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The Rise and Fall of Unions in the U.S.*

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Abstract

Union membership in U.S. displayed a $\cap$-shaped pattern over the 20th century, while income inequality sketched a $\cup$. A model of unions is developed to analyze this phenomenon. There is a distribution of productivity across firms in the economy. Firms hire capital, plus skilled and unskilled labor. Unionization is a costly process. A union chooses how many firms to organize and the union wage. Simulation of the model establishes that skill-biased technological change, which affects the productivity of skilled labor relative to unskilled labor, can potentially explain the above facts. Statistical analysis suggests that skill-biased technological change is an important factor in deunionization.

Keywords: Computers; Distribution of Income; Flexible Manufacturing; Income Inequality; Mass Production; Numerically Controlled Machines; Relative Price of New Equipment; Skill-Biased Technological Change; Simulation Analysis; Union Coverage; Union Membership; De-unionization

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1 Introduction

In 1900, around 7% of the American workforce in the non-agricultural private sector were union members. The percentage of union members in the private sector rose until the middle of the century, as shown in Figure 1, reaching its apex at roughly 40%. It then began a slow decline. At the end of century, only about 7% of American workers in the private sector belonged to a union. Income inequality followed a different path. At the beginning of the 20th century, the top 10% of workers earned 41% of income. This measure of income inequality first declined, hitting a low of 31% around mid-century. It then steadily increased to 41% around 2000.[1] What could have caused the ∩-shaped pattern of union membership and the ∪-shaped one for income inequality? Are they related?

The hypothesis here is that skill-biased technological change underlies the rise and fall in union membership, along with the up and down in income inequality. The beginning of the 20th century witnessed a shift away from an artisan economy toward one transformed by assembly line and mass production. This transformation favored unskilled labor. The premium for skill declined.[2] Unskilled labor is homogenous almost by definition, making it easier to unionize than skilled labor. When the demand for unskilled labor rises there is a larger payoff to unionizing it. These trends started to shift at the midpoint of the century. The second industrial revolution was petering out and the information age was dawning. Transistors and silicon chips meant that automatons could replace the hoards of unskilled workers laboring on factory and office floors. These developments represented a reversal of the patterns observed earlier in the 20th century.

A general equilibrium model of unionization is developed. The union makes two inter-

[1] The income inequality measure is before individual income taxes–see the data appendix for more detail. Therefore changes in the progressivity of income taxation do *not* account for the ∪-shaped pattern in income inequality. The rise in inequality since the 1970s is well documented and holds for a wide variety of inequality measures–see Juhn, Murphy, and Pierce (1993) for an early documentation of this trend for many measures of wage inequality.

[2] Interestingly, Goldin and Katz (2008, Figure 8.1, p. 290) report a ∪-shaped pattern for the college-graduate wage premium for the period of study here. Somewhat surprisingly, they also show that during the first part of the twentieth century the high-school graduate wage premium actually fell; i.e., the return to a less-than-high-school education rose. These facts fit well into the framework laid out here.

connected decisions. First, it picks a common wage rate for its members. Second, the union selects which firms in the economy to organize. Unionization is a costly process. Firms sell output in a competitive market. They hire both skilled and unskilled labor. These inputs are substitutable to some extent. When the productivity of unskilled labor is high (relative to skilled labor) the union can pick a high wage. It also pays to organize more firms. Firms differ in their productivity, so when organizing labor the union will select the most profitable firms. Those firms that are not unionized can hire labor in a competitive market.

The modeling of unions builds upon the work of MacDonald and Robinson (1992), who do not focus on the emergence and decline of unions. They present a model of the extent of unionization in a competitive industry where all firms are the same. The key ingredients of their model are: (i) unionization is a costly activity; (ii) unions must offer their members a wage net of dues that exceeds the competitive one; (iii) the union wage must allow organized firms to make non-negative profits. MacDonald and Robinson (1992) model an industry in partial equilibrium, and start off at the level of a firm's cost function. Modeling skill-biased technological change requires, instead, starting off from a firm's production function that can accommodate both skilled and unskilled labor. In addition, analyzing the implications of this form of technological change for income distribution in the economy requires a general equilibrium model that embeds unions, as well as heterogeneous individuals and firms. These elements are needed to address the question studied here: What caused the rise and fall of unions in the U.S.?

The hypotheses proposed here is taken to the data in three ways. First, historical evidence is presented regarding the evolution of unionization and skill-biased technological change, with particular attention to the transformation of the U.S. economy over the 20th century by, initially, mass production, and later, computerization. Second, the developed model is calibrated and simulated to see whether or not it is capable of explaining the extent of unionization and the level of income inequality that was observed over the course of the 20th century. It is. The required pattern of skill-biased technological progress is in line with the qualitative picture painted by the historical evidence. Third, statistical analysis is undertaken to relate unionization to skill-biased technological change in a regression framework where other potential factors that may have influenced unionization are controlled for. Incorporating these other factors into the developed general equilibrium model is not desirable, both for reasons of clarity and practicality. The statistical evidence suggests that skill-biased technological change, the model's exogenous driver, is statistically and economically important in explaining both the recent rise in the relative demand for skilled labor in the U.S. and the decline of unionization. Additionally, it is shown that the analysis also has relevance for deunionization in other OECD countries.

Acemoglu, Aghion and Violante (2002) also analyze how skill-biased technological change can lead to deunionization. Their framework is very different from the one developed here. In particular, there are two sectors in the economy, one unionized, the other non-unionized. Skilled workers only work in the non-unionized sector. Unskilled labor can work in either sector. As the productivity of skilled workers relative to unskilled workers rises more people choose to become skilled and hence are employed in the non-unionized part of the economy. Their analysis is entirely theoretical in nature.

Acikgoz and Kaymak (2011) embed a model of unionization into a Mortensen-Pissarides style job matching model. In their framework, workers differ both by their ability and skill levels. Firms observe both attributes, while unions see only the latter. They argue that a rise in the skill premium, which rewards both ability and skill, reduces the incentive for a skilled worker to join a union. The rise in the skill premium is also associated with unskilled workers becoming less productive. This renders them less attractive for firms to hire at high union wages. The current analysis stresses, by contrast, the interplay between firms and unions. Unions organize the most profitable slice of the spectrum of firms. The size of this slice depends on the state of the production technology in the economy and the cost of union organizing. Furthermore, not only the fall, but also the rise, of unions is explained here by technological change. Finally, in the empirical work, a direct measure of skill-biased technological progress is used. The model's mechanism is also explored for several OECD countries, in addition to the U.S.

2 Mass Production and Computerization

2.1 The Rise of Unions, 1913-1955

Mass production and Fordism were interchangeable terms at one time. In 1913 Ford's Highland Park plant became the first automobile factory to have a moving assembly line. It signalled the death of the craft production methods that characterized the previous century. This was achieved through the use of standardized parts, pioneered in the 19th century arms industry. Time spent fitting inexact parts was eliminated. The moving assembly line was also inspired by the flow production techniques used in flour milling and meat packing. It reduced the unnecessary handling of the product associated with ferrying the work between production operations–in early factories the placement of machines was often organized by their intrinsic operations (say drilling or milling) and not by where they lay in the production sequence. The result was a greater specialization of labor.

At the beginning of the 20th century, automotive, carriage and wagon, and machine and metal-working workshops were artisanal in character. They had three types of workers: skilled mechanics, specialists, and laborers. The skilled mechanics undertook the productive operations. They also supervised the other workers. A census report stated that the "machinist, in its highest application, means a skilled worker who thoroughly understands the use of metal-working machinery, as well as fitting and working at the bench with other tools." Laborers were unskilled and did "manual labor that requires little or no experience or no judgement, such as shovelers, loaders, carriers, and general laborers." The semi-skilled specialist lay between these two categories. The census referred to them as "machinists, of inferior skill." It stated that "those who are able to run only a single machine or perhaps do a little bench work, are classified as second class machinists and grouped with machine tenders and machine hands." Meyer (1981, pp 13-14) describes how Ford engines were put together just before the assembly line was born:

> At the assembly bench, the skilled worker occupied a central place. He began with a bare motor block, utilized a wide range of mental and manual skills, and

> attached part after part. Not only did he assemble parts, but he also 'fitted' them. If two parts did not go together, he placed them in his vice and filed them to fit. The work routines contained variations in tasks and required considerable amounts of skill and judgment. Additionally, unskilled truckers served the skilled assemblers. When an assembler completed his engine, a trucker carried it away and provided a new motor block. The laborer also kept the assembler supplied with an adequate number of parts and components. Here, the division of labor was relatively primitive–essentially, the skilled and unskilled. Under normal conditions, a Ford motor assembler needed almost a full day of work to complete a single engine.

Mass production involved breaking down the manufacturing process into a series of elementary tasks and the transfer of skill to machines. Frederick W. Taylor wrote in 1903 that "no more should a mechanic be allowed to do the work for which a trained laborer can be used" and that "a man with only the intelligence of an average laborer can be taught the most difficult and arduous work if it is repeated; and this lower mental caliber renders him more fit than the mechanic to stand the monotony of repetition." A 1912 report of the American Society of Mechanical Engineers stated that "after the traditional skill of a trade, or the peculiar skill of a designer or inventor, has been transferred to a machine, an operator with little or no previously acquired skill can learn to handle it and turn off the product."

An 1891 sample of metal-working establishments in Detroit shows the importance of skilled labor in artisanal production. As Table 1 illustrates, mechanics accounted for 40% of the workforce. Meyer (1981) feels that this pattern would have been characteristic of the early Ford Motor Company as well. The composition of the workforce at the Ford Motor Company had changed by 1913, as shown in Table 2. Operators made up the majority of workers. These were unskilled specialists performing routine machine operations. Mechanics accounted for only a small portion of the workforce. The deskilling of the workforce is nicely related by Wolmack et al. (1990, pg. 31):

> The assembler on Ford's mass production line had only one task–to put two

> nuts on two bolts or perhaps attach one wheel to each car. He didn't order parts, procure his tools, repair his equipment, inspect for quality, or even understand what the workers on either side of him were doing. Rather, he kept his head down and thought about other things. The fact that he might not even speak the same language as his fellow assemblers or the foreman was irrelevant for the success of Ford's system.

Only a few minutes of training was required to teach someone to be an assembler. This system of manufacturing rapidly diffused through the American economy. The pinnacle of the mass production era was 1955.

Before proceeding on to a discussion about the decline of unionization, a caveat is in order. While the analysis here stresses the role that mass production played in driving unionization, changes in labor laws undoubtedly contributed to the very rapid rise in unionization that occurred during the 1930s and 1940s. The shifts in labor laws for this period are chronicled in Ohanian (2009). He also analyzes their impact on the Great Depression. Union wages were required to be paid on federal public works contracts by the Davis–Bacon Act in 1931. The Norris–Laguardia Act, which was passed in 1932, limited the power of courts to issue injunctions against union strikes, picketing, or boycotts. It also outlawed "yellow dog" contracts. These contracts prohibited workers from joining a union; they could be fired if they did. The Wagner Act of 1935 provided for collective bargaining and placed very few restrictions on the rights of workers to strike. Some of the rights that unions had won during the 1930s were rolled by back by the Taft-Hartley Act in 1947. It outlawed closed shops, required an 80 day notice for strikes, allowed states to pass right to work laws, among other things. Of course, the dawning of the mass production era may have provided a catalyst for enacting such laws. Doepke and Tertilt (2009) discuss how technological progress, which increased the importance of education, may have led to an expansion of women's rights. Similarly, one could argue that a rise in the strength of unions may increase the demand for technologies that place less reliance on unionized labor. All of these considerations are abstracted from here.

2.2 The Fall of Unions, 1955-

In 1952 MIT publicly demonstrated an automatic milling machine. The machine read instructions from a paper punch tape. The instructions were fed to servo-motors guiding the position of the cutting head of the machine relative to the part being manufactured along the x, y and z axes. Feedback from sensors regulated the process. By changing the instructions the machine could manufacture a different part. Such a "flexible machine" could make small batches of many different parts. The world had entered the age of numerically controlled machines. Numerically controlled machines were slow to catch on. The MIT machine would not have been reliable for commercial production; it had 250 vacuum tubes, 175 relays, and numerous moving parts. Programming an early numerically controlled machine was a time consuming task. Standardized languages had been developed for programming automated machine tools by the 1960s. At the same time, the arrival of less expensive computers in the 1960s made them economical. The separation of software from hardware also lowered the costs of implementing numerical control systems. As calculating power increased, computers could aid the design of products (CAD). Computers could also be used for planning and managing business in addition to running the machines on the factory floor (computer-aided manufacturing or CAM). In fact, sometimes they could automate virtually the entire business (computer-integrated manufacturing or CIM). The use of computers reduced the need for unskilled labor in factories and offices.

Mass production is an inflexible system. It is difficult to change a product or the manufacturing procedure once an assembly line has been instituted. As Henry Ford said "Any customer can have a car painted any color that he wants so long as it is black." This didn't suit Japanese manufacturing in the early postwar period, which had small production runs. The dies (or the forms) used in presses to shape metal parts had to be switched frequently. It took specialists in an American plant a day to change dies. Dies weighed tons and had to be set in the presses with absolute precision. Otherwise, defects would appear in the manufactured parts. In the 1940s and 50s, Taiichi Ohno, Toyota's chief production engineer, perfected a simple system where they could be changed in minutes. Since the presses had to remain idle while the dies where changed, Ohno reasoned that the production workers could do this. Furthermore, they could check the manufactured parts for defects thereby catching mistakes early on in production process. Quality control was at the end of the process in the typical mass production facility. Over time, Toyota's production system gradually evolved to one where teams of workers were responsible for segments of the assembly line. Besides production, they looked after housekeeping, minor machine repairs and quality checking for their section of the line. According to Wolmack et al. (1990), in a mass production automobile plant about 20% of area and 25% of working time are devoted to fixing mistakes. This is eliminated in a Toyota "lean production" facility. The Toyota production system favors skilled workers rather than unskilled ones. It has now been widely adopted in manufacturing.

The upshot of computerization in production and new organizational structures was that the demand for unskilled labor fell relative to the demand for skilled labor. This is shown in Figure 2, where unskilled workers are defined as clerical workers, laborers, operatives, and sales personnel, while skilled ones are taken to be craftsmen, managers, and professionals.

2.3 Proneness of Unionized Industries and Occupations to Employment Decline

Skill-biased technological progress favored unskilled labor during the first part of the 20th century. Since unskilled labor is more homogenous than skilled labor, it is easier to organize. Therefore, unionization tended to be more concentrated in occupations and industries that attracted unskilled labor. While the first part of the 20th century witnessed a rise in unionization, starting in the mid-1950's skill-biased technological change dislocated unskilled workers replacing them with mixes of capital and skilled workers. Therefore, in the second half of the century, industries and professions with higher initial unionization rates should in general exhibit lower growth (or even decline) in employment than those with lower initial unionization rates, because the former industries and professions had disproportionately bigger shares of unskilled labor.

Some observations from the *Union Membership and Coverage Database* support this hypothesis–the Appendix contains a description of the various data sources used in this paper. Over the period 1973 to 2012, the non-agricultural private-sector union membership rate in the U.S. declined from 24.6% to 6.6%. The decline was more pronounced in the manufacturing and construction sectors. Over the same period, the union membership rate fell from 38.9% to 9.6% in the former, and from 39.5% to 13.2% in the latter. Now, highly unionized occupations were especially hard hit. Table 3 lists the unionization rates for the 20 fastest declining and growing occupations between 1983 and 2002, the period for which unionization rates are available for finer industry and occupation classes.[3] The 20 fastest declining occupations consist mainly of laborers, machine operators, and clerical workers. As many as 9 of these occupations had a 1983 unionization rate that was in the top quartile of the 1983 unionization rates across occupations. In contrast, of the 20 fastest growing occupations, only 4 had unionization rates that were in the top quartile. The fastest growing occupations largely pertain to skilled technical workers, such as engineers, managers, and other professionals.

Is the pattern in Table 3 more general? Have industries and occupations with higher initial unionization rates in 1983 generally experienced greater employment losses between 1983 and 2002? The answer should be yes, if skill-biased technological change reduced the demand for unskilled labor, which in turn was disproportionately represented in the unionized sector of the economy. In other words, the initial unionization rate in an industry or occupation can be viewed as a proxy for the degree of proneness of that industry or occupation to employment loss due to skill-biased technological change.

Figure 3 presents nonparametric local polynomial smoothing and linear regression estimates of the relationship between the growth rate in employment in an occupation between 1983 and 2002 and the initial percentage unionization rate.[4] The initial unionization rate

[3] The employment (e) growth rates are calculated using the robust growth measure $\widetilde{g}_e = 100 \times 2(e_{2002} - e_{1983})/(e_{2002} + e_{1983})$, which is related to the commonly used growth rate, $g_e = 100 \times (e_{2002} - e_{1983})/e_{1983}$, via $\widetilde{g}_e = 2g_e/(2 + g_e)$. The focus on 1983-2002 period is primarily due to the fact that industry and occupation codes after 2002 are not consistent with those during this period.

