Investment-Specific Technological Change, Skill Accumulation, and Wage Inequality*

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ABSTRACT

Wage inequality between education groups in the United States has increased substantially since the early 1980s. The relative quantity of college-educated workers has also increased dramatically in the postwar period. This paper presents a unified framework where the dynamics of both skill accumulation and wage inequality arise as an equilibrium outcome driven by measured investment-specific technological change. Working through capital-skill complementarity and endogenous skill accumulation, the model is able to account for much of the observed changes in the relative quantity of skilled workers. The model also does well in replicating the observed rise in wage inequality since the early 1980s. Based on the calibrated model, we examine the quantitative effects of some hypothetical tax-policy reforms on skill formation, inequality, and welfare.

JEL classification: E25 (Aggregate factor income distribution); J31 (Wage differentials by skill); O33 (Technological change)

Key Words: Skill Premium; Skill Formation; Technological Change; Capital-Skill Complementarity.

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1 Introduction

In the postwar period, the U.S. economy has experienced steady growth in per capita income, accompanied by substantial changes in income inequality. As shown in Figure 1, income inequality measured by the relative wage of college-educated workers (i.e., college wage premium) increased in much of the 1960s, then declined modestly in the 1970s, and has since increased substantially starting in the early 1980s. In the meantime, the number of skilled workers (e.g., those with college degrees) has steadily grown relative to the number of unskilled workers (e.g., those with high school diplomas), as is evident in Figure 2. Understanding potential causes of the observed dynamics in wage inequality and skill accumulation is of great interest to both academic economists and policy makers.

The literature on wage inequality is large and growing. Most studies attribute the dynamics of wage inequality to skill-biased technological change (SBTC). One possible mechanism through which SBTC may affect wage inequality is proposed by Katz and Murphy (1992). Based on a simple supply and demand framework, they argue that, if there is a constant secular trend in SBTC, then the increase in the supply of skilled workers in the 1970s associated with the baby boom generation leads to a temporary fall in inequality, which, before moving back to its secular trend, is bound to increase at an accelerated rate (see also Bound and Johnson, 1992). It is unclear, however, what drives the trend in SBTC. Acemoglu (1998) proposes that SBTC can be endogenous and can respond to the market size for skilled workers. As the relative supply of skilled workers increases, there will be a larger market size and more monopoly rents for skill-complementary technologies. This provides a greater incentive for innovating firms to upgrade the productivity of skilled workers. As a result, the skill premium initially falls and then rises.1

Most studies in the SBTC literature do not examine the quantitative contributions of the underlying mechanisms that may drive wage inequality. Yet, to understand the driving mechanisms of the changes in inequality and other labor market phenomena, “it is necessary to formulate dynamic models that can quantitatively include the main alternative explanations so that one can measure the impact of each one of them” (Eckstein and Nagypal, 2004, p. 26).

In an important contribution, Krusell et al. (2000, henceforth KORV) build a quantitative framework to study the evolution of wage inequality. They show that, if capital equipments are more complementary to skilled workers than to unskilled workers (e.g., Griliches, 1969), then

1Other theories on wage inequality include, for example, openness to international trade, changes in the unionization rate, and changes in real minimum wages. A general consensus is that SBTC theories provide a more compelling story than these other theories. For a survey of this literature, see, for example, Acemoglu (2002) and Aghion (2002).
variations in the quantities of input factors help account for much of the observed changes in
college wage premium in the post-war U.S. economy. They interpret capital-skill complementarity
as a form of SBTC. They further suggest that the observed changes in capital equipments can
be attributable to investment-specific technological change in the spirit of Greenwood, Hercowitz,
and Krusell (1997, henceforth GHK). The study by KORV (2000) is particularly important from a
macroeconomic perspective because it relates the driving forces of the relative demand for skilled
workers and skill premium to input factors that can be explicitly measured.

A common feature of these SBTC-based theories — including KORV (2000) — is that tech-
nological change drives wage inequality through affecting the relative demand for skilled workers,
taking as given the relative supply of skilled workers.\(^2\) In the current paper, we would like to turn
the question around and ask: What quantitative framework helps account for the dynamics of
both skill accumulation and wage inequality, taking as given some measures of SBTC? In other
words, we would like to build a quantitative model with endogenous human capital accumulation
(instead of taking the supply of skills as given), and to examine whether the observed changes in
wage inequality and the relative quantity of skilled workers can arise as an equilibrium outcome
driven by measured technological change.

For this purpose, we build a general equilibrium model with vintage capital, in which produc-
tion of capital equipments becomes increasingly efficient over time (as in Greenwood, Hercowitz,
and Krusell, 1997). To examine the quantitative effects of such capital-embodied (or investment-
specific) technological change on the equilibrium dynamics of wage inequality and skill accumu-
lation, we assume that capital equipments are more complementary to skilled workers than to
unskilled workers (as in KORV, 2000), and that the accumulations of both physical capital and
human capital require scarce resources (as in Stokey, 1996). With reasonable parameter values,
we find that the model driven by measured investment-specific technological change is able to
account for much of the steady growth in the relative quantity of skilled workers in the postwar
U.S. economy, and the model does well in replicating the substantial rise in wage inequality after

\(^2\)There are a few notable exceptions. For instance, Heckman, Lochner, and Taber (1998) develop and estimate
an overlapping generations (OLG) model with heterogenous skills, endogenous (once-for-all) schooling choice, and
post-school on-the-job investment to study college wage premium and skill formation. For their purpose, they
approximate SBTC by a trend estimated from an aggregate technology, rather than using direct measures, such
as that based on observed changes in the relative price of equipments. Greenwood and Yorukoglu (1997), on the
other hand, emphasize the role of declining prices of producer durables and equipments in explaining the rise in
wage inequality and the slowdown in productivity growth. Unlike KORV (2000), both of these studies abstract
from capital-skill complementarity. For a more recent quantitative study of the changes in college wage premium
and college enrollment rate, see He (2005), who constructs an OLG model that incorporates demographic change,
investment-specific technological change, and capital-skill complementarity.
the early 1980s. Further, we find that investment-specific technological change in our model accounts for about 62% of the average annual growth rate of output per hour during the postwar period, which is remarkably close to the finding in Greenwood, Hercowitz, and Krusell (1997), who abstract from capital-skill complementarity and human capital accumulation.

Our model contains a simple mechanism that propagates the investment-specific technological change (denoted by \( q \)) to generate the observed patterns in skill accumulation and wage inequality. As \( q \) grows over time, the relative price of capital equipments falls, which encourages investment in new equipments. Given capital-skill complementarity, the expectation that the stocks of equipments will rise in the future provides incentive for increased investment in human capital, since increases in equipments would raise the marginal productivity of skilled workers and lower the marginal productivity of unskilled workers. Of course, the increase in the relative quantity of skilled workers tends to dampen the rise in the skill premium. With plausible capital-skill complementarity and a calibrated skill accumulation process, the model is able to deliver both the steady growth in the relative quantity of skilled workers and the substantial rise in wage inequality after the early 1980s.

