m}\right).$$

Policy experiment {3}: Assume a tax only on skilled workers: $\tau_s = \tau > 0$ and $\tau_u = 0$. The budget constraint implies: $w_s s\tau = \varepsilon G(m)$. We obtain the equilibrium condition such that:

$$H(m,\mu) = \frac{1-\alpha}{\alpha} - \left(\frac{\tau}{1-\tau}\right)\left(\frac{1-m}{m}\right).$$

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