[4] As in Table 3, in the regressions the employment growth rates are calculated using the robust growth measure $\widetilde{g}_e = 100 \times 2(e_{2002} - e_{1983})/(e_{2002} + e_{1983})$. The implied growth rates, g_e, of employment based on

is measured in two ways: the employment share of union members within an occupation, and the share covered by a union. Both the nonparametric and the linear fits in Figure 3 indicate a statistically significant negative association between employment growth in an occupation and the initial unionization rate. Over the sample period of 20 years, the slopes of the linear fits imply that a 10 percentage point increase in the initial union membership rate is associated with roughly a 1.6 percentage point decline in employment growth, and a 10 percentage point increase in the initial union coverage rate is associated with a 1.5 percentage point decline in employment growth.

Figure 4 repeats the analysis in Figure 3 for private-sector industries. The main conclusion from Figure 3 prevails. Employment growth is negatively associated with the extent of initial unionization, although this relationship is somewhat noisier at the higher end of unionization where data is sparse. The linear fit implies that a 10 percentage point increase in the initial union membership rate is associated with a decline of 1.7 percentage points in employment growth. Similarly, employment growth is lower by 1.6 percentage points when the initial union coverage rate increases by 10 percentage points.

This preliminary investigation supports the hypothesis that in recent times more unionized industries and occupations have been more prone to employment loss. These findings, however, are suggestive, and they constitute only indirect evidence on the connection between unionization and technological change. The statistical analysis conducted in Section 7 provides more direct evidence on the link between skill-biased technological change and unionization in light of the model presented next.

3 The Setting

Imagine a world inhabited by a representative family with tastes given by

$$\sum_{t=1}^{\infty} \beta^{t-1} \ln \mathbf{c}_t, \text{ with } 0 < \beta < 1,$$

the regressions are backed out from the estimated growth rates for $\widetilde{g}_e$.

where $\mathbf{c}_t$ represents household consumption in period t.[5] The family is made up of a continuum of members with a mass of one. Each household member supplies one unit of labor. A fraction σ of these members are skilled, the rest unskilled.[6] A skilled worker earns the wage rate v_t. Unskilled members may work in the unionized part of the labor force or in the non-unionized one. A unionized worker earns the wage rate u_t, while a non-unionized one receives w_t. The fraction of unskilled household members that work during period t in the unionized part of the labor force is m_t, a variable that is determined in equilibrium. The household saves in the form of physical capital, $\mathbf{k}_t$. A unit of physical capital earns the rental r_t in period t. Capital depreciates over time at the rate δ. Finally, the household earns profits, $\boldsymbol{\pi}_t$, from the firms that it owns.

There is a unit mass of firms in the economy. In period t a firm produces output, o_t, according to the production function

$$o_t = x_t z k_t^{\kappa}[\theta_t l_t^{\rho} + (1-\theta_t)(\xi_t s_t)^{\rho}]^{\alpha/\rho}, \text{ with } 0 < \alpha + \kappa < 1,$$

where k_t represents the amount of capital hired, l_t denotes the input of unskilled labor and s_t is the quantity of skilled labor. The variable x_t is a neutral shift factor for the technology that is common across firms. The variable x_t is assumed to grow at the constant rate g; specifically, $x_t = x_0 g^t$. A firm-specific shift factor is given by $z > 1$. This denotes a firm's

[5] Variables in bold represent economy-wide aggregates that will need to be distinguished from the analogous firm-level quantities. One can think of aggregate consumption as the total of all households' consumptions. Similarly, the aggregate capital stock and level of profits represent the sum of capital stocks and profits across all firms, respectively.

[6] The relative supply of skilled versus unskilled labor is assumed to be fixed over time. There is no doubt that supply shifts have occurred over the course of history, in particular due both to changes in the return from and the cost of an education (the latter due to changes in its public provision). The model abstracts from these supply effects. Research on the evolution of the skilled-to-non-skilled wage premium over the 20th century indicates that skill-biased technological change played a very important role–see Goldin and Katz (2008) and Krusell et al. (2000). More generally, Greenwood and Yorukoglu (1997) document how times of rapid technological progress are often associated with shifts in the income distribution. The concept of skill cannot be mapped straightforwardly into years of education. As Goldin and Katz (2008) note, a high school degree would have been considered well-educated in 1915, while to be labeled this today would require a college degree or more. See Restuccia and Vandebroucke (2011) for a model of the rise in educational attainment.

type and is drawn at the beginning of time from a Pareto distribution

$$z \sim F(z) \equiv \frac{\zeta}{z^{\zeta+1}}, \text{ for } z > 1,$$

where F is the density function for a Pareto distribution.

Observe that skilled and unskilled labor are aggregated via a CES production function. The technology variables θ_t and ξ_t change over time and will capture the notion of skill-biased technological change.[7] There are diminishing returns to scale in production (since $\alpha + \kappa < 1$). There is a fixed cost ϕ_t associated with operating a firm. This fixed cost is assumed to grow at a constant rate, $\phi_t = \phi_0(g^t)^{1/(1-\kappa)}$. The growth rate is the one at which output and wages will grow along a balanced growth path in the model. That is, one would expect the fixed cost of setting up a firm to keep pace with the cost of labor in a growing economy. The combination of diminishing returns to scale in production and a fixed operating cost ensure that it is not desirable to organize all the firms in the economy.

Finally, there is a union in the economy. The union organizes unskilled labor in firms. An organized firm must use union workers for unskilled labor. The union believes in equality so all union members are paid the same wage, u_t. Unionization is a costly activity. Specifically, the period-t cost of organizing is given by the quadratic function

$$\frac{m_t^2}{2},$$

where m_t is the number of union members. These costs are recovered from the membership in the form of dues, d_t. Skilled labor is not unionized. In the real world, this may be because skilled labor is too heterogenous in nature to be organized effectively to bargain for a common wage. The union is given the following set of preferences:

$$\sum_{t=1}^{\infty} \beta^{t-1}(u_t - d_t - w_t)^{\omega} m_t^{1-\omega}, \text{ with } 0 < \beta, \omega < 1.$$

These preferences presume that the union has two regards. It values the surplus that a union member will earn over a non-unionized worker, $u_t - d_t - w_t$, as well as the number

[7] It may be uncommon to let θ_t vary over time. Rios-Rull and Santaeulalia-Llopis (2010) use a similar approach in their study of how labor's share of income fluctuates over the business cycle.

of unionized workers, m_t, that will receive it. As will be seen, there is a trade-off between these two regards.

4 Decision Problems

4.1 Households

The problem facing the representative family is standard, with due alteration for the setting under study. Specifically, the household desires to maximize its lifetime utility subject to the budget constraint it faces each period. This problem reads

$$\max_{\{\mathbf{c}_t,\mathbf{k}_{t+1}\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \beta^{t-1} \ln \mathbf{c}_t, \qquad \text{P(1)}$$

subject to

$$\mathbf{c}_t + \mathbf{k}_{t+1} = (1-\sigma-m_t)w_t + m_t(u_t - d_t) + \sigma v_t + (r_t + 1 - \delta)\mathbf{k}_t + \boldsymbol{\pi}_t \text{ (for } t = 1, 2, \cdots).$$

In the above maximization problem the household takes the number of union members, m_t, as given. Since $u_t - d_t > w_t$, it would like as many unskilled household members as possible to be employed in union firms.

4.2 Firms

A firm in period t hires capital, k_t, and skilled and unskilled labor, s_t and l_t, to maximize profits. The firm's period-t choice problem is

$$\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot) \equiv \max_{k_t^q, l_t^q, s_t^q} \{x_t z (k_t^q)^{\kappa} [\theta_t (l_t^q)^{\rho} + (1-\theta_t)(\xi_t s_t^q)^{\rho}]^{\alpha/\rho} - r_t k_t^q - v_t s_t^q - q_t l_t^q\} - \phi_t \ ,$$

$$\text{for } q = u, w. \quad \text{P(2)}$$

With some abuse of notation, the variable q in superscript form will denote whether the firm is unionized ($q = u$) or not ($q = w$), while the variable q in regular form will represent the wage rate (again for $q = u, w$). Now, express the solution to the above problem for the amount of unskilled labor that a type-z firm will hire at the wage rate q_t by $l_t^q(z) = L_t^q(z; q_t, \cdot)$, for $q = u, w$–the "$\cdot$" represents the other arguments that enter the function L^q, which are suppressed to keep the subsequent presentation simple. Likewise, represent the amount of capital and skilled labor hired by $k_t^q(z) = K_t^q(z; q_t, \cdot)$ and $s_t^q(z) = S_t^q(z; q_t, \cdot)$. The amount of output produced by a firm is denoted by $o_t^q(z) = O_t^q(z; q_t, \cdot)$ and its profits are written as $\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot)$.

Production is not a forgone conclusion due to the presence of the fixed operation cost, ϕ_t. A firm will only produce if it makes nonnegative profits. Thus, it must transpire that in equilibrium

$$\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot) \geq 0, \text{ for } q = u, w.$$

Denote the period-t threshold value for z, at which it is just profitable for a firm to produce, by z_t^q. This threshold value solves the equation

$$\Pi_t^q(z_t^q; q_t, \cdot) = 0, \text{ for } q = u, w. \tag{1}$$

It should be clear that $\Pi_t^q(z_t^q; q_t, \cdot) > 0$ for $z > z_t^q$ and $\Pi_t^q(z_t^q; q_t, \cdot) < 0$ for $z < z_t^q$.

From the two first-order conditions associated with hiring labor, it transpires that

$$\frac{s_t^q}{l_t^q} = [\xi_t^\rho \frac{(1-\theta_t)}{\theta_t} \times \frac{q_t}{v_t}]^{1/(1-\rho)}, \text{ for } q = u, w. \tag{2}$$

The ratio of skilled to unskilled labor, s_t^q/l_t^q, in a firm depends on the price of unskilled labor relative to skilled labor, q_t/v_t. It also depends on the skill-biased technology term $\xi_t^\rho(1-\theta_t)/\theta_t$. This term captures the notion of skill-biased technological change in the model. When $\xi_t^\rho(1-\theta_t)/\theta_t$ is low, either because ξ_t is small or θ_t is high, unskilled labor is favored, relatively speaking. The benefit of unionizing unskilled workers will be large.

Now consider the move toward assembly line production at the beginning of the 20th century (and away from the artisanal production techniques of the 19th century). This is portrayed in Figure 5, where the (absolute value of the) slope of an isoquant is given by $\theta_t/[(1-\theta_t)\xi_t^\rho](s_t^q/l_t^q)^{1-\rho}$. A movement toward assembly line techniques can be represented by an upward shift in $\theta_t/[(1-\theta_t)\xi_t^\rho]$, due either to a fall in ξ_t or a rise in θ_t. It will cause the slope of an isoquant to increase along a ray from the origin. This is shown by the shift in the isoquant from S to U. As a consequence, at a given skill ratio, an extra unit of unskilled labor becomes more valuable in terms of skilled labor. If factor prices remained fixed, then the firm would substitute away from skilled labor toward unskilled labor, as reflected by the movement from l to l' in the diagram.

4.3 The Union

Recall that the union has two regards. First, it values the surplus over the competitive wage that union members earn. Second, it also puts worth on the number of workers that will earn the union wage. It is intuitive that the union should organize the firms with the highest level of productivity first. They can better afford to pay the union premium and provide larger employment to union. There is a limit to the wage that the union can set. Specifically, a unionized firm must earn nonnegative profits. So, if any unionized firm earns zero profits then all firms with a higher level of productivity will be unionized and those with a lower level will not. Because more productive firms are also larger in the model, the union organizes larger firms. This prediction of the model is consistent with studies indicating higher likelihood of unionization among larger firms.[8]

Now, turn to the optimization problem faced by a union. Assume that the profits of the last firm unionized are squeezed to zero. The number of unionized workers in period t, m_t, will be given by

$$m_t = \int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot) F(z) dz. \tag{3}$$

The dues paid by a union member, d_t, are

$$d_t = \frac{\chi m_t^2}{2 m_t} = \frac{\chi [\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot) F(z) dz]}{2}. \tag{4}$$

The union's decision problem appears as

$$\max_{\{u_t, z_t^u\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \{u_t - \frac{\chi [\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot) F(z) dz]}{2} - w_t\}^{\omega} [\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot) F(z) dz]^{1-\omega}, \tag{P(3)}$$

[8] Dinlersoz, Greenwood, and Hyatt (2013) find that in the U.S. the likelihood of unionization increases with a firm's productivity, as proxied by both firm size and age. Fang and Heywood (2006) also find that in Canada unionized plants are larger.

subject to the zero-profit constraint (1) holding (when $q = u$) for the marginal union firm, z_t^u.[9] When solving its problem, the union takes the wages for non-unionized unskilled and skilled labor, w_t and v_t, as given.

Is it possible that the union won't pick the wage rate so that the threshold firm earns zero profits? The answer is no. Suppose that the marginal firm earned positive profits. The cost of raising the union wage incrementally is the loss of membership that will occur from all of the inframarginal firms. It turns out, though, that this loss can be made up for by increasing the number of unionized firms or lowering z_t^u. How far can u_t be raised and z_t^u simultaneously lowered? At some point the firms with the lowest z_t^u will no longer be able to earn profits due to the presence of the fixed cost ϕ_t. Then the process must stop. Without the fixed cost, ϕ_t, every firm would be unionized. In this situation, all firms would earn some profits, albeit for some of them profits might be infinitesimally small. In general not all of the unskilled work force will be hired.

Lemma 1 *(Zero profits for the marginal firm) The union always picks the wage rate, u_t, so that the zero-profit constraint (1) is binding (when $q = u$) for the last firm organized.*

Proof. See Appendix. ■

The union's two regards must be traded off in the maximization problem P(3). By applying the envelope theorem to a unionized firm's optimization problem P(2), for $q = u$, it can be easily calculated from equation (1) that

$$\frac{du_t}{dz_t^u} = \frac{O^u(z_t^u; u_t, \cdot)}{z_t^u L_t^u(z_t^u; u_t, \cdot)} > 0.$$

This implies that lowering the threshold hold, z_t^u, or equivalently unionizing more firms, can only be accomplished by reducing the union wage, u_t. Additionally, it can be seen from

[9] Rudanko and Krusell (2012) also focus on a monopoly union, but take a Nash bargaining approach. Their analysis focuses on how unionization (and the ability to commit to contracts) impacts on unemployment and wages in a frictional labor market. For the analysis undertaken here, which abstracts away from issues of efficiency, the exact model of unionization probably doesn't matter too much. What does matter, however, is how the union values membership, an issue with or without bargaining, which determines the tradeoff between membership and wages. Observations on union membership and the wage premium are used to tie this down here.

equation (4) that a rise in membership, $m_t = \int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz$, comes at the expense of higher dues, d_t, because of the increasing costs involved with unionization.

5 Equilibrium

In equilibrium the markets for capital, labor and goods must clear. Equilibrium in the capital market requires that

$$\int_{z_t^w}^{z_t^u} k_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} k_t^u(z)F(z)dz = \mathbf{k}_t. \tag{5}$$

The market-clearing condition for skilled labor is

$$\int_{z_t^w}^{z_t^u} s_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} s_t^u(z)F(z)dz = \sigma, \tag{6}$$

while that for unskilled labor reads

$$\int_{z_t^w}^{z_t^u} l_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} l_t^u(z)F(z)dz = 1 - \sigma. \tag{7}$$

Last, equilibrium in the goods market implies

$$\mathbf{c}_t + \mathbf{k}_{t+1} + m_t d_t + \phi_t = \int_{z_t^w}^{z_t^u} o_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} o_t^u(z)F(z)dz + (1-\delta)\mathbf{k}_t. \tag{8}$$

Note that the aggregate amount of union dues, $m_t d_t$, appears in the resource constraint. These exactly cover the resource cost of organizing– see (4).

A definition of the equilibrium under study will now be presented to take stock of the situation so far.