An implication of the model’s mechanism is that, not only changes in \( q \), but other factors that can raise the stocks of capital equipments can also raise wage inequality. To investigate this possibility, we present a counterfactual experiment based on the calibrated model. In the experiment, we lower the capital income tax rate from 39.7% to 0 in the spirit of the optimal Ramsey taxation literature (e.g., Chamley, 1986), and examine the effect of this capital-income tax reduction on capital and skill accumulations and on wage inequality. When we eliminate capital income taxes, we adjust the labor income tax rate to keep the present value of the tax revenue unchanged. We assume that the same time series for \( q \) drives equilibrium dynamics before and after the tax reform.\(^3\) We also examine the effects of the tax reform on welfare, which is measured by a consumption equivalence in the spirit of Lucas (1987). We find that lowering the capital tax rate to zero leads to a substantial increase in the stock of capital equipments and in the relative quantity of skilled workers. The tax reform also creates a sizable increase in welfare. Yet, perhaps surprisingly, its effect on wage inequality is small.

The reduction in capital income taxes works through three channels to affect wage inequality. First, the reduction in capital taxes raises the stocks of capital equipments and, with capital-skill complementarity, raises the relative marginal productivity of skilled workers as well. Second, related to the first, the reduction in capital taxes encourages skill accumulation and thereby

\(^3\) More accurately, we are comparing two economies with the same \( q \) series (and the same tax revenue), but with different factor-income tax rates.
lowers the skill premium, since the relative supply of skilled workers increases. Third, to keep the present value of tax revenue unchanged, the reduction in capital taxes requires an increase in the labor income tax rate. Since the labor income tax is proportional and thus progressive, it discourages skill accumulation and thereby raises the skill premium. The third effect of capital-tax reduction reinforces the first to generate higher wage inequality, but the second effect tends to offset the other two. Under calibrated parameters, the net effect of the capital-tax reduction on wage inequality is small.

In a second counterfactual experiment, we examine the effectiveness of two (revenue-neutral) policy changes that aim at reducing income inequality. One such policy is to raise the progressiveness of labor income taxes, and the other is to provide subsidies for human-capital investment. Under calibrated parameters, increasing the progressiveness of labor taxes turns out to be ineffective in reducing wage inequality, since it discourages skill accumulation and thereby increases the scarcity of skilled labor. Further, by lowering the average skill level, such a policy change can lead to a decline in average productivity and inflict a substantial welfare loss. In contrast, subsidizing human capital accumulation can effectively reduce the skill premium through raising the relative quantity of skilled workers, and the policy change is unambiguously welfare-improving.

In what follows, we present the model in Section 2, describe the calibration and solution methods in Section 3, discuss the main results in Section 4, present the counterfactual policy experiments in Section 5, and conclude in Section 6. In an appendix, we describe the data and computation methods.

2 The Model

We now present a general equilibrium model with vintage capital. The model features (i) investment-specific (or capital-embodied) technological change, under which the production of new capital equipments becomes increasingly efficient over time; (ii) capital-skill complementarity, under which capital equipments are more complementary to skilled workers than to unskilled workers; and (iii) endogenous accumulations of human capital.

2.1 The Economic Environment

Time is discrete. The economy is populated by a large number of identical, infinitely lived households. Each household consists of two types of worker members: skilled and unskilled. The

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4Proportional labor-income taxes have no direct effects on the skill premium since the skill premium is the ratio of skilled wage to unskilled wage, and the wage incomes are subject to the same tax rate.
representative household supplies labor inelastically, so that her time allocation problem involves
divisions of her time endowment (normalized to one unit) between the supplies of skilled labor
and of unskilled labor, but there is no labor-leisure trade-off. The household consumes a final
good, which is produced by a large number of firms. Production of the final good requires four
input factors, including skilled labor, unskilled labor, capital equipments, and capital structures.
The final good can be used for consumption and for accumulations of physical capital (equip-
ments and structures) and human capital (skills). There is a government that collects revenues
through proportional taxes on labor incomes and capital incomes, and rebates the proceeds to
the representative household through lump-sum transfers. All agents have perfect foresight.

The representative household has a lifetime discounted utility function given by
\[
\sum_{t=0}^{\infty} \beta^t c_t^{1-\sigma} \frac{1}{1-\sigma},
\]
where $\beta \in (0,1)$ is a subjective discount factor, $c_t$ is the household’s consumption of the final
good, and $\sigma > 0$ is a relative risk aversion parameter.

The representative firm has access to a constant-returns production technology to produce the
final good. The production function is given by
\[
y = k_s^\theta \left[ \mu(zu)^\nu + (1 - \mu)[\lambda k_e^\phi + (1 - \lambda)(zs)^\phi]^\nu/\phi \right]^{1-\theta/\nu},
\]
where $y$ denotes output, $k_s$ denotes input of capital structures, $k_e$ denotes input of capital equip-
ments, $u$ denotes input of unskilled workers, $s$ denotes input of skilled workers, $z$ denotes a
(neutral) labor-augmenting technological change, and we have suppressed the time-script to save
notations. The parameter $\theta \in (0,1)$ measures the elasticity of output with respect to capital struc-
tures, and the parameters $\phi$ and $\nu$ determine the elasticities of substitution between equipments
and skilled labor and between the skill-equipment composite and unskilled labor, respectively. If
$\phi < \nu < 1$, then equipments are more complementary to skilled workers than to unskilled workers.

Physical capitals depreciate over time. Denote by $\delta_s$ and $\delta_e$ the depreciation rates for capital
structures and equipments, respectively. Then, the laws of motion for these capital stocks are
given by
\[
k'_s = (1 - \delta_s)k_s + i_s,
\]
and
\[
k'_e = (1 - \delta_e)k_e + i_e q,
\]
where a variable with a prime denotes its next-period value, and $i_s$ and $i_e$ are new investments in
capital structures and capital equipments. We interpret the term $q$ in (4), in the spirit of GHK
(1997), as investment-specific technological change that enhances the productivity of newly formed
capital equipments. One can also interpret $1/q$ as the relative price of new capital equipments, which, according to the evidence provided by GHK (1997) and Cummins and Violante (2002), is declining for much of the postwar period, and the decline has accelerated since the mid-1970s. We will discuss more about $q$ in the calibration section.\footnote{Our model can be reinterpreted as a two-sector model, in which one sector produces consumption good and capital structures, and the other produces equipments. Each sector is subject to a sector-specific productivity shock. Then, under some conditions (e.g., perfect factor mobility and identical capital-labor ratio across sectors), such a two-sector model is isomorphic to the model used in our quantitative analysis. See also GHK (1997) for a similar result in an environment with Cobb-Douglas technologies.}

Following Stokey (1996), we assume that the stock of human capital (i.e., skills) evolves according to the law of motion

$$s' = (1 - \eta)s + B \left( \frac{i_h}{z} \right)^\alpha,$$

where $s'$ denotes the fraction of skilled workers available in the next period, $i_h$ denotes the resources (in terms of the final good) used to form new skills, the parameter $\eta \in (0, 1)$ represents the depreciation rate of human capital, and we assume $B > 0$ and $\alpha \in (0, 1)$. We divide $i_h$ by $z$ in (5) to be consistent with balanced growth, under which the investment-specific technological change $q$ settles down at a constant level while the neutral technological change $z$ grows at a constant rate. Equation (5) captures the idea that some scarce resources are required to form new skills or to transform unskilled labor into skilled labor. The assumption that $\alpha < 1$ reflects costly adjustment in human capital accumulations: a lower value of $\alpha$ implies a higher adjustment cost. One may also interpret $\alpha < 1$ as capturing the existence of some fixed factors in the production of human capital. The parameter $B$ measures the efficiency of human capital investment. Unlike $q$, which measures the productive efficiency of newly formed capital equipments over time, the term $B$ here is assumed to be constant. We also assume that investments in physical and human capitals are non-negative, so that $i_s, i_c, i_h \geq 0$.

