A Joint Theory of Polarization and Deunionization*

Tobias Föll, Anna Hartmann

Center for Macroeconomic Research, University of Cologne

Abstract

Over the past 40 years, the U.S. and several European labor markets have undergone two important developments: job market polarization and deunionization. In this paper, we argue that routine-biased technical change not only drives polarization, as is commonly assumed, but that it is also the driving force behind deunionization. We show that the shifting demand structure in favor of low- and high-skill occupations worsens the bargaining position of unions in a search and matching framework with an occupational choice and endogenous union formation, and therefore makes collective bargaining coverage less attractive for workers. The ensuing deunionization provides further incentives for middle-wage workers to switch occupations and thus amplifies job market polarization.

Keywords: Unions, Occupational Choice, Search and Matching

JEL classification: E02; E24; J51; J62; J64; O33

*We are very grateful to Michael Krause and Christian Bredemeier for all their guidance and support. For many useful comments we are also grateful to Almut Balleer, Dan Black, David Dorn, Judith Hellerstein, Barış Kaymak, Tali Kristal, Ilse Lindenlaub, Pascal Michaillat, Johannes Pfeifer, Robert Shimer, Nawid Siassi, Christian Siegel, Hale Utar, and seminar participants at Barcelona GSE, Cologne, the 5th International Conference on Technology, Demographics, and the Labor Market, the 2019 SMYE, the 9th Annual Search and Matching Conference, the 2019 Midwest Macroeconomics Meeting, the 2019 IZA Summer School, and the 2019 EEA-ESEM.

Email addresses: `foell@wiso.uni-koeln.de` (Tobias Föll), `anna.hartmann@wiso.uni-koeln.de` (Anna Hartmann)

1. Introduction

Job market polarization and deunionization have radically changed the labor market over the last decades. Job market polarization refers to the falling employment shares in middle-skill occupations and increasing employment shares in low-skill and high-skill occupations. The share of employment in the middle range of skills in the U.S. has been continuously decreasing and is now more than 10 percentage points below its value in the 1980s.[1] Deunionization describes the ongoing decline in union membership rates.[2] According to the Union Membership and Coverage Database constructed by Hirsch and Macpherson (2003), U.S. private sector union membership rates declined from 24.2% of all employed workers in 1973 to 6.4% in 2018. This decline is present throughout several industries and occupations.

Deunionization and polarization have both proven to be especially harmful for low-wage to middle-wage workers: job market polarization because the relative shifts in labor demand away from routine occupations have suppressed wage growth in that area, and deunionization because unionization rates are typically highest among lower middle-skill workers. American middle class workers have been in focus for U.S. politicians not just since President Barack Obama declared himself "a warrior for the middle class".[3] Even though the share of U.S. households classified as middle class by the American Institute for Economic Research (AIER) has declined steadily since the

[1]Empirical studies on this phenomenon include the seminal work by Autor et al. (2006), Goos and Manning (2007), Goos et al. (2009), Autor and Dorn (2013) among many others.

[2]Important empirical contributions include Troy and Sheflin (1985), Waddington and Whitston (1997), Baldwin (2003), Checchi et al. (2010), and Frandsen (2012).

[3]Remarks by the president on the economy, Knox College, Galesburg, IL, 24.06.2013.

1980s, in 2013 still roughly 50% of households count as middle class.[4] Thus, identifying and implementing suitable policies to support the middle class has become an ever more pressing issue for today's policymakers, especially considering the recent trends of political radicalization among this group.[5]

In this paper, we develop a joint theory of polarization and deunionization. Routine-biased technical change is shown to be the driving force behind both polarization and deunionization. As deunionization amplifies employment changes, ignoring the role of the union structure in a country leads to substantial biases when assessing the effect of routine-biased technical change on polarization.[6] Figure 1, which depicts the relative price for investment goods (proxying routine-biased technical change), the employment share of workers in routine occupations, and the union membership rate for the U.S. between 1977 and 2005, illustrates a first motivation for a joint theory of polarization and deunionization: the union membership rate and the share of routine workers display a very similar trend over the last decades (with a correlation of 0.98). Further empirical evidence is provided in Section 2.

To study job market polarization and deunionization in a joint theoretical framework, we endogenize both the occupational choice of workers and the union status of a firm. We employ a search and matching model of the labor market with heterogenous workers that differ with respect to their ability. When unemployed, previous routine workers have the option to switch

[4]The AIER defines households with a disposable income of two thirds to twice the median income for their household size as middle class.

[5]See Post (2017) for a detailed account of radicalization among the middle class.

[6]Both in the data and in our model, ceteris paribus higher unionization rates in a country imply a lower degree of polarization.

to manual occupations. Similar to the structure proposed in Taschereau-Dumouchel (2017), employed manual and routine workers in a firm decide via an election whether they want to form a union, and consequently a collective bargaining unit, or individually bargain over their wages with the firm.[7]

The main mechanism behind our results is quite simple. Relative prices for computer capital, which is able to replace routine tasks, fall (proxying for routine-biased technical change). This reduces the demand for routine workers, whereas manual and abstract workers, who are complementary to routine tasks, are in greater demand. The change in the labor demand structure implies that wages in manual occupations increase by more than wages in routine occupations. Manual workers, who benefit from the changing demand structure, are discouraged from voting in favor of a collective bargaining agreement.[8] Previously unionized low-skilled routine workers, when faced with lower wages compared to manual workers, decide to switch occupations. This amplifies the initial polarization caused by routine-biased technical change.[9]