Definition 2 *(Definition of a competitive equilibrium) A competitive equilibrium is a time path for consumption and savings, $\{\mathbf{c}_t, \mathbf{k}_{t+1}\}_{t=1}^{\infty}$, a set of labor and capital allocations for union ($q = u$) and non-union ($q = w$) firms $\{l_t^q(z), s_t^q(z), k_t^q(z)\}_{t=1}^{\infty}$, a set of factor prices $\{u_t, w_t, v_t, r_t\}_{t=1}^{\infty}$, a sequence for union dues, $\{d_t\}_{t=1}^{\infty}$, and a sequence determining the threshold points for union and non-union firms, $\{z_t^u, z_t^w\}_{t=1}^{\infty}$, such that for a given time profile for technology $\{\theta_t, \xi_t, x_t, \phi_t\}_{t=1}^{\infty}$:*

1. *The time path for consumption and savings, $\{\mathbf{c}_t, \mathbf{k}_{t+1}\}_{t=1}^{\infty}$, solves the representative household's problem, P(1), given the time path for factor prices, $\{u_t, w_t, v_t, r_t\}_{t=1}^{\infty}$, profits, $\boldsymbol{\pi}_t = \int_{z_t^w}^{z_t^u} \pi_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} \pi_t^u(z)F(z)dz$, and the size of the union sector, $m_t = \int_{z_t^u}^{\infty} l_t^u(z)F(z)dz$.*

2. *The time paths for firms' input utilizations,* $\{l_t^q(z), s_t^q(z), k_t^q(z)\}_{t=1}^{\infty}$*, solve their profit maximization problems, as specified by P(2), given the time paths for factor prices,* $\{q_t, v_t, r_t\}_{t=1}^{\infty}$ *(for* $q = u, w$*) and technology* $\{\theta_t, \xi_t, x_t, \phi_t\}_{t=1}^{\infty}$*.*

3. *The sequences for union wages,* $\{u_t\}_{t=1}^{\infty}$ *and the threshold,* $\{z_t^u\}_{t=1}^{\infty}$*, solve the union's problem P(3), given the time paths for factor prices,* $\{q_t, v_t, r_t\}_{t=1}^{\infty}$ *(for* $q = u, w$*), technology,* $\{\theta_t, \xi_t, x_t, \phi_t\}_{t=1}^{\infty}$*, and the solution to the unionized firm's problem,* $l_t^u(z) = L_t^u(z; u_t, \cdot)$ *and* $\pi_t^u(z) = \Pi_t^u(z; u_t, \cdot)$*, as implied by P(2). The sequence for union dues,* $\{d_t\}_{t=1}^{\infty}$*, is determined in line with (4).*

4. *The sequence for non-union thresholds,* $\{z_t^w\}_{t=1}^{\infty}$*, solves (1) when* $q = w$*, given* $\pi_t^w(z) = \Pi_t^w(z; w_t, \cdot)$ *from P(2) and the time paths for factor prices,* $\{w_t, v_t, r_t\}_{t=1}^{\infty}$*, and technology,* $\{\theta_t, \xi_t, x_t, \phi_t\}_{t=1}^{\infty}$*.*

5. *The markets for capital, labor and goods, all clear so that equations (5) to (8) hold.*

6 Simulation Analysis

6.1 Calibration

Before the model can be simulated, values must be assigned for its parameters. Table 6 lists the parameter values. The period is taken to be five years. Accordingly, the discount factor is set so $\beta = 1/(1.04)^5 \simeq 0.82$, which implies an annual interest rate of 4%. This is a standard value. The annual depreciation rate for capital is taken to be 0.08, another standard value. Likewise, labor's share of income is set at 60%, implying $\alpha = 0.60$, a typical value if one assumes that part of the capital stock includes intangibles. Note that a firm's production function exhibits diminishing returns to scale. Guner, Ventura and Xi (2008) estimate that the share of profits in output is 20%. Capital's share of income, κ, is therefore set at 0.20. Katz and Murphy (1992) estimate that the elasticity of substitution between skilled and unskilled labor is 1.4, corresponding to a value of 0.29 for ρ.

The rest of the model's parameters are selected so that a steady state for the model hits 5 data targets for the year 1955, roughly the peak year of the unionization movement (see Figure 1). This involves computing the model's steady state in conjunction with the 5 data targets, while taking the 5 parameters θ_{1955}, ϕ_{1955}, ω, χ and ζ as additional variables. The technology variable ξ is normalized so that $\xi_{1955} = 1$. While the nonlinear system of equations used to calibrate the model is simultaneous in nature, certain parameters play a key role in matching each of the data targets. The five data targets and their importance for identifying the five parameters are discussed now.

The first target is the union membership rate of 37% in 1955. Therefore, the steady state is computed subject to the restriction

$$m_{1955} = 0.37. \tag{T(1)}$$

The weight on the extent of membership in the union's objective function, $1-\omega$, plays a key role in attaining this target.

Let the top 10% of the population represent skilled labor. Thus, $\sigma = 0.10$. The share of the top 10% of the work force in earnings was 0.32 in 1955. Therefore, the steady state must satisfy the equation below for the second target

$$\frac{\sigma v_{1955}}{m_{1955}u_{1955} + (1 - m_{1955} - \sigma)w_{1955} + \sigma v_{1955}} = 0.32. \tag{T(2)}$$

Not surprisingly, the constant term on unskilled labor in the production function, θ_{1955}, is important for hitting this objective.

Union dues are assumed to amount to 1% of a union member's wages. MacDonald and Robinson (1992, p 47) state that this is a reasonable value. Indeed, this is exactly what the UAW currently charges salaried workers. Thus, the third target can be expressed as

$$\frac{d_{1955}}{u_{1955}} = 0.01. \tag{T(3)}$$

The term χ in the union's cost function is instrumental in meeting this target.

The distribution of employment across establishments in the U.S. is highly skewed and dispersed. Based on the *Longitudinal Business Database* of the U.S. Census Bureau, the coefficient of variation (CV) of employment across U.S. establishments with at least one employee had an average value of approximately 7 over the period 1976-2011, varying in a narrow band of 6 to 8.[10] The average value of 7 is used to provide guidance for the choice of

[10] See Appendix for the calculation of the descriptive statistics for the establishment-size distribution. Using less granular data, Henley and Sanchez (2009, p 427) report a coefficient of variation of 8 for 1974 and find that it remained relatively constant after that.

the Pareto distribution parameter, ζ.[11] Note that in the U.S., unionization tends to occur at the establishment level and not the firm level, so the CV of establishment employment is the appropriate statistic to use. In the model there is no distinction between establishments and firms. The fourth target is represented by

$$\text{CV}(l + s) = 7. \qquad \text{T}(4)$$

Last, in classic work, H. Greg Lewis (1963) reported that the wage premium from union membership was 15%. Here, Card, Lemieux, and Riddell's (2003, Table 4) more recent estimate of 20% is used. This implies the final equation for the fifth target

$$\frac{u_{1955}}{w_{1955}} = 1.20. \qquad \text{T}(5)$$

Remember that the last firm unionized earns zero profits when it pays the union wage, u, and incurs the fixed cost, ϕ. This condition can be used to back out the fixed cost in 1955, ϕ_{1955}.

6.2 Results

Can the model explain the ∩-shaped pattern of union membership along with the ∪-shaped profile for income inequality over the 20th century? To investigate this question requires inputting in a time series process for technology, $\{\theta_t, \xi_t\}_{t=1910}^{2000}$. A perfect foresight path for the model is calculated using a variant of the Fair and Taylor (1983) algorithm, which is useful for computing saddle path solutions for two-point boundary value problems. The Fair and Taylor (1983) algorithm is a relative of the multiple shooting algorithm used to solve difference equation systems. The first boundary condition for the economy is the initial capital stock, while the second one is capital stock associated with the terminal steady state.

The process for $\{\theta_t, \xi_t\}_{t=1910}^{2000}$ is constructed in a crude way. Steady states for the model are computed for 1910 and 2000, the starting and ending years for the simulation analysis.

[11] Note that picking the coefficient of variation for a Pareto random variable implies that the mean and variance are also simultaneously matched, because the mean, variance and coefficient of variation are uniquely defined by the single parameter, ζ, of the Pareto distribution.

Union membership and income inequality are taken as targets for these years. Solutions for θ and ξ that hit these targets are backed out, while holding all other parameter values fixed. Assume that θ_t and ξ_t are separately quadratic in t. Each quadratic will have three parameters. Fit these two quadratics to the triplets $(\theta_{1910}, \theta_{1955}, \theta_{2000})$ and $(\xi_{1910}, \xi_{1955}, \xi_{2000})$, respectively. The resulting time profile for skill-biased technological change, as represented by $[\xi_t^{\rho}(1-\theta_t)/\theta_t]^{1/(1-\rho)}$, is shown in Figure 6. After the year 2000 all technological change is shut off. The capital stocks associated with the 1910 and 2000 steady states are taken as the initial and terminal capital stocks when computing the transitional dynamics for the model, although the model needs to be run for somewhat more than 90 years to reach the final steady state.

Is the pattern of skill-biased technological change shown in Figure 6 reasonable? The skill-biased term drops by a factor of 1.5 from peak to trough. Over the 1910 to 2000 period real per-capita income grew by 2.1% a year. This implies that real per-capita GDP rose by a factor of 6.7. To achieve this in the model, the parameter governing neutral technological change, x_t, must rise by a factor of $g^{2000-1910} = 6.7^{1-\kappa} = 4.6$, which implies $g = 1.017$ or that x growths at 1.7% a year. The fixed cost, ϕ_t, needs to rise by a factor of 6.7 if the economy is to remain on a balanced growth path in the absence of changes in θ_t and ξ_t. Therefore, the required amount of skill-biased technological change is smaller than the required amount of neutral technological change, as Figure 6 illustrates.

The framework does a good job accounting for the rise and fall in union membership, as Figure 7 illustrates. It misses membership at the peak of the union movement, but not by much. It also mimics the fall and rise in income inequality as well. This is shown in Figure 8. In the analysis, skill-biased technological change is the sole driver of both the $\cap$-shaped time series for unionization and the $\cup$-shaped one for income inequality; i.e., the $\cup$-shaped pattern in income inequality is not caused by the $\cap$-shaped time series for unionization. By this account, very little of postwar rise in inequality can be accounted for by the decline in unionization.[12] Goldin and Katz (2008), Greenwood and Yorukoglu

[12] A drop in unionization has a minor impact on income inequality in the model. As will be seen in the

(1997), and Krusell at el. (2000) all stress technological change as a force underlying shifts in the income distribution.

6.3 Welfare Cost of Unions

So, what is the welfare cost of unions? Rees (1963) asked this question a long time ago. He found that the welfare loss from unions in 1957 amounted to 0.14% of GDP. The model developed here can also be used to address this question. Suppose that the model economy is resting in its 1955 steady state, the peak of the union power. Now, eliminate unions. The model would then imply a welfare increase of 0.66% of GDP. While this is 4.7 times as big as Rees's number, it is paltry.

Figure 9 illustrates the situation in an alternative Reesian fashion. The picture draws the demands for unskilled labor by both union and non-union firms. These demands must sum up to 0.9, the size of the unskilled labor force as a proportion of the total labor force. In the economy without unions, the union firms would hire unskilled labor amounting to 49.6% of the total labor force at the competitive wage rate w^c. Unions increase this wage to u. As a consequence, unionized firms cut their employment of unskilled labor from 49.6% of the total labor force to 36.7%. This leads to a welfare loss measured by the area *acde*. But, the labor displaced by union firms is picked up by non-union ones. The wage rate for nonunion labor falls from w^c to w. The gain in welfare from the increased employment by non-union firms is represented by the area *cdeb*. The net loss is the area in the triangle *acb*. This triangle represents the difference in productivities between the unionized and non-unionized firms. It amounts to $0.5 \times 0.20 \times w \times (0.496 - 0.367)$. Expressing this as a percentage of

next section, this is due to the facts that: (i) the union wage premium is of moderate size; (ii) it applies to a relatively small part of the aggregate wage bill; (iii) a fall in union wages for unskilled workers implies a rise in nonunion wages. Hence, a drop in unionization does not account for the large observed shifts in income inequality in the model. In fact, if one assumes that all unskilled workers get the non-union wage then the plot obtained for the income distribution looks virtually identical to that displayed in Figure 8.

aggregate output, $\mathbf{o}$, gives

$$
\begin{aligned}
100\% \times \frac{0.5 \times 0.20 \times w \times (0.496 - 0.367)}{\mathbf{o}} &= 100\% \times 0.5 \times \underbrace{\frac{0.20 \times w \times 0.367}{\mathbf{o}}}_{0.0305} \times \underbrace{\frac{(0.496 - 0.367)}{0.367}}_{0.351} \\
&= 0.54\%.
\end{aligned}
$$

This number is very close to the model-based figure of 0.66%. It is easy to see why this number is small. First, the union premium, 0.20, only applies to small part of wage bill expressed as a fraction of output, $w \times 0.367/\mathbf{o}$. This represents the base of the triangle. Second, the proportional shift in union labor, $(0.496 - 0.367)/0.367 \simeq 0.35$, is not that large. This is the height of the triangle.

The fact that the welfare cost of unions is so small does not imply that they have little effect on the economy. The impact of unions is restricted here by the assumption that firms are competitive. Whether or not this is a good approximation for the U.S. economy across the time period studied is an open question. Perfect competition limits the wages that unions can obtain. Unions are more likely to have a large impact on economic activity when they are negotiating with producers that have monopoly power. This was the case in U.S. iron ore industry prior to the 1970s. After this time, producers faced intense competition from foreign exporters. Schmitz (2005) documents how this increased competition led to a large rise in labor productivity. Firms were forced to abandon the productivity-hindering work practices that they had negotiated with unions earlier. His analysis might also apply at points in time to the aircraft, airline, auto industries, for example. Similarly, Cole and Ohanian (2004) study the impact unions had on the economy during the Great Depression. They stress the cartelization of industries allowed by Roosevelt under the New Deal, which were then abandoned prior to World War II. Taschereau-Dumouchel (2011) argues that just the threat of unionization may be enough to generate large welfare costs. To keep unions out, firms have to offer high wages to low-skilled workers in his model. Finally, Alder, Lagakos and Ohanian (2013) suggest that union power played an important role in the decline of the rust belt.

7 Empirical Evidence

Is skill-biased technological change, as highlighted in the model, an empirically relevant factor in the decline of unionization in the U.S.? This question will be examined in two ways. First, the model predicts that the ratio of skilled labor to non-skilled labor should increase with skill-biased technological change. This implication can be seen directly from equation (2): the ratio s_t^q/l_t^q is positively related to the term that captures skill-biased technological change, $\xi_t^\rho(1-\theta_t)/\theta_t$. Second, the fraction of the labor force that is unionized, m_t, is negatively related to skill-biased technological progress, as the simulation analysis established. To test these two predictions, a measure of skill-biased technological change is needed.

Measures of skill-biased technological progress are difficult to come by. The macroeconomics literature, in particular Krusell at el. (2000), suggests that the relative price of new capital goods is one measure. In an influential paper, Solow (1960) argued that technological progress is embodied in the form of new capital goods, which is now commonly referred to as investment-specific technological progress. Investment-specific technological progress is incarnated in new technologies, such as more powerful computers, faster and more efficient means of telecommunication, and numerically-controlled industrial machines. As new technologies come on line, they tend to become less expensive due to process innovation and the entry of competitors. Greenwood, Hercowitz and Krusell (1997) illustrate how investment-specific technological progress manifests itself in the form of decreasing relative prices for new capital goods, measured in terms of consumption goods. Similarly, Krusell at el. (2000) suggest that the decline in the relative price of capital goods is a driver of skill-biased technological progress. Now, different industries use different mixes of capital goods, and the level and growth rate of prices associated with these mixes of goods differ across industries and over time. This variation will be exploited to explore the link between skill-biased technological change and unionization. If skill-biased technological change is embodied in the form of capital goods, then those industries where the price of capital goods is lower should in general have lower unionization rates. Furthermore, a faster decline in the price of new capital goods should imply a faster rate of deunionization.

Calculating the relative price of capital goods in quality-adjusted terms at the industry level is not a straightforward task. Cummins and Violante (2002) have done this calculation for equipment and software (E&S). Their price series will be used here.[13] E&S include four major groups: industrial equipment, transportation equipment, office information processing equipment, and other equipment. Technological progress in E&S is viewed as complementing skilled workers more so than unskilled workers. Compared with other candidate measures, such as the stock of E&S or real investment in E&S, the Cummins and Violante (2002) relative price measure has some advantages. It takes into account the quality improvements in E&S over time, and it measures the quality-adjusted price of E&S with respect to the price of constant-quality consumption goods. The connections between skill-biased technological progress and investment in E&S, or the stock of E&S, are likely to be more ambiguous in nature. An increase in E&S investment or stock may be associated, for instance, with an expansion in industry output, but not necessarily with an advance in technology favoring skilled workers. Furthermore, as higher quality and more advanced E&S becomes available at lower prices, conventionally-measured E&S investment or stock may not show much of a rise, and could even decrease. Investment and the capital stock are also more susceptible to endogeneity issues at the industry level, whereas the rapid decline in the relative price of E&S used by an industry is likely to occur from technological progress in the overall economy, which can be taken as exogenous with respect to the process of unionization and the composition of skill in a narrowly defined industry. For instance, if inventory management software constitutes a large share of software used in a narrowly defined industry, the decline in the relative price of this software due to its general diffusion in the rest of the economy can have a disproportionate effect on this industry's employment, but unionization in the industry is not going to be the main driver of the relative price of the software in the economy.

The relative price series constructed by Cummins and Violante (2002) indeed exhibit significant variation both across industries and over years during the period 1983-1999 for

[13] See Cummins and Violante (2002) for the details on the construction of this relative price series.

which industry-level unionization and the relative price of E&S are consistently available. In 1983, the relative price of E&S had a mean of 0.35, and a standard deviation of 0.19, across industries used for the empirical analysis below. By 1999, the mean had declined to 0.16, and the standard deviation was 0.12. All industries exhibited a decline in the relative price. The growth rates of relative prices over the period 1983-1999 also vary considerably. The industries in the analysis experienced an average decline of 60% in the relative price of E&S, with a standard deviation of 10%. The largest decline occurred in air transportation industry (81%), and the smallest decline was in farms (29%).