The government collects tax revenues through proportional taxes on the household’s capital income and labor income. In calculating the tax base for capital income taxes, there is a depreciation allowance. The government rebates tax revenues to the representative household through lump-sum transfers, so that

$$\tau_k[(r_s - \delta_s)k_s + (r_e - \delta_e/q)k_e] + \tau_l(w_s + w_u) = T,$$

where $\tau_k$ and $\tau_l$ are the tax rates on capital income and labor income, $r_s$ and $r_e$ are the rental rates on structures and equipments, $w_s$ and $w_u$ are the wage rates for skilled and unskilled workers, and $T$ is the lump-sum transfer.
2.2 Competitive Equilibrium

The representative household owns the physical capital (equipments and structures), which she rents to the representative firm at the competitive rental rates $r_e$ for equipments and $r_s$ for structures. The household is also endowed with one unit of time, which is divided into two types of labor (skilled and unskilled). The household supplies the two types of labor to the firm at the competitive wage rates $w_s$ for the skilled and $w_u$ for the unskilled. The household’s dynamic optimization problem, given the wage rates and the rental rates, is to choose consumption, investments in capital structures and equipments, investment in human capital, and the next-period values of the capitals to maximize the discounted utility

\[
V(k_s, k_e, s, z, q) = \max_{\{c, k'_e, k'_s, s', i_e, i_s, i_h\}} \frac{c^{1-\sigma}}{1-\sigma} + \beta V(k'_s, k'_e, s', z', q')
\]

subject to the budget constraint

\[
c + i_e + i_s + i_h \leq (1 - \tau_l)(w_s s + w_u (1 - s)) + (1 - \tau_k)(r_e k_e + r_s k_s) + \tau_k (\delta_e k_e / q + \delta_s k_s) + T,
\]

and the laws of motion (3), (4), and (5) for the physical capitals and the human capital, along with non-negativity constraints on $c$, $i_e$, $i_s$, and $i_h$.

The firm takes the wage rates and the rental rates as given, and chooses the quantities of inputs $\{\tilde{k}_e, \tilde{k}_s, \tilde{u}, \tilde{s}\}$ to solve a profit-maximizing problem

\[
\max \pi = y - w_s \tilde{s} - w_u \tilde{u} - r_e \tilde{k}_e - r_s \tilde{k}_s,
\]

where the output $y$ is related to the inputs through the production function (2). As the production technology exhibits constant returns and the firm faces perfectly competitive markets, profit is zero in equilibrium.

Let $\Phi = (k_s, k_e, s, z, q)$ denote the vector of aggregate state variables. A competitive equilibrium is a set of allocation rules $c = C(\Phi)$, $k'_e = K_e(\Phi)$, $k'_s = K_s(\Phi)$, $s' = S(\Phi)$, $i_e = I_e(\Phi)$, $i_s = I_s(\Phi)$, and $i_h = I_h(\Phi)$; a set of pricing function $r_e = R_e(\Phi)$, $r_s = R_s(\Phi)$, $w_s = W_s(\Phi)$, and $w_u = W_u(\Phi)$; and a transfer function $T = T(\Phi)$ such that

1. Taking prices as given, the allocations $c = C(\Phi)$, $k'_e = K_e(\Phi)$, $k'_s = K_s(\Phi)$, $s' = S(\Phi)$, $i_e = I_e(\Phi)$, $i_s = I_s(\Phi)$, and $i_h = I_h(\Phi)$ solve the household’s problem (7).

2. Taking prices as given, the allocations $\tilde{k}_e, \tilde{k}_s, \tilde{u}$, and $\tilde{s}$ solve the firm’s problem (9).

3. Markets for the input factors clear so that $\tilde{k}_e = k_e$, $\tilde{k}_s = k_s$, $\tilde{s} = s$, and $\tilde{u} = 1 - s$, and the market for the final good also clears so that

\[
y = c + i_s + i_e + i_h.
\]
2.3 Equilibrium Dynamics

We now characterize the equilibrium dynamics. The household’s optimizing conditions can be reduced to three intertemporal Euler equations with respect to the three forms of capital: structures, equipments, and skills, along with the three laws of motion for these capital stocks given by (3), (4), and (5).

The Euler equation for capital structures is given by

\[ c_t^{-\sigma} = \beta c_{t+1}^{-\sigma} \left[ (1 - \tau_k)(r_{s,t+1} - \delta_s) + 1 \right]. \tag{11} \]

The left-hand side of the equation gives the marginal utility loss of foregoing one unit of consumption good to invest in capital structures in period \( t \). The right-hand side of the equation gives the present value of marginal-utility gains from such investment in period \( t + 1 \), which equals the after-tax net return on capital structures. In equilibrium, the household breaks even, so that the utility gain and the utility loss are equal.

The Euler equation for capital equipments is given by

\[ c_t^{-\sigma} \frac{1}{q_t} = \beta c_{t+1}^{-\sigma} \frac{1}{q_{t+1}} \left[ (1 - \tau_k)(r_{e,t+1}q_{t+1} - \delta_e) + 1 \right]. \tag{12} \]

This equation is similar to (11), except that the units need to be appropriately converted using the relative price \( 1/q_t \) for new equipments.

The Euler equation for skill accumulation is given by

\[ c_t^{-\sigma} \frac{z_t^\alpha}{\alpha B_i^{\alpha-1} h_{t+1}^{\alpha-1}} = \beta c_{t+1}^{-\sigma} \left[ \frac{(1 - \eta)z_{t+1}^\alpha}{\alpha B_i^{\alpha-1} h_{t+1}^{\alpha-1}} + (1 - \tau_l)(w_{s,t+1} - w_{u,t+1}) \right]. \tag{13} \]

To understand this equation, note that each unit of consumption good invested in skill formation in period \( t \) would result in \( \alpha B_i^{\alpha-1} z_t^\alpha \) units of new skills. In other words, \( z_t^\alpha / (\alpha B_i^{\alpha-1}) \) measures the shadow price of newly formed skills. The left-hand side of (13) then gives the marginal utility loss of forming an additional unit of skills in period \( t \). The right-hand side gives the present value of the marginal utility gains from this additional unit of skills. In particular, the utility gains include the after-depreciation value of the new skills and the after-tax marginal gains in wage income associated with transforming unskilled labor into skilled labor. In equilibrium, the utility gains and losses are equal, so that the household remains indifferent at the margin of skill formation decisions.

The firm’s optimizing decisions equate the prices of input factors to their marginal products. In particular, we have

\[ r_s = \theta \left( \frac{H}{k_s} \right)^{1-\theta}, \tag{14} \]
\[ r_e = \lambda(1-\theta)(1-\mu)k_e^\theta H^{1-\theta-\nu}([\lambda k^\phi_e + (1-\lambda)(zs)^\phi]^\frac{1}{\phi} - 1 k^\phi_e - 1) \]  
\[ w_s = (1-\lambda)(1-\theta)(1-\mu)k_s^\theta H^{1-\theta-\nu}([\lambda k^\phi_e + (1-\lambda)(zs)^\phi]^\frac{1}{\phi} - 1 z^\phi s^\phi - 1) \]  
\[ w_u = (1-\theta)\mu k_s^\theta H^\frac{1-\phi}{1-\nu} - 1 u^\nu - 1 z^\nu, \]

where \( H = [\mu(zu)^\nu + (1-\mu)[\lambda k^\phi_e + (1-\lambda)(zs)^\phi]^\nu/\phi]^{1/\nu}. \)

Denote by \( \pi_s = \frac{w_s}{w_u} \) the skill premium. From equations (16) and (17), the skill premium is given by

\[ \pi_s = \frac{(1-\mu)(1-\lambda)}{\mu} \left[ \lambda \left( \frac{k_e}{s} \right)^\phi + (1-\lambda) \right]^\frac{\nu-\phi}{\phi} \left[ \frac{u}{s} \right]^{1-\nu}. \]  

If \( 1 > \nu > \phi \), then capital equipments are more complementary to skilled labor than to unskilled labor.\(^6\) With such capital-skill complementarity, we have

\[ \frac{\partial \pi_s}{\partial (k_e/s)} > 0, \quad \frac{\partial \pi_s}{\partial (s/u)} < 0. \]

In other words, capital-skill complementarity implies that the skill premium increases with the capital-skill ratio (the capital-skill complementarity effect), and decreases with the skilled-unskilled ratio (the relative quantity effect, or diminishing marginal product effect).

To summarize, the three Euler equations (11)–(13), the three capital accumulation equations (3)–(5), the four factor-price equations (14)–(17), and the aggregate resource constraint (10) provide a system of 11 equilibrium conditions that jointly determine the equilibrium values of 11 variables \( \{c_t, i_{st}, i_{et}, i_{ht}, k_{e,t+1}, k_{s,t+1}, s_{t+1}, r_{et}, r_{st}, w_{st}, w_{ut}\}^{\infty}_{t=0}. \)

### 2.4 Balanced Growth

Since investment-specific technological change \( q \) is capital augmenting rather than labor augmenting, the model economy with a CES production function as given by (2) would attain balanced growth only if there is no secular growth in \( q \) (e.g., Hornstein and Krusell, 2003). Of course, if the production function is Cobb-Douglas, as in GHK (1997), then balanced growth can be attained even if \( q \) grows at a constant rate. More formally, we have the following proposition.

**Proposition 1:** The balanced growth path (BGP) in this economy cannot be achieved unless there is no secular growth in the investment-specific technological change or the elasticities of substitution between input factors are unitary.

**Proof:** By contradiction. Without loss of generality, suppose that the neutral technological change \( z \) stays constant. Suppose there were a BGP with a positive growth in the investment-specific technological change \( q \). Along the BGP, the growth rates of \( y, k_e, \) and \( k_s \), and the levels

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\(^6\)The elasticity of substitution between capital equipments and skilled labor is given by \( \frac{1}{1-\phi} \), and the elasticity of substitution between the equipment-skill composite and unskilled labor is given by \( \frac{1}{1-\nu} \). Thus, \( \nu > \phi \) implies that capital is more substitutable for unskilled labor than for skilled labor.
of $s$ and $u$ are all constant. Let $\gamma_x$ denote the growth rate of a variable $x$. Then, from the resource constraint and the laws of motion of physical capital stocks, we have $\gamma_y = \gamma_k$ and $\gamma_s = \gamma_y + \gamma_q$.

Given the production function $y = k^\theta \tilde{y}^{1-\theta}$, where

$$\tilde{y} = \left[\mu (zu)^\nu + (1-\mu)(\lambda k^\phi + (1-\lambda)(zs)^\phi)\nu / \phi \right]^{1/\nu},$$

(19)

it follows that $\gamma_y = \gamma_{\tilde{y}}$, which leads to a contradiction because $\gamma_{\tilde{y}}$ is in general not a constant, as $k_e$ grows at a constant rate, while the levels of $s$ and $u$ remain constant.

In the case with unitary elasticities of substitution between input factors (i.e., Cobb-Douglas production function), there exists a BGP, as shown by GHK (1997).

$Q.E.D.$

We do not consider the case with a Cobb-Douglas production function because it does not seem to be consistent with evidence of capital-skill complementarity; we do not restrict $q$ to be constant because we would like to emphasize the role of investment-specific technological change (i.e., a time-varying $q$) in accounting for the observed dynamics in wage inequality and skill accumulation. In computing the equilibrium dynamics, we interpret the growth in the investment-specific technological change as a transition from some initial steady state to a new steady state, and we focus on computing the transition dynamics of wage inequality and the relative quantity of skilled workers.

3 The Calibration and Solution Methods

We now describe our approach to calibrating the parameters to be used in our computation of the transition dynamics.

The parameters to be calibrated include $\beta$, the subjective discount factor; $\sigma$, the relative risk-aversion parameter; $\theta$, $\mu$, and $\lambda$, which determine the income shares of capital structures, capital equipments, and labor skills; $\phi$ and $\nu$, which determine the elasticities of substitution between equipments and skilled labor and between the equipment-skill composite and unskilled labor; $\delta_s$, $\delta_e$, and $\eta$, the depreciation rates of structures, equipments, and skills; $B$ and $\alpha$, parameters in the human capital accumulation process; and $\tau_k$ and $\tau_l$, the tax rates on capital and labor incomes. In addition, we normalize the neutral technological change $z = 1$, and measure the investment-specific technological change (i.e., $q_t$) based on the study by Cummins and Violante (2002). The calibrated parameter values are summarized in Table 1.

We set $\sigma = 1.5$, a standard value used in the literature. We follow GHK (1997) and set $\theta = 0.13$, $\delta_s = 0.056$, and $\delta_e = 0.124$. We set $\phi = -0.495$ so that the elasticity of substitution between capital equipments and skilled labor is about 0.67, which is the value obtained by KORV (2000). Based on the estimation obtained by Duffy et al. (2004), we set $\nu = 0.79$ as a benchmark,
corresponding to an elasticity of substitution between the equipment-skill composite and unskilled labor of about 4.76. We also consider lower values of $\nu$ in our counterfactual policy experiments. We follow Stokey (1996) and set $\alpha = 0.70$ and $\eta = 0.08$. We set the average capital income tax rate to $\tau_k = 0.397$, a value used by Domeji and Heathcote (2004), and the average labor income tax rate to $\tau_l = 0.277$, following the work by McGrattan (1994) and Mendoza et al. (1994).

This leaves four parameters to be calibrated, including $\beta$, $\mu$, $\lambda$, and $B$. We assign values to these parameters so that the initial steady state in the model matches four moment conditions observed in the data in 1949. We choose 1949 as the initial steady state, since our $q_t$ series constructed based on Cummins and Violante (2002) appears fairly stable between 1947 and 1949.

1. The college wage premium (i.e., the average wage of college graduates relative to the average wage of high-school graduates) is 1.4556 in 1949 (Census data).

2. The ratio of skilled labor (i.e., college graduates) to unskilled labor (i.e., high-school graduates) is 0.2876 in 1949 (Census data).

3. The average capital-output ratio is 2.6591 for the period between 1947 and 1949 (NIPA data).

4. The average income share of capital stock is 0.2672 for the period between 1947 and 1949 (NIPA data).

The values for $\beta$, $B$, $\mu$, and $\lambda$ reported in Table 1 (i.e., $\beta = 0.9879$, $B = 0.3191$, $\mu = 0.4230$, and $\lambda = 0.4926$) are required to match these four initial moment conditions.