7.1 Skill Composition and Skill-biased Technological Change

The model relates the skilled-to-unskilled labor ratio to skill-biased technological change. Consider the logarithm of the firm-level skilled-to-unskilled labor ratio defined by (2)

$$\ln \frac{s_t^q}{l_t^q} = \frac{1}{1-\rho} \ln \xi_t^\rho \frac{(1-\theta_t)}{\theta_t} + \frac{1}{1-\rho} \ln \frac{q_t}{v_t}, \text{ for } q = u, w. \quad (9)$$

The term $\xi_t^\rho(1-\theta_t)/\theta_t$ captures skill-biased technological progress, while q_t/v_t is the relative price of unskilled labor with respect to skilled labor. Equation (9) implies that when $\xi_t^\rho(1-\theta_t)/\theta_t$ is higher, skill ratio is also higher.

One measure of the skill ratio, s_t^q/l_t^q, is the ratio of non-production workers to production workers in a firm. This ratio is readily available at the industry level annually for manufacturing industries from the *NBER-CES Manufacturing Industry Database*. One may argue that non-production workers embody more skill or human capital than production workers, at least on average. Non-production workers include managers, professionals such as engineers and lawyers, and many other employees who are not directly involved in production.[14] Non-production workers' wages are much higher than production workers' wages.[15] Denote

[14] See Gujarati and Dars (1972) for a detailed description of these two types of workers, as defined by the U.S. Census Bureau.

[15] For instance, in the 1997 Census of Manufactures, the average wage of production workers was about $21,000, compared with about $39,000 for non-production workers, a difference that is also highly statistically significant. In *NBER-CES Manufacturing Industry Database*, the ratio of the average wage of non-production

by s_{it} the ratio of non-production workers to production workers in industry i for year t. Based on (9), consider a panel regression of the form

$$\ln s_{it} = \alpha + \beta \ln p_{it} + \gamma \ln \widetilde{w}_{it} + \boldsymbol{\lambda}' \ln \mathbf{x}_{it} + \tau_t + \iota_i + \varepsilon_{it}. \tag{10}$$

The panel regression (10) is implemented at the industry level.[16] In (10), p_{it} is the relative price of equipment and software that measures the state of skill-biased technological change in industry i for year t. Based on the model, β is negative: as the relative price of equipment and software declines, the skilled-to-non-skilled labor ratio increases. $\widetilde{w}_{it}$ is the ratio of the average wage of production workers to that of non-production workers, which has a positive association with s_{it} based on the model.[17] $\mathbf{x}_{it}$ is a vector of industry-year varying controls, τ is a year fixed effect, ι is an industry fixed effect, and ε_{it} is an error term clustered at the industry level. The fixed-effects specification in (10) can be estimated using the balanced panel of 19 two-digit manufacturing industries available from the *NBER-CES Manufacturing Industry Database* over the sample period $1958-1999$. The relative price is available at the two-digit SIC code level only, so the analysis is restricted to two-digit SIC code manufacturing industries.[18]

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workers to that of production workers ranges from 1.14 to 2.43 across 2-digit manufacturing industries during the 1958-1999 period.

[16] Note that equation (9) is defined at the firm level. In the model, the ratio s_t^q/l_t^q is identical across firms for a given $q = u, w$, but differs across unionized and non-unionized firms because of the different relative wages. One could aggregate equation (9) to the industry level. Specifically, let $f_t = p_t/(1-\sigma)$ be the fraction of unskilled labor in unionized firms. The logarithm of the industry-level ratio, s_t/l_t, is then given by

$$\begin{aligned} \ln(s_t/l_t) &= \ln\left[f_t(s_t^u/l_t^u) + (1-f_t)(s_t^w/l_t^w)\right] \\ &= \ln[\xi_t^\rho(1-\theta_t)/\theta_t]^{1/(1-\rho)} + \ln[f_t\,(u_t/v_t)^{1/(1-\rho)} + (1-f_t)\,(w_t/v_t)^{1/(1-\rho)}]. \end{aligned}$$

This relationship is approximated here by the form given in (10).

[17] In the general equilibrium model, the skill premium, q_t/v_t for $q_t = w_t, u_t$, is endogenous. Loosely speaking, it is be a function of the technology parameters θ_t, ξ_t, x_t, and the aggregate capital stock, k_t–see the definition given for a competitive equilibrium. Therefore, the skill premium embeds, in part, the effects of skill-biased technological change. This would be true in the real world as well, of course. The wage ratio $\widetilde{w}_{it}$ can also be influenced by other exogenous factors. The inclusion of $\widetilde{w}_{it}$ in the regression also controls for the influence that these considerations have on the skill mix through the skill premium.

[18] One two-digit industry is not included in the estimation because it is not in the Cummins and Violante (2002) data. The sample period ends in 1999, the last year for which the relative price measure for industries is available from Cummins and Violante (2002).

The controls $\mathbf{x}_{it}$ include real output to measure the potential effect of industry scale on s_{it}. Labor productivity (real output per worker) is also added to $\mathbf{x}_{it}$ to capture the effect of general improvements in industry labor productivity on s_{it}. The model features a firm-level production technology that exhibits neutral-technological advance in addition to skill-biased technological progress. Along a balanced growth path, neutral technological change will not affect s_{it}. However, the data may exhibit deviations from the clinical model environment. For instance, imagine a situation where demand is fixed in an industry but there is neutral technological progress. One would expect a fall in this industry's employment. If the production technology does not exhibit constant returns to scale, then this fall may have a differential impact on skilled versus unskilled labor. Skilled and unskilled labor may have different costs of moving across industries. Hence, variations in industry demands and production technologies may induce changes in the relative employments of skilled and unskilled labor. Industry scale and labor productivity are used as controls for some of these potential deviations.

The real capital stock and the conventionally-measured real price of investment are also added as controls. While s_{it} does not depend on the capital stock in the model, the data may exhibit deviations. In a more general formulation, skill-biased technological change could operate through the capital stock, which is influenced by the price of investment. Furthermore, if p_{it} measures the quality of capital to an extent not possible by conventional measures of the capital stock and its price, then any significant connection between p_{it} and s_{it} should survive the addition of these controls. Finally, in (10), the relative price of E&S, p_{it}, is treated as exogenous to s_{it}. As argued earlier, this may be a reasonable assumption at the industry level. For a robustness check on this assumption, the regression analysis in (10) is also implemented using a two-stage least squares (2SLS) estimation. The model's timing suggests that lagged (period $t-1$) values of $p_{it}, \widetilde{w}_{it}$, and aggregates such as output, capital, and labor productivity, are pre-determined and should be orthogonal to the error term in (9) at time t. The instruments used for the main independent variable of interest, p_{it}, are thus one-period lagged values of p_{it}, $\widetilde{w}_{it}$, real output, labor productivity, the real capital stock, and the real price of investment.[19]

Between 1958 (near the peak year, 1955, of unionization) and 1999, the average of s_{it} across the two-digit manufacturing industries in the sample grew from 0.29 to 0.39, an increase of 34%. In the meantime, the average of p_{it} across the same group fell sharply from 0.83 to 0.14, a decrease of 83%. Table 5 contains the results of the estimation based on (10). In all the specifications displayed in Table 5, a statistically significant negative association between s_{it} and p_{it} emerges. Across specifications with controls (specifications 2 to 10), a 1% decline in p_{it} is connected with a 0.16% to 0.41% increase in s_{it}. The wage ratio, $\widetilde{w}_{it}$, is also positively associated with s_{it}, as expected, and is statistically significant. The industry elasticity of s_{it} with respect to $\widetilde{w}_{it}$ ranges between 1.38 to 1.93.[20] The estimated coefficients of real output and labor productivity vary across specifications, but in general there does not seem to be a consistently significant link between these two variables and s_{it}. The real capital stock is positively associated with s_{it}, whereas the real price of investment is negatively related to s_{it}, although the latter relation is significant only in specification 10. Because p_{it} can be viewed as a particular measure of the price of investment/capital, its connection with s_{it} is expected to weaken when other measures related to capital and its price are included in the regression. This is the case in specifications 7 to 10. Despite this attenuation, however, the estimated β does not vanish or lose its significance in the presence of these other measures, suggesting that p_{it} may indeed measure the price of equipment to an extent not captured completely by more conventional measures of capital stock and the real price of investment, which do not take into account the quality of capital. Overall, Table 5 suggests that the skill-biased technological change measure, p_{it}, has a negative association with s_{it}, as predicted by the model.

[19] The first-stage regressions using the instruments indicate high F statistics, and the instruments appear to be strong in terms of explanatory power for $\ln p_{it}$. Potential endogeneity of wages, labor productivity and real output was also addressed by using lagged values as instruments. Any potential bias in the estimated coefficients of these variables are less crucial, as the primary coefficient of interest is that of $\ln p_{it}$.

[20] This implies an industry-level value for the parameter ρ in the range 0.27 to 0.48, which also contains the firm-level value $\rho = 0.29$ used in the model's calibration.

7.2 Unionization and Skill-biased Technological Change

Next, consider the connection between unionization and skill-biased technological change, the main relationship of interest. The fraction unionized in the model economy is determined in general equilibrium by consumers' consumption/savings decisions, firms' input choices, the union's decisions about wage setting and organizing, and various market-clearing conditions– see definition (2). This relationship cannot be represented by a simple expression as could be done for the skill ratio, s_t^q/l_t^q. Following (10), unionization in industry i in year t, m_{it}, as measured either by the percentage of industry employees who are union members or by the percentage covered by a union, is approximated in a log-linear form as

$$\ln m_{it} = \alpha + \beta \ln p_{it} + \boldsymbol{\lambda}' \ln \mathbf{x}_{it} + \boldsymbol{\gamma}' \ln \mathbf{z}_t + \iota_i + \varepsilon_{it}. \tag{11}$$

The fixed-effects specification in (11) can be estimated using a balanced panel of 59 industries for which unionization and the relative price of equipment and software are available for the period 1983 to 1999. These industries include the 19 manufacturing industries used in the previous section plus non-manufacturing industries, and exclude agriculture and public-sector industries. It is important to assess how the effects of other factors typically associated with the decline in unionization over time compare with the effects of skill-biased technological change. For this purpose, (11) is implemented with time-varying covariates $\mathbf{z}_t$ that capture some of the trends in the U.S. relevant for unionization.

The sign of the estimated β based on (11) is expected to be positive: as the relative price of equipment and software declines–indicating skill-biased technological progress– unionization should decline, as the model's simulation suggests. The controls $\mathbf{x}_{it}$ include the number of establishments per capita in an industry, in addition to real output and labor productivity. The motivation for including real output and labor productivity was discussed earlier. The number of establishments per capita is intended as a measure of the intensity of competition. Although the degree of competition is not part of the model which assumes a competitive environment, more intense competition in general can strip rents from firms that can otherwise be captured in part by unions. A direct measure of the markup at the industry level is not straightforward to construct especially for non-manufacturing industries, so the number of establishments per capita is used as a proxy. Smaller number of establishments per capita indicate lower markups, ceteris paribus, and hence should be associated with lower rents.[21] Therefore, a smaller number of establishments per capita should imply lower unionization.

The variables included in $\mathbf{z}_t$ assess the effects of various nationwide trends on unionization emphasized by earlier research. The share of part-time employment is included, as part-time employees are less likely to be union members, and an increase in the reliance on part-time labor can lead to lower unionization. The fraction of the U.S. population in the south and west controls for the migration of workers and firms to generally union-unfriendly, right-to-work law states in these regions.[22] This variable is also interacted with a dummy for manufacturing industries, as these industries were disproportionately affected by firms' migration to the south. Younger people may also have less friendly attitudes towards unions, as newer generations are less exposed to a strong union tradition. Therefore, as the fraction of young people (aged 18 to 45) in the population increases, unionization may decline. Finally, the trade variables, imports and exports, are both expected to have a negative association with unionization. Increasing imports or outsourcing adversely affects firms' output and employment, and therefore, unions, while escalating exports may signify greater exposure to foreign competition, which may reduce union rents. Exports may also proxy for the generally more advanced technology and the higher productivity of exporters, which may rely more heavily on skilled workers as opposed to unskilled ones.[23] These two variables were also interacted with the dummy for manufacturing, as their effects may have played a greater role in the decline of manufacturing industries, and unions in manufacturing sector. Similar to the estimation of (10), the instruments used for the relative price p_{it} are the lagged values of real output, labor productivity, the number of establishments per capita, and the relative

[21] See, e.g., Campbell and Hopenhayn (2005) for this connection.

[22] See Reder (1988) for a discussion.

[23] See Baldwin (2003) for an extensive investigation of the effects of trade on unionization in the U.S.

price and its square.[24]

The estimation results are in Table 6. Specifications 1-4 use only $\ln p_{it}$ as the regressor, and they yield a positive and significant estimated coefficient for $\ln p_{it}$. Specifications 5 to 18 include the controls $\mathbf{x}_{it}$ and $\mathbf{z}_t$. Specifications 9-12 and 15-18 analyze manufacturing and non-manufacturing industries separately, to see if there are any differences in the experiences of these two broad groups of industries. All but specification 16 result in a positive and significant estimate for β. The estimates of β across specifications 5 to 18 indicate that a 10% decline in p_{it} is associated with roughly a 2% to 4% decline in m_{it}.

The coefficient estimates for the controls are generally consistent across specifications 5 to 18, but only some exhibit statistical significance. The estimated coefficients of imports and exports generally have the expected negative signs, and they exhibit statistical significance in some specifications. Output has generally a negative and significant coefficient estimate, but labor productivity exhibits mixed coefficient estimates. The share of the population in south and the share of the young in the population have generally negative, and sometimes significant, coefficients. The interaction term for the population share in south and the manufacturing dummy exhibits a large negative estimated coefficient, which is generally statistically significant, as expected. The number of establishments per capita and part-time employment have coefficient estimates that are mixed in sign and only sometimes significant. In general, the estimated coefficients of the various controls indicate that factors other than skill-biased technological change also played an important role in the decline of unionization, as a large body of prior work indicates. Note also that the coefficient estimates for relative price in the case of manufacturing sector tend to be stronger than those in non-manufacturing sector, as indicated by specifications 9-12 and 15-18.

To assess the magnitude of the effect of technological progress on unionization, simple calculations can be made. The average annual decline in p_{it} across industries over the

[24] The model again suggests that these lagged values are predetermined and should be orthogonal to the error term in (11). The F statistics from first stage regressions indicate that these instruments do have high explanatory power for the potentially endogenous variables productivity, output, and relative price of E&S. Potential endogeneity of labor productivity and real output was also addressed, as before, by using lagged values as instruments.

entire 1983 to 1999 period was about 5.7%. Suppose that an industry experiences this average change in p_{it} in a linear fashion over the years, holding all other variables fixed. Then, the annual decline in union membership/coverage rate during the 1983 to 1999 period attributable only to the decline in p_{it}, holding all else fixed, amounts to about 1.2% to 1.3% based on specifications 5 to 18 in Table 6. This rate of decline would imply about 17% to 19% decline in unionization rate from its 1983 value. The average industry union membership rate in 1983 was 23%. Starting at this average, a decline of 17% to 19% would imply an average union membership rate of 18% to 19% as of 1999. The actual average in 1999 was about 15%.

A first-difference regression based on (11) was also run to explore the relationship between $\Delta \ln m_{it}$ and $\Delta \ln p_{it}$, as a further robustness check. If the variables used in Table 6 exhibit non-stationarity, then spurious correlations between the dependent variable and the regressors may result. First-differencing also helps address this issue.[25] The one-period lagged versions of the instruments for $\ln p_{it}$ used in Table 6 are used here as instruments for $\Delta \ln p_{it}$. The results, shown in Table 7, are consistent with the results in Table 6, and indicate a positive and statistically significant association between the change in unionization rates and the change in the relative price of E&S.

7.3 The Experience of Other Developed Countries

Deunionization is not unique to the U.S. If skilled-biased technological change is widespread across countries then similar declines should be expected in other developed countries. As shown in Figure 10, unionization (including both private and public sectors) in several OECD countries declined, starting usually in the early 1980's, and even earlier in some cases, notably

[25] The stationarity of all the differenced variables are investigated using panel unit root tests. There is no strong evidence to conclude against the hypothesis that the panels for the differenced relative price and union membership/coverage rates are trend-stationary. The panel unit root tests employed are the Levin-Lin-Chu, Harris-Tzavalis, Breitung, Im-Pesaran-Shin, Fisher-type tests based on Phillips-Perron, and Hadri LM. For the first difference of $\ln m_{it}$, all 5 tests indicate trend-stationarity, both for membership and coverage, at the 1% level. For the first difference of $\ln p_{it}$, 4 out of 5 tests conclude trend-stationarity at the 1% level. For each of the remaining differenced variables, at least 3 out of the 5 tests indicate trend-stationarity at the 1% level.

Austria, France, Japan, the Netherlands, and Switzerland. Only a handful of countries did not exhibit a decline after the 1980's, as displayed in Figure 11. The variation in the experiences of countries no doubt reflects, in part, differences in institutions, laws, and regulations. Nevertheless, the decline in unionization is a common theme across these countries, and it seems to have escalated in the 1980s, as computers and information technology started to diffuse more rapidly. While data on private-sector unionization rates is not available for this large cross section of countries, it is likely that private-sector unionization fell even faster, the decline possibly starting even earlier than the 1980s for many countries.