To measure the investment-specific technological change series $q_t$, we rely on the study by Cummins and Violante (2002), who construct a quality-adjusted time series of the price index for 24 types of equipments and softwares during the period from 1947 to 2000, in the spirit of an earlier study by Gordon (1990). Upon obtaining the price index for equipments and softwares, they divide it by the price index of consumer non-durables and services reported in the National Income and Product Accounts (NIPA) to obtain a relative price of new equipments and softwares. The investment-specific technological change (i.e., the $q_t$ series) is then the inverse of this relative price. The resulting $q_t$ series is plotted in Figure 3. The figure shows that $q_t$ has been increasing for most of the postwar period, and its growth has accelerated since the mid-1970s.

As we have discussed earlier, we interpret the growth in the investment-specific technological change (ISTC) during the period from 1949 to 2000 as part of a transition from some initial steady state to a new steady state, where the ISTC becomes stable. To compute the transition...
dynamics, we assume that the growth rate of the ISTC slows down linearly starting in year 2001, and reaches zero in 2050. To ensure convergence to the final steady state, we further extend the (hypothetical) sample period for the ISTC series to year 2108. This way, we obtain a time series for \( q_t \) with a length of 160 years, consisting of 52 years of actual observations between 1949 and 2000 taken from Cummins and Violante (2002) and 108 additional years for \( q_t \) to settle down at a new steady state.

To compute the transition dynamics in the model, we first solve for the initial steady state and the final steady state given the values of the \( q_t \) series in the initial and the final steady states. Table 2 summarizes the solutions for some key variables in the initial steady-state (with \( q_1 = 1 \)) and compares these solutions with the corresponding moments in U.S. data (i.e., the values in 1949). The first four moment conditions in Table 2 match the data by construction. The model does fairly well on the other three dimensions. The consumption-output ratio generated from the model comes quite close to that in the data (75.65% vs. 81.18%). The model also does fairly well in matching the ratio between capital equipments and structures (0.56 vs. 0.64). The model overstates the ratio of human-capital investment to output (0.0297 vs. 0.0183), although this ratio is likely to be underestimated in the data, as it omits, for example, expenditures related to on-the-job training (OJT).^8

Upon obtaining the solutions for the initial and the final steady states in the model, we compute the transition dynamics using the non-linear solution methods in the spirit of Conesa and Krueger (1999), Chen, İmrohoroglu and İmrohoroglu (2004), and He (2005). The details of the solution algorithm are described in the Appendix.

4 Dynamic Implications of the Model

We now describe the equilibrium dynamics of wage inequality and the relative quantity of skills, driven solely by the measured investment-specific technological change (i.e., the \( q_t \) series). We also compare the model’s predictions with the observations in U.S. data.

Figure 4 plots the dynamics of wage inequality generated from the model and that observed in U.S. data for the period between 1963 and 2000.^9 The model does well in accounting for the

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^8Perli and Sakellaris (1998) estimate that expenditures related to OJT in 1987 are about $165 billion (1989 dollars), while Clotfelter (1991) reports that total educational expenditures are about $331 billion in 1989. These numbers suggest that OJT expenditures may account for as much as half of total educational expenditures. Allowing for OJT in calculating the ratio of human-capital investment to output, we arrive at a number of 0.0275 in the data, which is quite close to what we get from the model.

substantial increase in wage inequality observed in U.S. data since the early 1980s. In particular, wage inequality measured by the relative wages of skilled workers in the U.S. economy has increased by about 19% between 1983 and 2000. The model predicts an increase of 14%. The model fails to capture the earlier episodes in the evolution of wage inequality, especially that in the 1970s. This is perhaps not surprising, since other factors such as demographic changes associated with the baby boom generation, which we do not model here, might also be driving the observed change in wage inequality in the 1970s (e.g., Katz and Murphy, 1992; He, 2005).

Figure 5 plots the dynamics of the relative quantity of skilled workers predicted by the model and observed in the data. The model’s prediction tracks the data surprisingly well for the entire sample period from 1963 to 1996. The result here suggests that the observed secular increase in the relative quantity of skilled labor, as well as its acceleration since the mid-1970s, can be mostly accounted for by investment-specific technological change.

Our model contains a simple mechanism that propagates the investment-specific technological change to generate the observed patterns in skill accumulation and wage inequality. As $q$ grows over time, the relative price of capital equipments falls, which encourages investment in new equipments. Given capital-skill complementarity, the expectation that the stocks of equipments will rise in the future provides incentive for increased investment in human capital, since increases in equipments would raise the marginal productivity of skilled workers and lower the marginal productivity of unskilled workers (i.e., the complementarity effect). Of course, the increase in the relative quantity of skilled workers through skill accumulation tends to dampen the rise in the skill premium (i.e., the relative quantity effect). Under our calibrated parameters, the model is able to deliver both the steady growth in the relative quantity of skilled workers and the substantial rise in wage inequality after the early 1980s.

The propagation mechanism in the model also implies that, as production of new equipments becomes more efficient over time, the average labor productivity measured by output per hour also grows. GHK (1997) find that investment-specific technological change accounts for nearly 60% of the average annual growth rate in output per hour in the United States for the period 1954–1990. Our model extends the model in GHK (1997) by incorporating capital-skill complementarity and

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10 The main discrepancy between the model’s predictions and the data seems to be the two spikes in the skill premium predicted (incorrectly) by the model. The timing of these spikes appears to coincide with those in the $q_t$ series (see Figure 3). It is not clear what drives the spikes in the $q_t$ series. The timing suggests that oil price shocks in the 1970s may have been a contributing factor. High oil prices render some capital equipments obsolete, leading to higher equipment investment and a higher equipment price. As the effects of oil shocks are expected to dissipate, the price of equipments is expected to fall, and thus productivity of the equipment sector (i.e., $q_t$) is expected to rise after the oil shocks.

11 Our data on the relative quantity of skills stop in 1996.
endogenous human-capital accumulation, but the presence of these new elements does not alter the main quantitative results obtained by GHK (1997). Our model driven solely by investment-specific technological change predicts that the average growth rate of output per hour is 1.24% during the period from 1964 to 2000, compared to the 2% in the data. In other words, investment-specific technological change in our model accounts for about 62% of the average growth in output per hour observed in the U.S. economy.

To summarize, our results suggest that investment-specific technological change is an important source of growth in output per hour. More importantly, the model accounts for much of the dynamic evolution in the relative quantity of skilled workers in the postwar U.S. economy, and it does well in replicating the substantial rise in wage inequality since the early 1980s.

5 Tax Reforms and Efficiency-Inequality Trade-offs

The dynamic behavior of wage inequality in our model is driven by two competing forces between a “relative quantity effect” and a “capital-skill complementarity effect.” Thus, not only investment-specific technological change, but other factors that affect capital accumulation might also affect wage inequality. In this section, we first illustrate this possibility by considering a counterfactual capital-income tax reform that encourages capital accumulation. We then examine the effectiveness of some hypothetical tax policies that aim at reducing income inequality.\footnote{For some recent quantitative studies about the effects of changes in tax policies on wage inequality and welfare, see, for example, Blankenau (1999) and Blankenau and Ingram (2002). A key difference between these studies and ours is that we emphasize the role of investment-specific technological change in driving wage inequality.}

5.1 Counterfactual Experiment I: Eliminating Capital Income Taxes

We now examine the quantitative effects of eliminating capital income taxes on wage inequality and skill accumulation. When we eliminate capital income taxes, we adjust labor income taxes so that the present value of the tax revenues during the entire transition period remains the same as in the benchmark economy. Since a zero capital income tax is consistent with the Ramsey optimal tax policy (e.g., Chamley, 1986), we also calculate the welfare gains from the tax reform.

In our quantitative experiment, we compare wage inequality and welfare in two economies, both driven by the same investment-specific technological change (i.e., our \( q_t \) series). The two economies are identical except for their tax policies. One economy is our benchmark model, which has positive tax rates on both capital and labor, with \( \tau_k = 39.7\% \) and \( \tau_l = 27.7\% \). The other economy has zero tax on capital, but a higher labor tax so that the present value of the total
tax revenue during the transition period remains the same as in our benchmark economy. The required labor income tax rate in this latter economy is $\tilde{\tau} = 32.9\%$.$^{13}$

Figure 6 plots the wage inequality for the two economies with different tax policies. Apparently, eliminating capital income taxes tends to raise wage inequality. For the period of our interest, 1949–2000, wage inequality in the economy with a zero capital income tax is on average 3.99% higher than that in the benchmark economy.$^{14}$ The effects of the tax reform on wage inequality also vary with time. Beginning in the early 1980s, as the growth in the investment-specific technological change accelerates, the tax reform has a larger impact on wage inequality than in the earlier periods.

As wage inequality measured by the skill premium depends on both the equipment-skill ratio and the skilled-unskilled ratio (see equation (18)), it is instructive to examine the effects of the capital tax reform on these two determinants. Figure 7 plots the effects of eliminating capital income taxes on the relative quantity of skilled labor (the top panel) and on the equipment-skill ratio (the bottom panel). The figure reveals that the reduction in capital taxes raises both the relative quantity of skilled labor and the equipment-skill ratio. The gap between the skilled-unskilled ratio before and after the capital tax reduction appears to become larger over time. The gap between the equipment-skill ratio displays substantial time variations, and becomes larger in the post-1980 period.

These results suggest that there are interesting interactions between the capital income tax reform and investment-specific technological change in shaping the dynamics of wage inequality and skill formation. As the production of new equipments becomes more efficient over time, eliminating capital income taxes would create further incentive for capital accumulation, which, through capital-skill complementarity, leads to greater wage inequality and more skill accumulation. The overall effect of the tax reform on wage inequality seems to be modest, with an average increase in wage inequality of about 3.99% during the period between 1949 and 2000 relative to the benchmark economy. The overall effect of the tax reform on skill accumulation seems to be large, with an average increase in the relative quantity of skilled labor of about 20.64%.$^{15}$

$^{13}$In calculating the present value, the discount factor that we use is the “state price” $D_{t,t+j} = \beta^j (c_{t+j}/c_t)^{-\sigma}$. Since we assume a complete asset market, the state price is unique.

$^{14}$We measure the difference between the two time series of wage inequality by the average distance between the two lines in the figure across all periods.

$^{15}$We have also computed the average differences between wage inequality and skill accumulation for the entire transition period (with 160 years). The average increase in wage inequality associated with the elimination of capital taxes in this extended sample becomes 1.80% of its pre-reform level, and the average effect on the relative quantity of skilled labor becomes 13.10%.
The reasons for the modest increase in wage inequality and for the substantial rise in skill formation upon eliminating capital income taxes are related. As we have alluded to in the introduction, the elimination of capital income taxes can affect wage inequality and skill formation through three channels. First, eliminating capital taxes encourages capital accumulation, and through the capital-skill complementarity, raises the marginal productivity of skilled workers relative to that of unskilled workers, and hence raises the skill premium. Second, related to the first, the expectation of a higher future skill premium creates an incentive for skill formation, which raises the skilled-unskilled ratio and reduces the skill premium. Third, to keep the tax reform revenue neutral, eliminating capital income taxes requires raising the labor income tax rate. Since the labor income tax is proportional and thus progressive, it discourages investment in new skills and thereby lowers the relative quantity of skilled labor and raises the skill premium. The third effect reinforces the first to create larger wage inequality associated with the tax reform, but the second effect tends to offset the other two. Under calibrated parameters, the capital tax reduction leads to a modest increase in wage inequality and a substantial rise in the relative quantity of skilled labor.

Since a zero capital income tax rate is consistent with Ramsey optimal fiscal policy (e.g., Chamley, 1986), one should expect the tax reform to increase social welfare in our model. Indeed, it does. We measure welfare gains by a consumption equivalence in the spirit of Lucas (1987). In particular, we define welfare gains from the reduction of capital income taxes as the permanent percentage increase in consumption that is required for the representative household to remain indifferent between living in two economies: the benchmark economy with positive capital and labor taxes, and an alternative economy with no capital income taxes but a higher labor income tax rate. During the period between 1949 and 2000, we find that the welfare gain from eliminating capital income taxes is equivalent to a 1.52% permanent increase in consumption. The size of the welfare gains here is quite close to that obtained by Domeji and Heathcote (2004) in a representative-agent version of their model (1.5%), and is quite sizable relative to the welfare cost of business cycle fluctuations calculated, for example, by Lucas (1987).

Eliminating capital income taxes creates a sizable welfare gain for two reasons. First, it removes intertemporal distortions in capital accumulation. Second, and more important, it raises average productivity through encouraging skill formation. The first channel is familiar in the Ramsey tax literature, but the second is new and is unique to our model with capital-skill complementarity and with endogenous skill accumulation.

A natural question is then: Are these results robust to variations in model parameters? We now examine the sensitivity of our quantitative results when we vary the value of $\nu$, the elasticity
of substitution between the equipment-skill composite and unskilled labor. We focus on $\nu$ for two reasons. First, we do not have an accurate estimate of its value, and the empirical literature provides a wide range of estimates for $\nu$. Second, and more important, $\nu$ is a key parameter that determines the strength of capital-skill complementarity, through which technological changes or tax policies can affect wage inequality. In addition to our benchmark calibration with $\nu = 0.79$, we examine the effects of the tax reform on wage inequality and skill formation under two alternative values of $\nu$ used in the literature. One is the value obtained by KORV (2000), which gives $\nu = 0.401$, corresponding to an elasticity of substitution between the equipment-skill composite and unskilled labor of about 1.67; the other is estimated by Hamermesh (1993, Table 3.7), which gives $\nu = 0.65$, implying an elasticity of substitution of about 2.86. We do the same counterfactual experiments of tax reforms using these alternative values of $\nu$. The results are reported in Table 3. The table shows that, for smaller values of $\nu$, the effects of eliminating capital income taxes on wage inequality, skill formation, and welfare all become smaller. These results are intuitive, because a smaller $\nu$ implies a weaker capital-skill complementarity. But even for the smallest value of $\nu$ that we have examined, the welfare gains from the tax reform are still sizable at 1.04%, which remains an order of magnitude larger than the cost of business cycles calculated by Lucas (1987).

To summarize, eliminating capital income taxes can lead to sizable welfare gains, but it has only modest effects on wage inequality. Our experiment thus suggests that a capital tax reform such as the one in 1986 is unlikely to be a good candidate for explaining the substantial rise in wage inequality since the 1980s.