Did skill-biased technological change play a role in the decline of unionization in other countries as well? If this is the case, unionization rates in other countries should also be positively associated with the relative price of new capital goods, which also exhibited decline over the past three decades in many countries. Table 8 provides the results of regressions based on (11), with countries replacing industries as the cross-sectional unit of observation. The relative price of new capital used in this regression is the real price of information and communication technologies (ICT) and transport and other machinery equipment divided by the real price of consumption. This series can be calculated only for certain countries and years due to data availability, resulting in a smaller sample than the entire set of countries for which union membership information is available. The share of imports and exports in GDP, labor productivity, the share of manufacturing in GDP, the share of public-sector employment, and the share of young people in the population are included as controls.[26] In the 2SLS regressions, the lagged value of the relative price is used as an instrument for the relative price. The results indicate a positive association between union membership and the relative price of capital, as in Table 6 and 7. While these country-level results are not as refined as in the case of U.S. due to lack of detailed data, they appear to support the findings in the previous section for the case of U.S.

[26] See the Appendix for data sources and details on the variables used.

8 Conclusion

A general equilibrium model of unionization is developed here. Firms hire capital, skilled labor, and unskilled workers. They differ in productivity. A union can organize unskilled labor at a cost. It cares about the wage rate that its members earn, and how many workers receive this wage. There is a trade off between these two objectives. The union sets its membership and the wage so that it squeezes all of the rents from the last firm organized. The higher is the union wage, the smaller is the number of unionized firms and the amount of unskilled labor each hires. The union targets the most productive firms in the economy. This prediction of the model is supported by recent research. Dinlersoz, Greenwood and Hyatt (2013) examine all union certification elections in the U.S. between 1977 and 2007, matched with micro data on business characteristics. They find that the likelihood of unionization increases with a firm's productivity, as proxied by both firm size and age.[27]

The structure of production influences the value of unskilled labor. When the productivity of unskilled labor is (relatively) high, it pays for the union to organize a lot of firms and demand generous wages. The shift from an artisan economy to an assembly line economy during the beginning of the 20th century was associated with an increase in the (relative) productivity of unskilled labor that led to an increase in unionization and a decrease in income inequality. The decline of the assembly line economy and the rise of the information age reversed this trend, leading to the $\cap$-shaped pattern of unionization and the $\cup$-shaped one for income inequality.

The empirical analysis proceeds on three fronts. First, qualitative evidence is presented from a historical perspective. This evidence lays out the evolution of unionization and the

[27] Specifically, suppose that a union learns, in a Bayesian fashion, a new establishment's productivity over time, and targets the establishment if it believes that it is profitable enough to unionize. Profitable establishments are likely to be the ones that have grown fast. The odds of being targeted is then positively associated with establishment size, given age, and negatively related with age, given size. This is born out in the data. Unionized establishments also have higher labor productivity. They also show that the odds of an establishment being targeted for a certification election have been declining since early 1980's. Furthermore, the exit rate for union establishments have also been greater than for non-union ones. This lead to a secular decline in the number of union establishments. These facts are consistent with skill-biased technological change.

shifts in the mix of skilled and unskilled labor used in production in the wake of some fundamental changes in the U.S. economy during the 20th century. These changes were brought about by the introduction of mass production techniques in the first half of the century and by computerization in the second half. Second, the constructed model is calibrated and simulated to gauge whether or not it could explain the above stylized facts. It can. To obtain the patterns in data, the amount of skill bias must follow a $\cap$-shaped pattern. The required change in skill bias is not that large. It also mirrors the qualitative pattern expected from economic history.

Third, some statistical analysis is undertaken to relate unionization to skill-biased technological change. Following the macroeconomics literature, the relative price of new equipment and software is taken as a measure of skill-biased technological change. Technological progress is embodied in the form of new capital goods and is reflected by a declining relative price for investment. Industries where the price of the capital inputs decline faster should experience greater skill-biased technological change and deunionization. This hypothesis finds support in several tests. First, the ratio of skilled to unskilled labor is found to be higher in those industries with a lower relative price of capital. Second, this relative price is negatively associated with unionization in an industry, and unionization declined faster in industries where the relative price fell more. Finally, deunionization was widespread across developed countries in recent decades, and additional analysis suggests that skill-biased technological progress may also be a factor in explaining the trends for a number of OECD countries.

References

Acemoglu, Daron, Aghion, Philippe and Giovanni L. Violante. "Deunionization, Technical Change and Inequality." *Carnegie-Rochester Conference Series on Public Policy*, 55, 1 (December 2001): 229-264.

Acikgoz, Omer T. and Baris Kaymak. "A Macroeconomic Analysis of the Rising Skill Premium and Deunionization in the United States." Manuscript. Department of Economics, Université de Montréal, 2011.

Alder, Simeon, Lagakos, David and Lee Ohanian. "The Decline of the U.S. Rust Belt: A Macroeconomic Analysis." Manuscript, Arizona State University, 2013.

Baldwin, Robert E. *The Decline of US Labor Unions and the Role of Trade.* Washington, DC: Peterson Institute for International Economics, 2003.

Campbell, Jeffrey and Hugo Hopenhayn "Market Size Matters." *Journal of Industrial Economics*, 53, 1 (March 2005): 1-25.

Card, David, Lemieux, Thomas and Craig Riddell. "Unionization and Wage Inequality: A Comparative Study of the U.S., the U.K., and Canada," NBER Working Paper 9473, January 2003.

Cummins, Jason G. and Giovanni L Violante. "Investment-Specific Technical Change in the United States (1947-2000): Measurement and Macroeconomic Consequences." *Review of Economic Dynamics*, 5, 2 (April 2002): 243-284.

Cole, Harold L. and Lee E. Ohanian. "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis." *Journal of Political Economy* 112, 4 (August 2004): 779-816.

Dinlersoz, Emin, Greenwood, Jeremy, and Henry R. Hyatt. "Do Unions Target Productive Businesses? Unionization over the Life-Cycles of U.S. Establishments" Research in Progress, U.S. Census Bureau, 2013.

Doepke, Matthias and Michèle Tertilt. "Women's rights: What's in it for Men?" *Quarterly Journal of Economics* 124, 4 (November 2009): 1541-1591.

Fair, Raymond C. and John B. Taylor. "Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models." *Econometrica*, 51, 4 (July 1983): 1169-1185.

Goldin, Claudia and Lawrence F. Katz. *The Race between Education and Technology.* Massachusetts: Harvard University Press, 2008.

Greenwood, Jeremy, Hercowitz, Zvi and Per Krusell. "Long-Run Implications of Investment-Specific Technological Change." *American Economic Review*, 87, 3 (June 1997): 342-362.

Greenwood, Jeremy and Mehmet Yorukoglu. "1974." *Carnegie-Rochester Conference Series on Public Policy*, 46 (June 1997): 49-95.

Gujarati, Damodar, and Dars, Lewis "Production and Nonproduction Workers in US Manufacturing Industries." *Industrial and Labor Relations Review,* 26, 1, (October 1972): 660-669.

Guner, Nezih, Ventura Gustavo and Yi Xu. "Macroeconomic Implications of Size-dependent Policies." *Review of Economic Dynamics,* 11 (October 2008): 721–744.

Henly, Samuel E. and Juan M. Sanchez. "The U.S. Establishment-Size Distribution: Secular Changes and Sectoral Decomposition." *Economic Quarterly*, 95, 4 (Fall 2009): 419–454.

Juhn, Chinhui, Murphy, Kevin M., and Brooks Pierce. "Wage Inequality and the Rise in Returns to Skill." *Journal of Political Economy*, 101, 3 (June 1993): 410-442.

Katz, Lawrence F. and Kevin M. Murphy. "Changes in Relative Wages, 1963–1987: Supply and Demand Factors." *Quarterly Journal of Economics*, 107, 1 (February 1992): 35–78.

Krusell, Per, Ohanian, Lee E., Ríos-Rull, José-Víctor and Giovanni L. Violante. "Capital-skill Complementarity and Inequality: A Macroeconomic Analysis." *Econometrica*, 68, 5 (September 2000): 1029-1053.

Krusell, Per and Leena Rudanko. "Unions in a Frictional Labor Market." Manuscript. Department of Economics, Boston University, 2012.

MacDonald, Glenn M. and Chris Robinson. "Unionism in a Competitive Industry." *Journal of Labor Economics*, 10, 1 (January 1992): 33-54.

Meyer III, Stephen. *The Five Dollar Day: Labor Management and Social Control in the Ford Motor Company 1908-1921*. Albany: State University of New York Press, 1981.

Ohanian, Lee E. "What - or Who - Started the Great Depression?" *Journal of Economic Theory*, 144, 6 (November 2009): 2310-2335.

Pease, William. "An Automatic Machine Tool." *Scientific American*, (September 1952): 101-115.

Reder, Melvin W. "The Rise and Fall of Unions: The Public Sector and the Private." *The Journal of Economic Perspectives*, 2, 2 (Spring, 1988): 89-110.

Rees, Albert. "The Effects of Unions on Resource Allocation." *Journal of Law and Economics,* 6, 2 (October, 1963): 69-78.

Restuccia, Diego and Guillaume Vandenbroucke. "Explaining Educational Attainment across Countries and over Time." Manuscript. Department of Economics, University of Southern California, 2011.

Rios-Rull, Jose-Victor and Raul Santaeulalia-Llopis. "Redistributive Shocks and Productivity Shocks." *Journal of Monetary Economics*, 57, 8 (2010): 931-948.

Schmitz, Jr, James A. "What Determines Productivity? Lessons From the Dramatic Recovery of the U.S. and Canadian Iron Ore Industries Following Their Early 1980s Crisis." *Journal of Political Economy* 113, 3 (June 2005): 582-625.

Solow, Robert M. "Investment and Technical Progress." In: Arrow, K., Karlin, S., Suppes, P. (Eds.), *Mathematical Methods in the Social Sciences*, 1959. Stanford University Press, Stanford, CA, 1960: 89–104.

Taschereau-Dumouchel, Mathieu. "The Union Threat." Manuscript. The Wharton School, University of Pennsylvania, 2011.

Womack, James P., Jones, Daniel T. and Daniel Roos. *The Machine that Changed the World*. New York: Free Press, 1990.

Wooldridge, Jeffrey M. *Econometric Analysis of Cross Section and Panel Data.* The MIT Press. Cambridge: Massachusetts, 2002.

Table 1: Workers in Detroit Metal Industries, 1891

Occupation	*No.*	*Percent*	*Mean Weekly Income*
Foreman	9	2	$19.67
Mechanics	153	39	12.58
Specialists	117	30	8.18
Unskilled Labor	113	29	6.60
Total	392	100	9.55

Source: Meyer (1981, pg. 46)

Table 2: Workers in Ford Motor Company, 1913

Occupation	*No.*	*Percent*
Mechanics and Subforeman	329	2
Skilled Operators	3,431	26
Operators	6,749	51
Unskilled Workers	2,795	21
Total	13,304	100

Source: Meyer (1981, pg. 50)

Fastest declining occupations

Rank in employment decline	Occupation	% Growth in employment (1983-2002)	% Union members in 1983
1	Brickmason and stonemason apprentices	-189.6	45.1
2	Shoe machine operators	-163.3	30.3
3	Railroad brake, signal, and switch operators	-159.6	94.8
4	Housekeepers and butlers	-155.9	1.4
5	Drilling and boring machine operators	-137.3	48.3
6	Helpers, mechanics, and repairers	-135.4	15.4
7	Patternmakers, lay-out workers, and cutters	-128.3	28.8
8	Patternmakers and model makers, wood	-120.5	0.0
9	Lathe and turning machine operators	-115.8	36.4
10	Typesetters and compositors	-114.4	14.5
11	Shoe repairers	-112.9	9.5
12	Solderers and brazers	-106.5	23.9
13	Rail vehicle operators, n.e.c.	-103.4	90.9
14	Milling and planing machine operators	-102.9	40.4
15	Adjusters and calibrators	-102.2	46.9
16	Lathe and turning machine set-up operators	-99.3	58.8
17	Roasting and baking machine operators, food	-97.6	72.5
18	Production samplers and weighers	-95.1	28.6
19	Winding and twisting machine operators	-94.8	11.3
20	Hand cutting and trimming occupations	-93.6	27.4
	Average:	-121.4	36.3

Fastest growing occupations

Rank in employment growth	Occupation	% Growth in employment (1983-2002)	% Union members in 1983
1	Numerical control machine operators	179.4	36.9
2	Helpers, surveyor	166.9	10.8
3	Optometrists	164.2	0.0
4	Managers, medicine and health	159.8	8.7
5	Inspectors, agricultural products	158.7	0.0
6	Health diagnosing practitioners, n.e.c.	156.4	32.2
7	Marine Engineers	147.7	100.0
8	Computer systems analysts and scientists	144.3	7.4
9	Graders and sorters, agricultural products	140.4	16.6
10	Physical scientists, n.e.c.	135.4	0.5
11	Medical scientists	128.8	6.2
12	Management analysts	125.7	3.4
13	Teachers, special education	124.2	55.0
14	Postsecondary teachers, subject not specified	121.2	13.4
15	Precision assemblers, metal	121.0	69.7
16	Authors	120.5	13.9
17	Health technologists and technicians, n.e.c.	116.4	10.9
18	Social scientists, n.e.c.	115.6	16.1
19	Investigators and adjusters, except insurance	112.4	10.9
20	Physical therapists	111.0	14.7
	Average:	137.5	21.4

Notes: Gray shading indicates a unionization rate in the top quartile of the 1983 unionization rates across occupations. Growth rates are calculated by using the average of the 1983 and 2002 employment levels as the denominator.

TABLE 3. Fastest declining and fastest growing occupations (1983-2002)

Table 4: Parameter values

Parameter	*Definition*	*Basis*
Tastes		
$\beta = (1.04)^{-5}$	discount factor	standard
Technology		
$\alpha = 0.60$	labor's share	Greenwood et al. (2010)
$\delta = 1 - (1 - 0.08)^5$	depreciation rate	standard
$\kappa = 0.20$	exponent on capital	Guner et al. (2008, p 732)
$\rho = 0.29$	elasticity of substitution	Katz and Murphy (1992, eq 19)
$\theta_{1955} = 0.53$	weight on skilled labor	skill premium, T(2)
$\xi_{1955} = 1.0$	shift factor on skilled labor	normalization
$\zeta = 2.005$	Pareto distribution	firm-size distribution, T(4)
$\phi_{1955} = 0.07$	fixed cost	union wage premium, T(5)
Unionization		
$\omega = 0.65$	ideals–wage	union membership, T(1)
$\chi = 0.05$	organization costs, constant	union dues, T(3)

Dependent variable: Logarithm of skill ratio, s_{it}									
Specification:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Independent variables: (in logs except for fixed effects)	**OLS**	**OLS**	**2SLS**	**OLS**	**2SLS**	**OLS**	**2SLS**	**OLS**	**2SLS**
industry relative price of equipment and software	-0.256***	-0.403***	-0.411***	-0.369***	-0.395***	-0.159**	-0.191***	-0.205*	-0.242***
	[0.05]	[0.09]	[0.03]	[0.07]	[0.04]	[0.07]	[0.04]	[0.10]	[0.04]
industry relative wage of production workers	-	1.660***	1.860***	1.669***	1.935***	1.383***	1.575***	1.623***	1.873***
		[0.37]	[0.09]	[0.39]	[0.10]	[0.25]	[0.10]	[0.37]	[0.10]
real industry output	-	-	-	0.004	0.034	-0.248**	-0.210***	-0.035	-0.007
				[0.08]	[0.02]	[0.11]	[0.03]	[0.09]	[0.02]
real industry output per worker	-	-	-	0.090	0.055	0.208*	0.183***	0.092	0.067*
				[0.08]	[0.04]	[0.10]	[0.03]	[0.09]	[0.03]
real industry capital stock	-	-	-	-	-	0.315***	0.281***	-	-
						[0.09]	[0.02]		
real industry price of investment	-	-	-	-	-	-	-	-0.659	-0.590***
								[0.41]	[0.08]
Industry fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year dummies	N	Y	Y	Y	Y	Y	Y	Y	Y
N	798	798	779	798	779	798	779	798	779
R-sq	0.47	0.75		0.76		0.82		0.78	

Notes: Constant is not reported. Standard errors clustered by industry are in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1% levels, respectively. The number of observations in the IV estimations is lower due to the lagged instruments.