5.2 Counterfactual Experiment II: Policies Designed to Reduce Inequality

In our model, dynamics in income inequality and skill accumulation are equilibrium outcomes and thus dependent upon tax policies. We now examine the effectiveness of two tax policies, both designed to reduce income inequality. One such policy is to increase the progressiveness of labor income taxes by imposing a higher tax rate on skilled labor income (denoted by $\tau_s$) than on unskilled labor income (denoted by $\tau_u$). When we change the labor income taxes, we adjust the capital income taxes so that the present value of the tax revenues during the entire transition period remains the same as in the benchmark economy. The other policy is to provide subsidies for human capital accumulation, while adjusting the labor income tax rate (common to both types of labors) to keep the policy change revenue neutral.

Table 4 reports the effects of increasing the progressiveness of labor income taxes on wage inequality, skill accumulation, and welfare (measured by the consumption equivalence discussed
in the previous subsection). The table shows that increasing the progressiveness of the labor income taxes is not effective in reducing income inequality. When we change the tax rates from the benchmark with \( \tau_s = \tau_u = 27.7\% \) to \( \tau_s = 33.24\% \) and \( \tau_u = 22.16\% \) (so that \( \tau_s/\tau_u = 1.5 \) and \( (\tau_s + \tau_u)/2 = 27.7\% \)), the skill premium rises by 0.51%. With a more progressive policy, for instance, with \( \tau_s/\tau_u = 2 \), the skill premium rises by even more (0.84%) relative to the benchmark economy. With \( \tau_s/\tau_u = 2.5 \), the skill premium rises by less, but is still higher than that in the benchmark. When the tax policies are sufficiently progressive, however, the skill premium becomes smaller than that in the benchmark economy. For example, when we set \( \tau_s = 41.55\% \) and \( \tau_u = 13.85\% \) (so that \( \tau_s/\tau_u = 3 \)), the skill premium falls by 1% relative to the benchmark.

Although increasing the progressiveness of the tax policy does not necessarily reduce income inequality, such policy change would unambiguously lead to a large decline in the relative quantity of skilled labor and a large welfare cost. Even a modest increase in the progressiveness, such as changing from the proportional tax policy into one with \( \tau_s/\tau_u = 1.5 \), would result in a 17.7% decline in skill accumulation and a 3.32% reduction in welfare. The declines in skill accumulation and welfare become more pronounced when the tax policy becomes more progressive.

Increasing the progressiveness of labor income taxes is ineffective in reducing income inequality because such policy changes tend to discourage skill accumulation. As the relative supply of skilled labor falls, all else equal, the skill premium should rise, not fall as the policy change is designed to achieve. Of course, the skill premium also depends on the equipment-skill ratio, as capital-skill complementarity is the other determinant of the skill premium. With more progressive labor income taxes, the reduction in the relative quantity of skilled labor implies a fall in average productivity and a decline in tax revenue. Thus, to keep the policy change revenue neutral (in the present-value sense), we need to raise the capital income tax rate. An increase in capital income tax discourages capital accumulations, which, through the capital-skill complementarity channel, leads to a fall in the relative marginal product of skilled workers and thus a decline in the skill premium. The net effect of an increase in the progressiveness of labor income taxes on the skill premium depends on the relative strength of two competing forces: by discouraging skill accumulation, the policy change tends to raise the skill premium; by discouraging capital accumulation, it tends to lower the skill premium. For moderately progressive labor income taxes, the former effect dominates; for sufficiently progressive labor income taxes, the latter effect may dominate. Further, by discouraging skill formation and capital accumulation, the increase in the progressiveness of labor income taxes reduces average productivity and lowers welfare.

We now consider the alternative policy that provides subsidies to human capital accumulation. Denote the subsidy rate by \( \tau_h \). Under the subsidy policy, the household’s budget constraint (8)
and the government budget constraint (6) should be modified accordingly. In particular, in the household’s budget constraint, the term $i_h$ should be replaced by $(1 - \tau_h)i_h$; and in the government budget constraint, the expenditure associated with the subsidy in the amount of $\tau_h i_h$ should be subtracted from the tax revenues. To maintain the present value of tax revenues the same as in the benchmark economy without subsidies, we adjust the labor income tax rate $\tau_l$ when we increase the value of $\tau_h$.

Table 5 reports the effects of increasing subsidies for human capital accumulation relative to the benchmark economy. The table shows that, as $\tau_h$ increases, the skill premium declines, and the relative quantity of skilled labor and welfare both increase. Even a modest increase in the subsidy rate, say from 0 (the benchmark economy) to 8%, can result in a sizable reduction in the skill premium (2.08%), a significant increase in the relative quantity of skilled labor (8.43%), and a non-trivial welfare gain (0.47%). Subsidizing human capital investment provides incentive for skill accumulation, and thereby raises the skilled-unskilled ratio and lowers the equipment-skill ratio, both of which tend to reduce the skill premium. As the average skill level rises, labor productivity increases, as does welfare. This result suggests that subsidizing human capital accumulation does not seem to involve a trade-off between equity and efficiency.

6 Conclusion

Understanding the driving forces of wage inequality is of great interest to both academic researchers and policy makers. In the literature, many potential mechanisms are proposed for explaining the qualitative changes in wage inequality. Yet, quantitative studies of the relative importance of these mechanisms are scarce. In the current paper, we have examined the quantitative importance of a skill-biased technological change, a popular mechanism proposed in the literature, in explaining the dynamics of wage inequality and skill formation. We measure the skill-biased technological change by the relative efficiency in the production of new capital equipments, and we examine the quantitative effects of such measured technological change on wage inequality and skill formation in a general equilibrium model. We find that, working through capital-skill complementarity and endogenous skill formation, investment-specific technological change is able to account for much of the observed dynamics in the relative quantity of skilled labor in the postwar U.S. economy, and the model does fairly well in replicating the substantial rise in wage inequality since the early 1980s. In our counterfactual experiments, we find that a revenue-neutral elimination of capital income taxes leads to a modest increase in wage inequality and a sizable welfare gain. We also find that a revenue-neutral increase in the progressiveness of labor income
taxes is not effective in reducing income inequality and, since it discourages skill accumulation, can potentially lead to large declines in average productivity and welfare. In contrast, a policy that provides direct subsidies for human capital accumulation tends to raise the skilled-unskilled ratio, lower the skill premium, and improve welfare.

A main reason why we focus on the role of investment-specific technological change in explaining the dynamic evolution of wage inequality and skill accumulation is that such technological change can be explicitly measured, thanks to the empirical work by Gordon (1990), GHK (1997), KORV (2000), and Cummins and Violante (2002). Such technological change turns out to be a quantitatively important mechanism in explaining wage inequality, but we do not claim it is the only mechanism. Future work should incorporate other mechanisms such as demographic changes (that affect human capital accumulation) or institutional reforms (that affect the relative returns to education), and evaluate the quantitative importance of these alternative mechanisms in explaining the dynamics of wage inequality, especially for the period before 1980.

Another direction to extend our study is to allow for consumer heterogeneity. Since our focus is on income inequality, we have taken a representative-agent approach, which implicitly assumes perfect risk-sharing between households. As such, there is no consumption inequality in our model. Allowing for consumer heterogeneity can be potentially important for evaluating the quantitative trade-offs between equity and efficiency when designing a public policy reform, such as the counterfactual policy experiments that we have considered in the current paper. Future work along these lines should help further improve our understanding of the causes and consequences of income inequality, and is thus both important and promising.

Appendix

In this appendix, we describe our data construction and computation methods.

Appendix A: Data

Our measure of wage inequality (i.e., skill premium) is the ratio of the mean wage for college graduates to that for high-school graduates, where the wages are annualized real wages (in 2002 dollars). To construct the wage data for different education cohorts, we follow Eckstein and Nagypál (2004) in selecting our sample. The sample includes data for all full-time, full-year workers between ages 18 and 65. The main source of the data is the March Current Population Survey (CPS) from 1962 to 2003. Earlier observations are taken from the 1950 and 1960 Census data.
Our measure of the relative quantity of skilled workers is the ratio of the number of college graduates to that of high-school graduates. These time series are taken from Katz and Autor (1999), who also use the Census and the CPS as their data source. Their sample includes all workers between ages 18 and 65, and we focus on college graduates and high-school graduates.

To construct average productivity (i.e., output per hour), we use the private real GDP as our measure of output, which is obtained by subtracting net exports and government expenditures from the real GDP series (in 2000 chained dollars) reported by the Bureau of Economic Analysis (BEA); and we use the labor hours series from the Bureau of Labor Statistics (which begins in 1964).

Appendix B: Computation

We solve the model by using the following algorithm:

1. Given $q_1 = 1$, solve the initial steady state. Save the values of initial consumption $c_1$, equipment $k_{e,1}$, structure $k_{s,1}$, skilled labor ratio $s_1$, investment in human capital $i_{h,1}$, in equipment $i_{e,1}$, and in structure $i_{s,1}$.

2. Given the terminal value of constructed ISTC sequence $q_T$, solve the final steady state. Save the values of final consumption $c_T$, equipment $k_{e,T}$, structure $k_{s,T}$, skilled labor ratio $s_T$, investment in human capital $i_{h,T}$, in equipment $i_{e,T}$, and in structure $i_{s,T}$.

3. Make linear interpolations between the initial and the final values, so we have sequences of the seven variables \{$c_t, k_{e,t}, k_{s,t}, s_t, i_{h,t}, i_{e,t}, i_{s,t}\}^T_{t=1}$. Take these sequences as the initial guess in solving the system of non-linear equations, which consists of equations (10), (3)–(5), and (11)–(13), together with non-negativity constraints on these variables. Hence we have $7 \times T$ equations in this system. Solve this system of equations using standard non-linear numerical methods.

4. Make sure $T$ is sufficiently large so that the transition dynamics between 1949–2000 are not affected by changes in $T$.

References


Table 1.
Calibrated parameter values

<table>
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<th>Preferences</th>
<th>$\sigma = 1.5$, $\beta = 0.9879$</th>
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<tbody>
<tr>
<td>Factor income shares</td>
<td>$\theta = 0.13$, $\mu = 0.4230$, $\lambda = 0.4926$</td>
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<tr>
<td>Elasticities of substitution</td>
<td>$\phi = -0.495$, $\nu = 0.79$</td>
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<td>Depreciation rates</td>
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<tr>
<td>Human-capital accumulation</td>
<td>$B = 0.3191$, $\alpha = 0.7$</td>
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<tr>
<td>Income tax rates</td>
<td>$\tau_k = 0.397$, $\tau_l = 0.277$</td>
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Table 2.
Initial moment conditions

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<thead>
<tr>
<th>Variable</th>
<th>Model</th>
<th>Data</th>
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<tr>
<td>Skill premium</td>
<td>1.4557</td>
<td>1.4556</td>
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<td>Skilled-unskilled ratio</td>
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<td>0.2876</td>
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<td>Capital-output ratio</td>
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<td>2.6591</td>
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<tr>
<td>Capital income share</td>
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<td>Consumption-output ratio</td>
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<td>$\frac{\delta_h}{y}$</td>
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<td>0.0183</td>
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<td>$\frac{k_e}{k_s}$</td>
<td>0.56</td>
<td>0.6372</td>
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Table 3.
Effects of eliminating capital income taxes

<table>
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<tr>
<th>ν</th>
<th>Skill premium</th>
<th>Rel. quantity of skills</th>
<th>Welfare gain</th>
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<td>0.79</td>
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<td>20.64%</td>
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<td>0.65</td>
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<td>0.401</td>
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<td>6.62%</td>
<td>1.04%</td>
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Table 4.
Effects of increasing progressiveness of labor income taxes

<table>
<thead>
<tr>
<th>τ&lt;sub&gt;s&lt;/sub&gt;/τ&lt;sub&gt;u&lt;/sub&gt;</th>
<th>Skill premium</th>
<th>Rel. quantity of skills</th>
<th>Welfare gain</th>
</tr>
</thead>
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<tr>
<td>1 (τ&lt;sub&gt;s&lt;/sub&gt; = τ&lt;sub&gt;u&lt;/sub&gt; = 27.7%, benchmark)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
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<td>1.5 (τ&lt;sub&gt;s&lt;/sub&gt; = 33.24%, τ&lt;sub&gt;u&lt;/sub&gt; = 22.16%)</td>
<td>0.51%</td>
<td>-17.70%</td>
<td>-3.32%</td>
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<td>2 (τ&lt;sub&gt;s&lt;/sub&gt; = 36.93%, τ&lt;sub&gt;u&lt;/sub&gt; = 18.47%)</td>
<td>0.84%</td>
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<td>2.5 (τ&lt;sub&gt;s&lt;/sub&gt; = 39.57%, τ&lt;sub&gt;u&lt;/sub&gt; = 15.83%)</td>
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<tr>
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</table>

Table 5.
Effects of subsidizing human capital investment

<table>
<thead>
<tr>
<th>τ&lt;sub&gt;h&lt;/sub&gt;</th>
<th>Skill premium</th>
<th>Rel. quantity of skills</th>
<th>Welfare gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (benchmark)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>0.02</td>
<td>-0.5%</td>
<td>1.95%</td>
<td>0.12%</td>
</tr>
<tr>
<td>0.04</td>
<td>-0.88%</td>
<td>3.47%</td>
<td>0.20%</td>
</tr>
<tr>
<td>0.06</td>
<td>-1.57%</td>
<td>6.31%</td>
<td>0.36%</td>
</tr>
<tr>
<td>0.08</td>
<td>-2.08%</td>
<td>8.43%</td>
<td>0.47%</td>
</tr>
<tr>
<td>0.10</td>
<td>-2.61%</td>
<td>10.74%</td>
<td>0.59%</td>
</tr>
<tr>
<td>0.12</td>
<td>-3.14%</td>
<td>13.15%</td>
<td>0.70%</td>
</tr>
</tbody>
</table>
Figure 1:—College wage premium: 1963–2000

Figure 2:—Relative quantity of college skills: 1963–1996
Figure 3:—Investment-specific technological change: 1949–2000
Figure 4: Dynamics of wage inequality: model vs. data
Figure 5: Dynamics of the relative quantity of skills: model vs. data
Figure 6: Effects of capital-tax reform on wage inequality
Figure 7:—Effects of capital-tax reform on the relative quantity of skills (top panel) and on the capital-skill ratio (bottom panel)