TABLE 5. Fixed-effects panel regression analysis of the relationship between the skill ratio and the relative price of equipment and software

	Dependent variable: Logarithm of percent union membership (*mem.*) or coverage (*cov.*)																	
Specification:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
	mem.	***cov.***	***mem.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***	***mem.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***
Independent variables: (in logs, except dummies)	**OLS**	**OLS**	**2SLS**	**2SLS**	**OLS**	**2SLS**	**OLS**	**2SLS**	**2SLS (mfg.)**	**2SLS (non-mfg.)**	**2SLS (mfg.)**	**2SLS (non-mfg.)**	**2SLS**	**2SLS**	**2SLS (mfg.)**	**2SLS (non-mfg.)**	**2SLS (mfg.)**	**2SLS (non-mfg.)**
industry relative price of equipment and software	0.472***	0.495***	0.444***	0.466***	0.205**	0.252***	0.209**	0.262***	0.357***	0.267***	0.380***	0.277***	0.323***	0.377***	0.308***	0.294	0.324***	0.407***
	[0.05]	[0.05]	[0.02]	[0.02]	[0.10]	[0.08]	[0.09]	[0.07]	[0.11]	[0.10]	[0.10]	[0.09]	[0.11]	[0.09]	[0.11]	[0.20]	[0.10]	[0.14]
real industry output	-	-	-	-	-	-	-	-	-	-	-	-	-0.303***	-0.259***	-0.203**	0.305	-0.163*	-0.261**
													[0.09]	[0.08]	[0.10]	[0.50]	[0.10]	[0.11]
real industry output per worker	-	-	-	-	-	-	-	-	-	-	-	-	0.494***	0.485***	-0.047	-0.896	-0.076	0.603***
													[0.14]	[0.12]	[0.16]	[0.79]	[0.15]	[0.17]
number of industry establishments per capita	-	-	-	-	-0.040	-0.035	-0.020	-0.015	-0.497***	0.008	-0.476***	0.027	0.100	0.114*	-0.251*	-0.255	-0.255*	0.133
					[0.09]	[0.05]	[0.08]	[0.04]	[0.11]	[0.06]	[0.10]	[0.05]	[0.08]	[0.07]	[0.14]	[0.28]	[0.13]	[0.09]
% U.S. employment classified as part time	-	-	-	-	0.473*	0.409	0.316	0.249	0.088	0.490	0.094	0.236	0.234	0.154	-0.350	0.338	-0.225	0.354
					[0.26]	[0.27]	[0.25]	[0.23]	[0.28]	[0.39]	[0.26]	[0.33]	[0.30]	[0.27]	[0.25]	[0.53]	[0.24]	[0.42]
% U.S. population in south	-	-	-	-	-0.275	0.793	-0.799	0.183	-1.019	1.203	-0.979	0.391	1.675**	0.960	-0.589	2.254*	-0.681	0.736
					[0.66]	[0.71]	[0.53]	[0.61]	[0.69]	[0.91]	[0.64]	[0.77]	[0.81]	[0.73]	[0.65]	[1.26]	[0.63]	[1.00]
% share of imports in U.S. GDP	-	-	-	-	-0.494**	-0.112	-0.571***	-0.228	-0.575***	0.055	-0.580***	-0.146	-0.097	-0.238	-0.184	-0.002	-0.252	-0.284
					[0.19]	[0.24]	[0.18]	[0.20]	[0.22]	[0.31]	[0.21]	[0.26]	[0.27]	[0.24]	[0.21]	[0.41]	[0.20]	[0.33]
% share of exports in U.S. GDP	-	-	-	-	-0.159	-0.296*	-0.078	-0.198	-0.164	-0.342*	-0.147	-0.219	-0.562***	-0.445***	0.011	-0.306	0.003	-0.472**
					[0.13]	[0.15]	[0.10]	[0.13]	[0.13]	[0.18]	[0.12]	[0.15]	[0.18]	[0.16]	[0.12]	[0.28]	[0.11]	[0.20]
% U.S. population classified as young	-	-	-	-	-1.082	0.765	-1.650**	-0.102	-1.172	1.783	-1.066	0.367	0.754	-0.245	0.293	-0.407	0.042	-0.392
					[0.73]	[1.12]	[0.77]	[0.96]	[1.16]	[1.61]	[1.08]	[1.36]	[1.25]	[1.13]	[1.04]	[2.25]	[1.00]	[1.74]
% U.S. population in south * manufacturing dummy	-	-	-	-	-1.293*	-1.477*	-1.032	-1.223*	-	-	-	-	-3.331***	-2.887***	-	-	-	-
					[0.74]	[0.84]	[0.65]	[0.72]					[0.92]	[0.83]				
% share of imports in U.S. GDP * manufacturing dummy	-	-	-	-	-0.141	-0.227	-0.187	-0.276	-	-	-	-	-0.085	-0.109	-	-	-	-
					[0.18]	[0.27]	[0.17]	[0.23]					[0.29]	[0.26]				
% share of exports in U.S. GDP * manufacturing dummy	-	-	-	-	0.027	0.088	-0.009	0.053	-	-	-	-	0.453*	0.356	-	-	-	-
					[0.17]	[0.24]	[0.14]	[0.21]					[0.26]	[0.24]				
Industry fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	1003	1003	1003	1003	1003	944	1003	944	336	608	336	608	656	656	256	400	256	400
R-sq	0.17	0.16	0.33	0.42	0.38		0.47											

Notes: Constant is not reported. Standard errors clustered by industry are in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1%, respectively. The number of observations in the IV estimations is lower due to the lagged instruments. The number of observations in specifications 13 to 18 is lower because not all industry codes in the data for the relative price of E&S could be matched to industry codes in the data for output. Industries exclude public sector and agriculture.

TABLE 6. Fixed-effects panel regression analysis of the relationship between unionization and the relative price of equipment and software

	Dependent variable: First-difference of the logarithm of percent union membership (*mem.*) or coverage (*cov.*)											
Specification:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Independent variables: First-difference of the logarithm of	***mem.***	***mem.***	***mem.***	***mem.***	***cov.***	***cov.***	***cov.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***
	OLS	**OLS**	**2SLS**	**2SLS**	**OLS**	**OLS**	**2SLS**	**2SLS**	**2SLS**	**2SLS**	**2SLS**	**2SLS**
industry relative price of equipment and software	0.555***	0.590***	0.374	0.408*	0.626***	0.662***	0.584***	0.620***	0.793**	0.747**	0.921**	0.882**
	[0.22]	[0.22]	[0.24]	[0.24]	[0.18]	[0.18]	[0.20]	[0.20]	[0.33]	[0.33]	[0.43]	[0.43]
real industry output	-	-	-	-	-	-	-	-	1.282*	1.205	1.229*	1.161*
									[0.75]	[0.76]	[0.65]	[0.65]
real industry output per worker	-	-	-	-	-	-	-	-	-1.532***	-1.523***	-1.565***	-1.562***
									[0.41]	[0.41]	[0.35]	[0.36]
number of industry establishments per capita	-0.419***	-0.430***	-0.429***	-0.440***	-0.235**	-0.247**	-0.233**	-0.245**	-0.598***	-0.593***	-0.444**	-0.443**
	[0.13]	[0.13]	[0.13]	[0.13]	[0.11]	[0.11]	[0.11]	[0.11]	[0.21]	[0.22]	[0.19]	[0.19]
% U.S. employment classified as part time	0.723**	0.709**	0.624*	0.613*	0.704**	0.690**	0.606**	0.595**	0.091	0.086	0.221	0.214
	[0.34]	[0.34]	[0.36]	[0.36]	[0.29]	[0.29]	[0.30]	[0.30]	[0.46]	[0.46]	[0.40]	[0.40]
% U.S. population in south	1.478*	2.709***	1.462*	2.682***	1.329**	2.339***	1.469**	2.479***	2.274**	3.054**	2.106**	2.703**
	[0.79]	[0.91]	[0.82]	[0.95]	[0.66]	[0.76]	[0.69]	[0.79]	[1.10]	[1.24]	[0.95]	[1.07]
% share of imports in U.S. GDP	-0.231	-0.233	0.147	0.311	-0.132	-0.079	0.142	0.337	-0.041	0.186	-0.122	0.079
	[0.22]	[0.26]	[0.29]	[0.34]	[0.18]	[0.22]	[0.24]	[0.29]	[0.37]	[0.45]	[0.32]	[0.39]
% share of exports in U.S. GDP	-0.229	-0.245	-0.301*	-0.377*	-0.189	-0.185	-0.238*	-0.283	-0.286	-0.308	-0.176	-0.143
	[0.16]	[0.20]	[0.17]	[0.21]	[0.14]	[0.17]	[0.14]	[0.17]	[0.26]	[0.29]	[0.22]	[0.25]
% U.S. population classified as young	-1.294	-1.423	1.150	1.000	-1.571	-1.702	-0.246	-0.404	-1.283	-1.309	-2.705	-2.752
	[1.70]	[1.70]	[2.04]	[2.04]	[1.42]	[1.42]	[1.71]	[1.71]	[2.68]	[2.69]	[2.31]	[2.32]
% U.S. population in south * manufacturing dummy	-	-3.244**	-	-3.237**	-	-2.620**	-	-2.638**	-	-2.008	-	-1.519
		[1.27]		[1.29]		[1.06]		[1.08]		[1.83]		[1.58]
% share of imports in U.S. GDP * manufacturing dummy	-	0.037	-	-0.450	-	-0.118	-	-0.537	-	-0.555	-	-0.493
		[0.40]		[0.53]		[0.34]		[0.45]		[0.68]		[0.59]
% share of exports in U.S. GDP * manufacturing dummy	-	0.041	-	0.212	-	-0.013	-	0.124	-	0.087	-	-0.057
		[0.33]		[0.35]		[0.27]		[0.29]		[0.46]		[0.40]
N	944	944	885	885	944	944	885	885	615	615	615	615
R-sq	0.28	0.31			0.32	0.35						

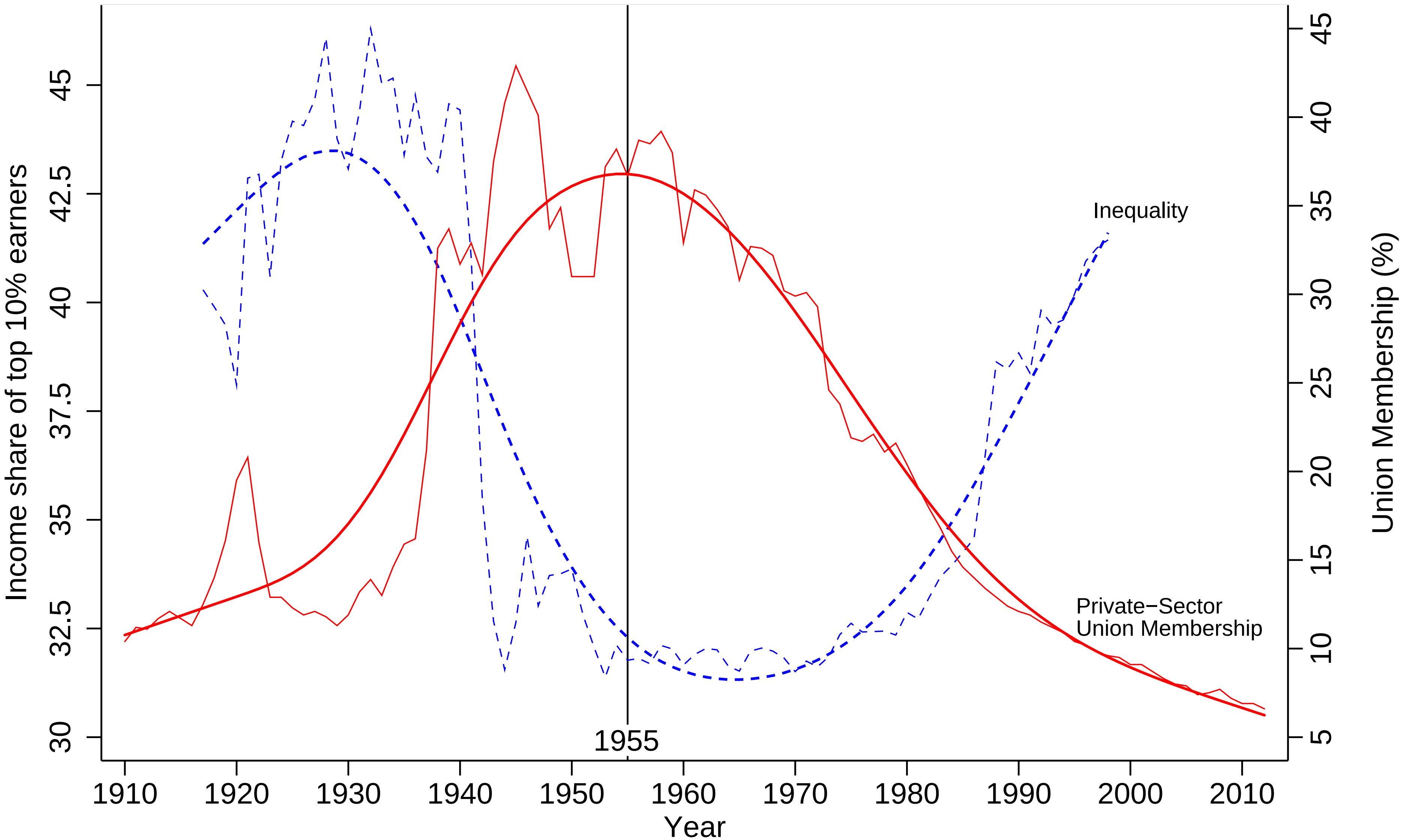
Notes: Constant is not reported. Standard errors clustered by industry are in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1%, respectively. The number of observations in the IV estimations is lower due to the lagged instruments. The number of observations in OLS estimations is lower than the total in the original sample because not all industries had matching output data.

TABLE 7. First-difference panel regression analysis of the relationship between unionization and the relative price of equipment and software

Dependent variable: Logarithm of percent union membership					
Specification:	**1**	**2**	**3**	**4**	**5**
Independent variables: (in logs)	***Country Fixed-Effects***			***First-difference***	
	OLS	**OLS**	**2SLS**	**OLS**	**2SLS**
relative price of capital	0.384***	0.280*	0.666***	0.108**	0.054**
	(0.05)	(0.14)	(0.15)	(0.04)	(0.02)
% share of imports in GDP	-	0.174	0.108	0.072**	0.067*
		(0.11)	(0.08)	(0.04)	(0.04)
% share of exports in GDP	-	-0.042	-0.137*	-0.035	-0.029
		(0.17)	(0.07)	(0.03)	(0.03)
labor productivity	-	-0.402*	-0.392***	-0.298**	-0.298**
		(0.21)	(0.11)	(0.12)	(0.12)
% share of manufacturing in GDP	-	0.455***	0.279**	0.067	0.012
		(0.11)	(0.12)	(0.12)	(0.12)
public sector employment	-	0.423	0.588***	0.593*	0.635*
		(0.34)	(0.16)	(0.31)	(0.34)
% of population classified as young	-	0.774	0.605**	0.504***	0.434***
		(0.71)	(0.27)	(0.14)	(0.15)
N	311	311	242	242	173
R-sq	0.65	0.65		0.44	

Notes: Constant is not reported. Standard errors clustered by country are in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1%, respectively. The number of observations in the IV estimations is lower due to the lagged instruments.

TABLE 8. Fixed-effects and first-difference panel regression analysis of the relationship between unionization and the relative price of capital -- selected OECD countries



Notes: Dashed plots indicate inequality, solid plots indicate union membership. The smooth curves are trends from HP−filtering. The vertical line indicates 1955.

Figure 1. Income inequality and private-sector union membership in the U.S. during the 20th century

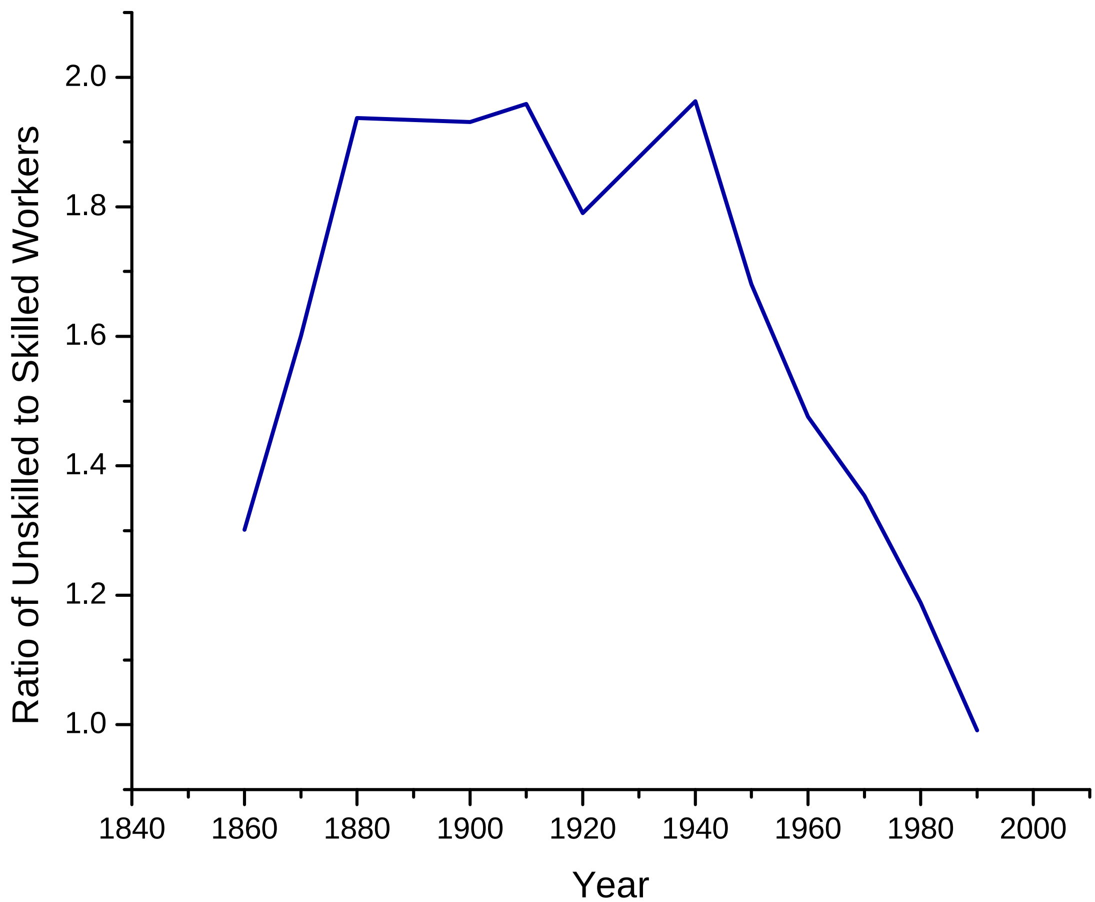
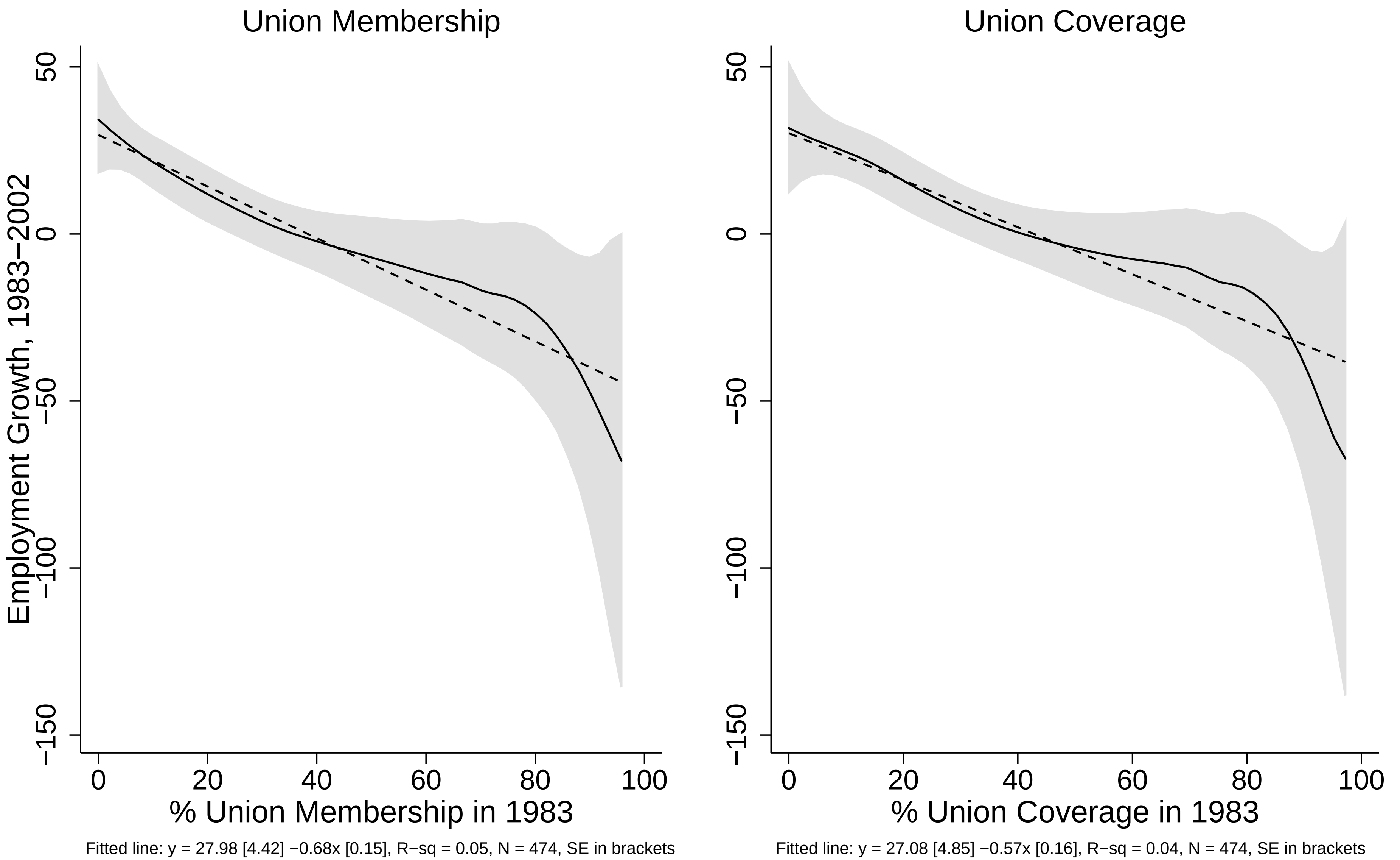
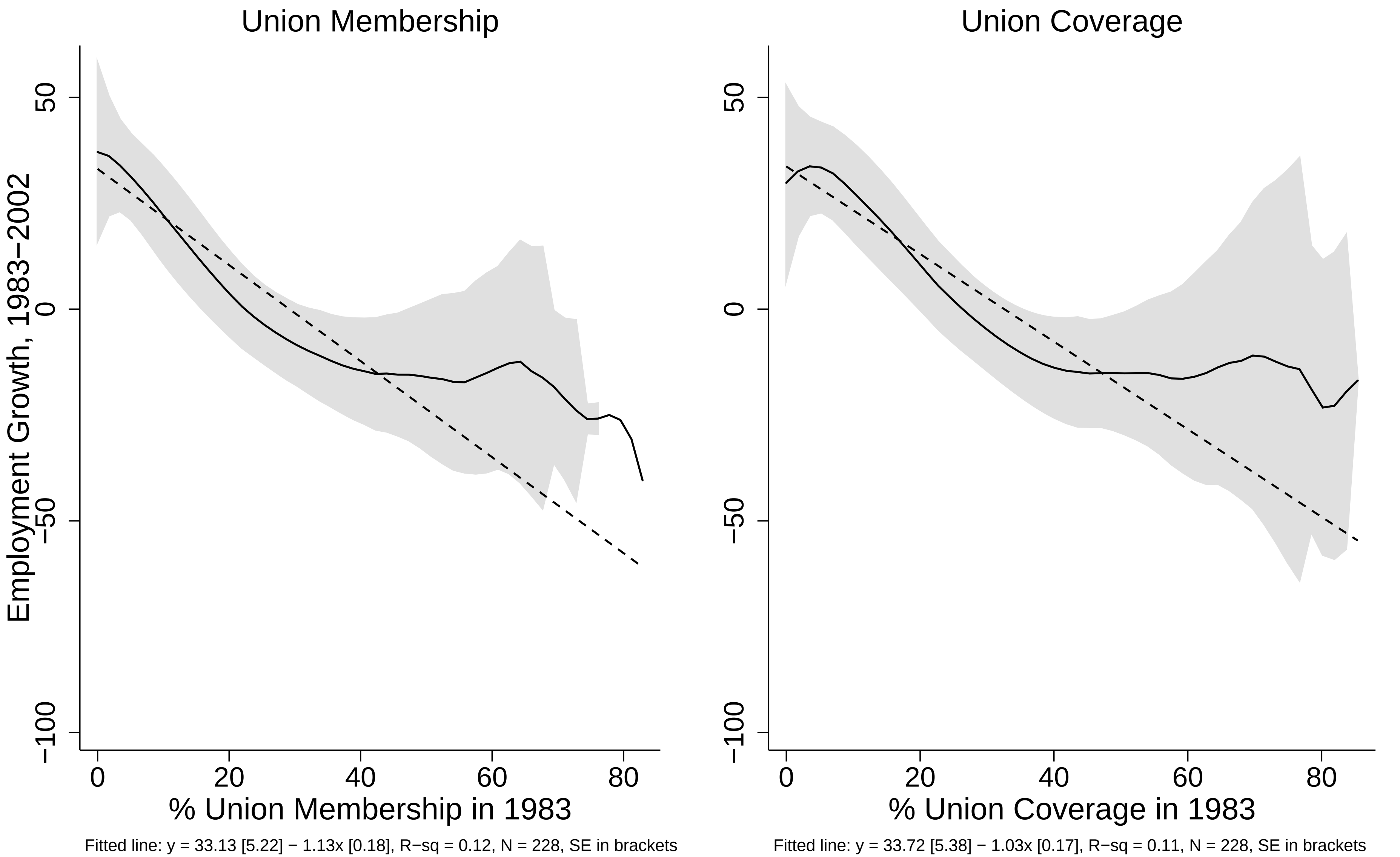


Figure 2: Ratio of unskilled to skilled workers, 1860 to 1990



Notes: The solid curve is the nonparametric fit with its 95% confidence intervals shaded gray. The dashed line is the linear fit. Local third−degree polynomial smoothing with an Epanechnikov kernel and a bandwidth of 40 is used to generate the nonparametric estimate.

Figure 3. The relationship between occupation employment growth and unionization



Notes: The solid curve is the nonparametric fit, with its 95% confidence intervals shaded gray. The dashed line is the linear fit. Local third−degree polynomial smoothing with an Epanechnikov kernel and a bandwidth of 40 is used to generate the nonparametric estimate.

Figure 4. The relationship between industry employment growth and unionization

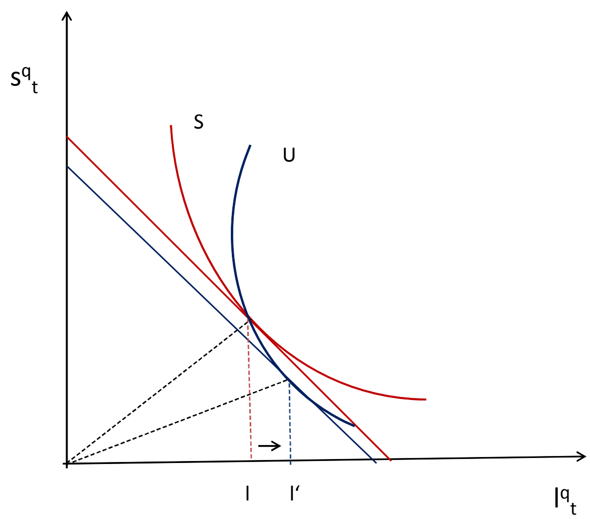


Figure 5: Skill-biased technological change: unskilled labor becomes more favored when the isoquant shifts from $S$to U, say due to the introduction of assembly line

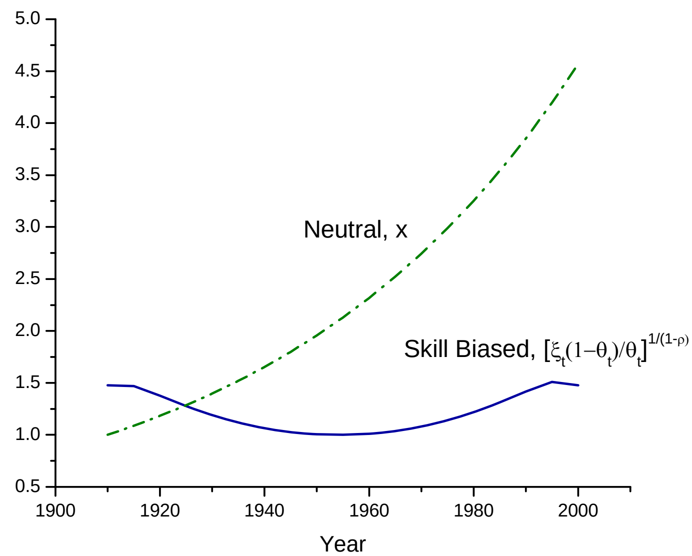


Figure 6: Skill-biased and neutral technological change, model

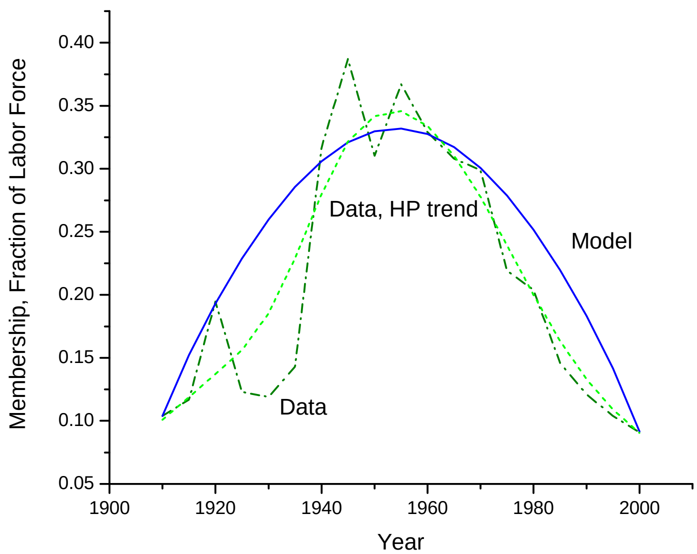


Figure 7: Union membership over the 20th century, data and model

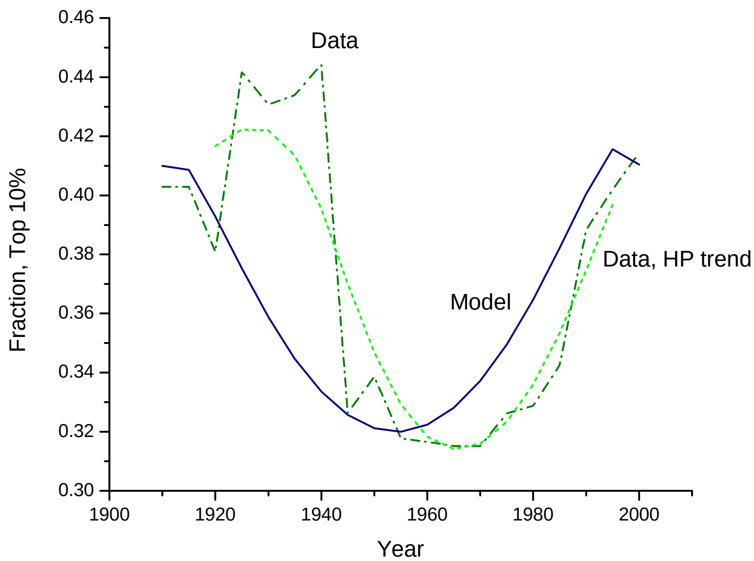


Figure 8: The distribution of income over the 20th century, data and model

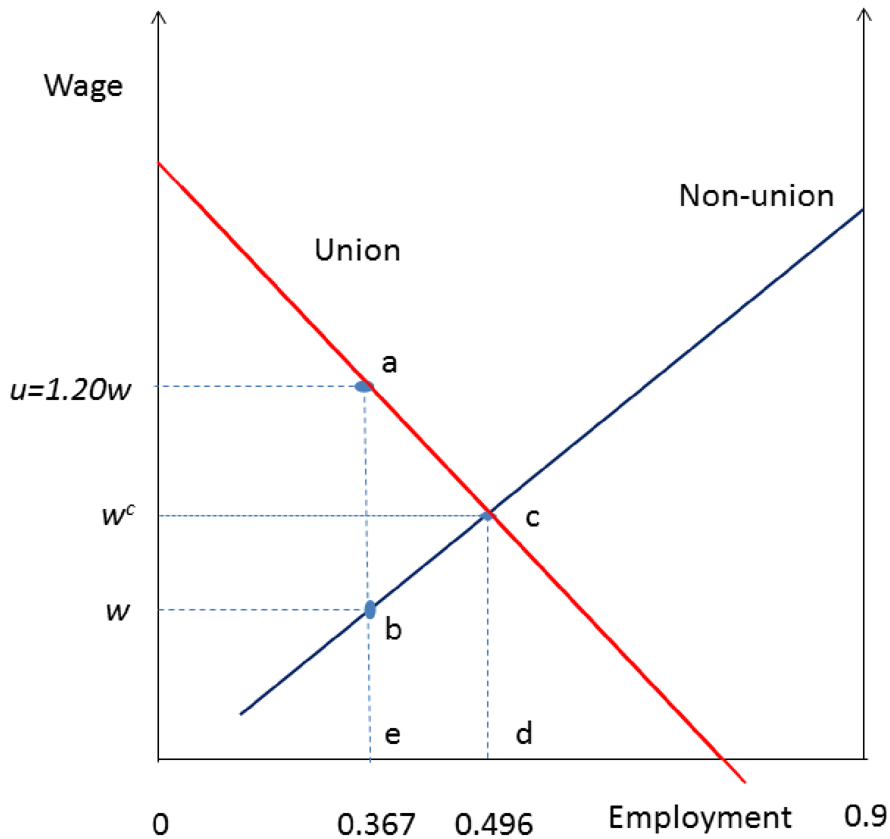
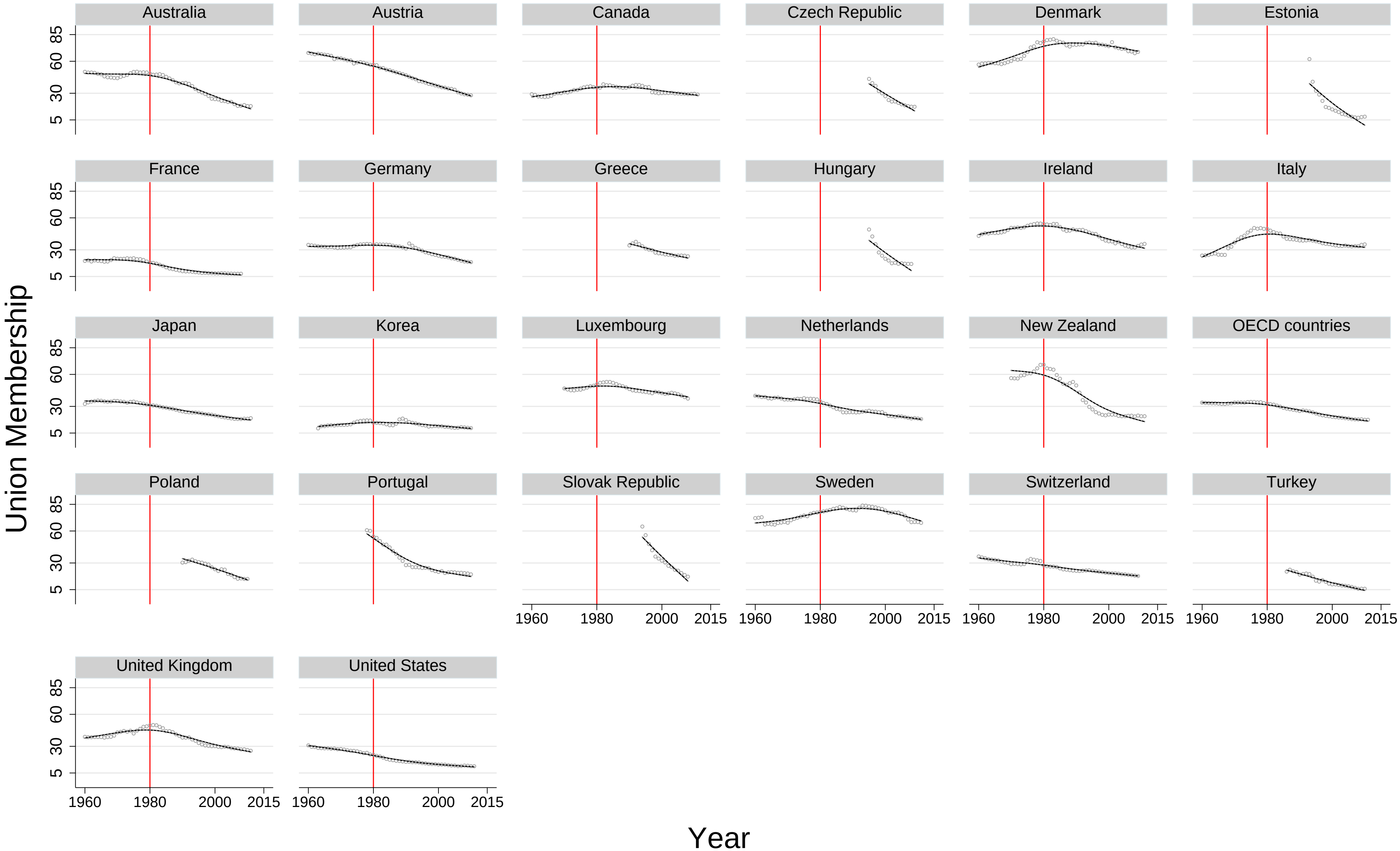


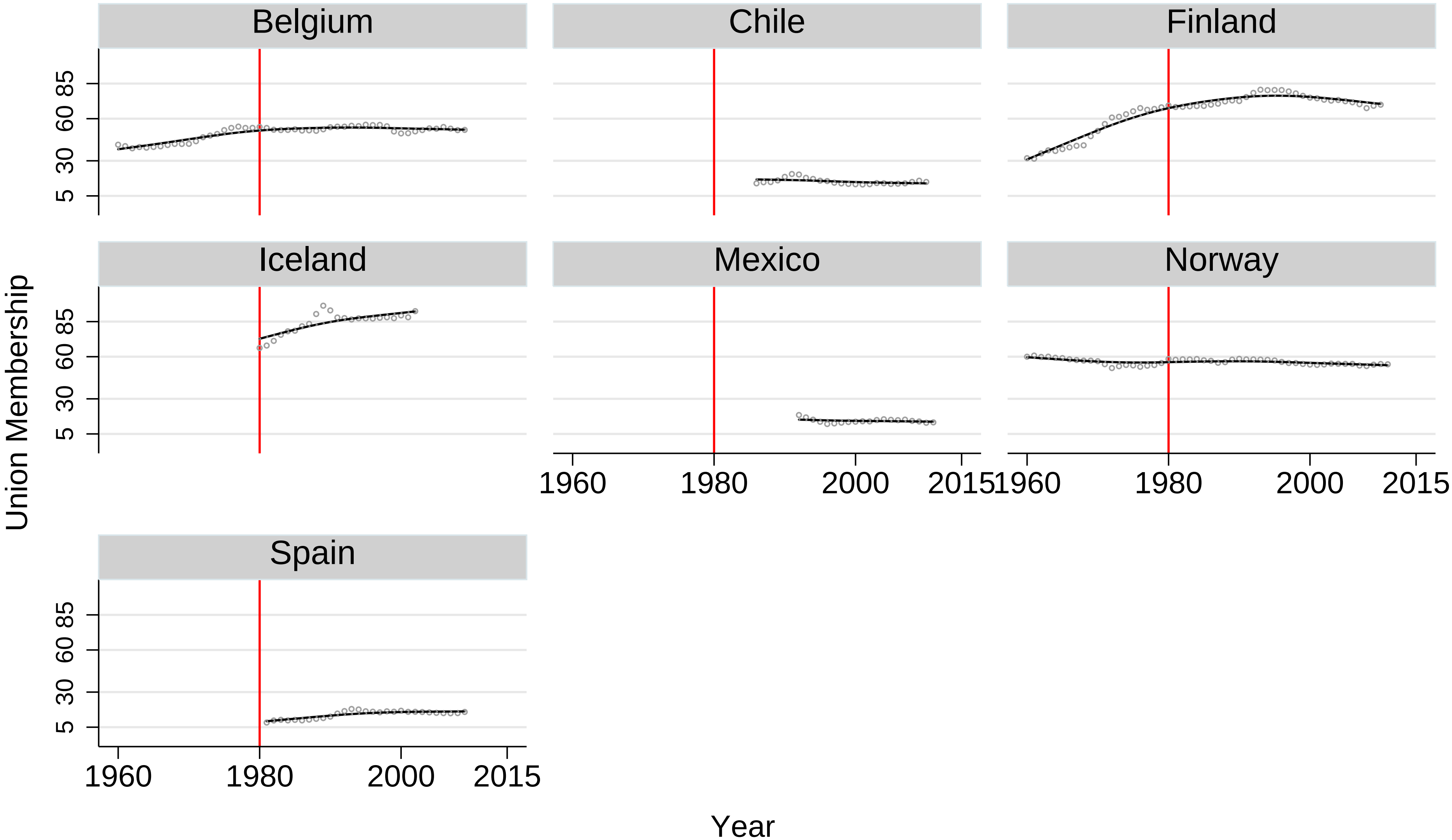
Figure 9: The welfare loss from unions



Notes: The vertical lines indicate 1980. The solid curves are the trends from the HP−filtered series. Slovenia also exhibited decline in union membership, but it was dropped because it had only four data points.

Source: OECD StatExtracts

Figure 10. Union membership in OECD countries − cases of decline after 1980



Notes: The vertical lines indicate 1980. The solid curves are the trends from the HP−filtered series.

Source: OECD Stat Extracts

Figure 11. Union membership in OECD countries − cases of no decline after 1980

9 Appendix

9.1 Data Sources

9.1.1 Figure 1

The private-sector union membership rates (excluding agriculture) for the period 1973-2012 come directly from the *Union Membership and Coverage Database* (www.unionstats.com), with 1982 imputed using the average of the adjacent years. For the period 1910-1972, several versions of the U.S. Census Bureau's *Statistical Abstract of the United States* are used to calculate membership rates. Employment in the private sector (excluding agriculture) is used for the denominator of the union membership rate for all years 1910-1972. For the numerator, the number of union members excluding those in public sector (federal, state, and local governments) is used. The number of total union members is available for all years 1910 to 1972. The numerator can be calculated from the available data items in the *Abstract* for the years 1910 to 1934. For the period 1935 to 1972, the number of public-sector union members is available for 1940, 1950, 1955, 1960, 1964-1966, 1968, and 1970. For these nine years, the share, h_t, of public-sector union members in total union members is as follows: 10% (1940), 13% (1950), 10% (1955), 12% (1960), 8% (1964), 9% (1965), 9% (1965), 11% (1968), and 13% (1970). For the rest of the years between 1940 to 1972 for which h_t is unavailable, a linear interpolation is used to impute a value, $\widehat{h}_t$. Private-sector union membership is then backed out as $1 - \widehat{h}_t$ times the total number of union members for each year for which h_t is unobserved. Alternative methods, such as using the grand average of h_t over the nine years for which it is available to impute the missing values, yield very similar time paths for the period 1935 to 1972. Note also that for the calibration of the model, the unionization rates for 1910, 1955 and 2000 are used, and these rates are not imputed.

The underlying data for the income distribution comes from *Historical Statistics of the United States: Millennial Edition*. The data is series Be29. It refers to the distribution of income among taxpaying units, specifically the share of income received by the 10th percentile. Income is net of corporate taxes and employer-paid payroll taxes, but is before individual income taxes and individual-paid payroll taxes; it excludes capital gains. The series is based on work by Thomas Piketty and Emmanuel Saez.

9.1.2 Figure 2

The underlying data series come from the *Historical Statistics of the United States: Millennial Edition*. The unskilled labor force is taken to be the sum of clerical workers (Series Ba1038), sales workers (Ba1039), operatives (Ba1041) and laborers (Ba1045). The skilled workforce is professionals (Ba1034) plus managers and officials (Ba1037) added together with craft workers (Ba1040). In the figure the ratio of these two series is plotted.

9.1.3 Establishment-Size Distribution

The descriptive statistics for the employee size of U.S. establishments come from the *Longitudinal Business Database* (LBD) of the U.S. Census Bureau. The LBD contains annual information on employment for all U.S. establishments. For each year in the period 1976 to 2011, the mean, standard deviation, and the coefficient of variation of the establishment employment are calculated across all establishments in the employer universe with at least one employee. The averages of the mean, standard deviation, and the coefficient of variation of employment over this period are approximately 17, 113, and 7, respectively. The average value (of about 7) for the coefficient of variation is used in guiding the simulation analysis. The coefficient of variation stayed in a narrow band with a slight decline during this period, as is shown in Figure 12. The coefficient of variation is slightly higher if establishments reporting zero employees are also included in the size distribution.

9.1.4 Union Membership and Coverage by Industry and Occupation in U.S.

The main data source for facts about unionization is the *Union Membership and Coverage Database* (available at www.unionstats.com), described in Hirsch and Macpherson (2003). This dataset contains two main variables that measure unionization: the union membership rate and the union coverage rate. These rates were constructed by occupation and industry using the union membership questions asked to individuals sampled in the *Current Popula-*

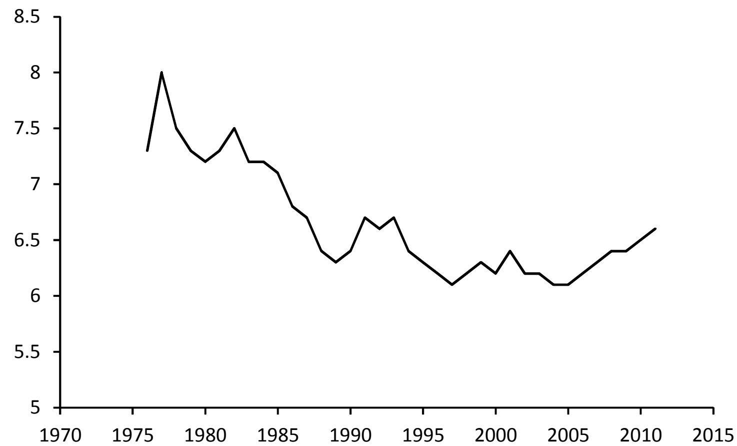


Figure 12: The coefficient of variation of establishment employment – U.S., 1976 to 2011

tion Survey (CPS). Their responses were aggregated by using the appropriate sample weights in the survey to estimate unionization at the industry and occupation levels. In the data a union member is defined to be a wage or salaried worker who answered that s/he belonged to a union. Persons covered by a union are defined to be union members and non-members who reported being covered by a collective bargaining agreement. Total employment in an industry or occupation is also available from the same data source. In the analysis here, the public sector is excluded from industries, but occupations include workers in the public sector. The focus on the 1983-2002 period in the analysis is primarily due to the fact that the detailed industry and occupation codes in the CPS before 1983 and after 2002 cannot be made consistent with those during this period. The union membership and coverage data by occupation and industry are used to generate Table 3, Figures 4-5, and Table 5.

9.1.5 Other Variables for U.S.

In Table 5, all variables other than p_{it} are from the *NBER-CES Manufacturing Industry Database* available at www.nber.org/nberces/. In Tables 6 and 7, the annual real output data at the industry level is taken from the BEA: www.bea.gov/industry/gdpbyind_data.htm. The percentage of the U.S. population in the south and west, part-time employment's share in total employment, the shares of imports and exports in U.S. GDP, and young people's share of the U.S. population all come from the U.S. Census Bureau. The annual number of establishments in an industry is obtained from *County Business Patterns,* versions 1983 to 1999, maintained by the U.S. Census Bureau: www.census.gov/econ/cbp/index.html.

9.1.6 Data for Other Countries

The union membership rates in Figures 10 and 11 come from the *OECD StatExtracts* (stats.oecd.org). The country-level data items used in the regressions in Table 8 are from the *OECD StatExtracts* and the *EU-KLEMS Database* (www.euklems.net). The price of capital used in the regressions reported in Table 8 is the average real price of ICT assets (computing, communications, software equipment) and transport and other machinery equipment, obtained from the *EU-KLEMS Database*–the series labelled *Ip_ IT*, *Ip_ CT*, *Ip_ Soft*, *Ip_ TraEq*, and *Ip_ OMach*. The capital price series are available only for certain countries and years: Australia (1970-2007), Austria (1976-2007), Canada (1970-2004), Denmark (1970-2007), Spain (1970-2007), Germany (1991-2007), Italy (1970-2007), Japan (1970-2006), the Netherlands (1970-2007), Sweden (1993-1007), the United Kingdom (1970-2007), and the United States (1977-2007). The price of consumption is also obtained from the *EU-KLEMS Database* (series *GO_ P*). The rest of the variables used in Table 8 come from the *OECD StatExtracts*. The shares of exports, imports and manufacturing are calculated with respect to GDP. Labor productivity is real GDP divided by employment. Public-sector employment is the sum of employment in public sector, plus education and health sectors. The young population is the share of people aged 18-45 in the population.

9.2 Theory

Proof of Lemma 1. Suppose not, and that an interior solution for unionization occurs. Then, the two first-order conditions associated with the above problem will be

$$\omega[u_t - \frac{\chi m_t}{2} - w_t]^{\omega-1} m_t^{1-\omega}[1 - \frac{\chi}{2}\int_{z_t^u}^{\infty} \frac{dl_t^u(z)}{du_t}F(z)dz]$$
$$+ (1-\omega)[u_t - \frac{\chi m_t}{2} - w_t]^{\omega} m_t^{-\omega}\int_{z_t^u}^{\infty} \frac{dl_t^u(z)}{du_t}F(z)dz = 0,$$

and

$$(1-\omega)[u_t - \frac{\chi m_t}{2} - w_t]^{\omega} m_t^{-\omega} l^u(z_t^u) F(z_t^u) \\ - \omega[u_t - \frac{\chi m_t}{2} - w_t]^{\omega-1} m_t^{1-\omega} \frac{\chi}{2} l^u(z_t^u) F(z_t^u) = 0.$$

[Recall that $l_t^u(z) = L_t^u(z_t^u; u_t, \cdot)$.] Take the second first-order condition and multiply it by $\int_{z_t^u}^{\infty} [dl_t^u(z)/du_t] F(z) dz$ to obtain

$$(1-\omega)[u_t - \frac{\chi m_t}{2} - w_t]^{\omega} m_t^{-\omega} \int_{z_t^u}^{\infty} [dl_t^u(z)/du_t] F(z) dz \\ - \omega[u_t - \frac{\chi m_t}{2} - w_t]^{\omega-1} m_t^{1-\omega} \frac{\chi m_t}{2} \int_{z_t^u}^{\infty} [dl_t^u(z)/du_t] F(z) dz = 0.$$

Using this in the first first-order condition then gives

$$\omega[u_t - \frac{\chi m_t}{2} - w_t]^{\omega-1} m_t^{1-\omega} = 0.$$

The last condition can only be true if

$$u_t - \frac{\chi m_t}{2} - w_t = 0.$$

This cannot transpire, hence a contradiction. ■