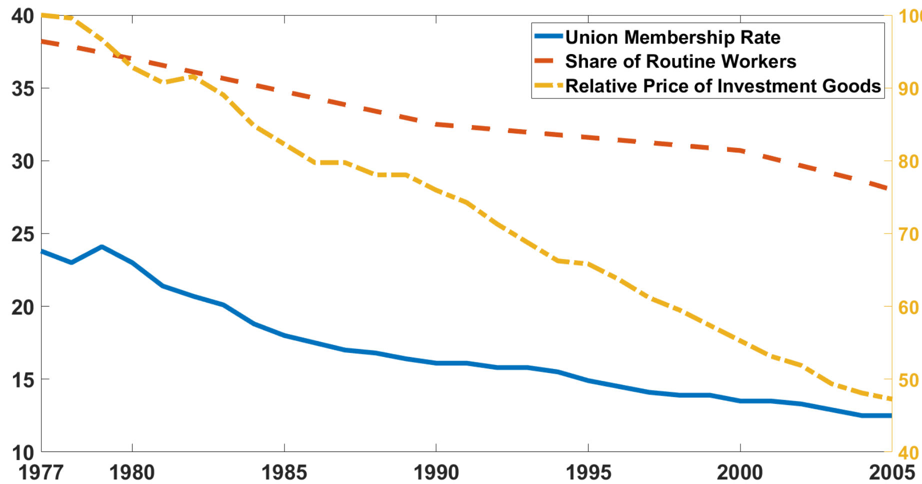
We simulate an economy with heterogeneous unions that distribute their

[7] A bargaining unit is commonly defined as a group of employees that shares a set of interests and may be reasonably represented by a collective bargaining agreement. When a majority of the bargaining unit votes in favor of a union, all workers are covered by a collective bargaining agreement, regardless of their individual voting decision. Else, all workers bargain individually with the firm. While the union structure is similar, neither polarization nor deunionization, the main points of interest in our paper, are considered in Taschereau-Dumouchel (2017).

[8] This is in line with Baccaro and Locke (1998) and Checchi et al. (2010), who argue that disillusion with respect to potential wage growth is the reason for declining membership rates among the least-skilled workers.

[9] Empirical evidence for this amplification mechanism is provided in Section 6.

Figure 1: Relative Price for Investment Goods, Share of Routine Workers, and U.S. Union Membership Rate



Note: The share of workers in routine occupations is constructed using the dataset and the occupational classification from Autor and Dorn (2013). Data for the union membership rates are taken from the U.S. union database constructed by Hirsch and Macpherson (2003) and include all wage and salary workers. Public sector and agricultural workers are included here in order for the data to be comparable to the data used in Autor and Dorn (2013). The FRED series for the relative price of investment goods is measured as the investment deflator divided by the consumption deflator and displayed as an index with 1977 = 100. The relative price for investment goods was preferred over the price for computer capital since the data is more reliable and available for a longer time period. The price index is plotted against the right axis, while the left axis displays the percentage share of routine workers and of union members.

share of the joint surplus equally across their members and differ with respect to their bargaining power. The model is calibrated to match U.S. data for the time period between 1977 and 2005. Predicted changes in employment and wages are close to the data. Routine-biased technical change, through changes in the labor demand structure, leads to a drop of 15.5 percentage points in overall union density compared to a drop of 14 percentage points in the data. Up to 20% of the simulated changes in low- and middle-skilled employment are driven by deunionization, as losing their union wage premia encourages previously unionized routine workers to change occupations. Because of small average union wage premia the overall effect of deunionization on inequality measured by the Gini index is small.[10] However, deunionization has substantial effects for low- to lower middle-skilled workers, who traditionally receive the largest union wage premium. For this group of workers, wage growth in the model is nearly twice as large in unionized compared to non-unionized firms.[11]

Our results suggest that unions could in principle dampen deunionization and polarization if they were able and willing to adjust the wage distribution, allowing for less equality inside the collective bargaining agreement. However, empirical evidence suggests that unions are characterized by rigid structures that partly prevent them from adjusting to recent developments on the labor market.[12] A recent article in The Economist puts forth the argument that new technology could help unions to regain members.[13] This is supported by evidence in Bryson et al. (2016) who argue that the decline in union membership rates across countries is strongly related to the degree of progressiveness of the unions. While the recent example of a union of Youtube employees that was formed by potential members joining a facebook group might be nothing more than a marketing gag, it seems that a more modern and progressive structure is needed in order for unions to attract more and especially younger members.

The remainder of the paper is organized as follows. Previous research

[10] This is in line with Frandsen (2012), Checchi et al. (2010), and DiNardo and Lee (2004) who all find small effects of deunionization on inequality.

[11] For evidence on union wage premia across skill groups see, for example, Card et al. (2004).

[12] See, for example, Waddington (2005) and Bryson et al. (2016).

[13] Technology may help to revive organised labour, The Economist, 15.11.2018.

and the links between job market polarization and deunionization are discussed in the next section. The model, building on the union framework in the U.S. discussed in Section 3, is presented in Section 4. In Section 5 we provide a theoretical, and in Section 6 a quantitative evaluation of the model. Policy implications are discussed in Section 7. To conclude, the results are summarized in Section 8.

2. Linking Polarization and Deunionization

We argue that job market polarization and deunionization have a common cause in routine-biased technical change. Overall union membership rates in the U.S. began to decrease in the late 1950s, which is usually explained by political resistance and the sharp increase in labor force participation of women, who tend to be less unionized.[14] The statistics in Troy and Sheflin (1985) illustrate that in no year since the late 1890s were more unions started than in 1970. The most terminations in recent decades are observed in 1980, while in the 1950s and 1960s almost no unions were terminated. This evidence on union creation and termination suggests that the slow decline in union membership rates since the 1950s and the accelerated decline since 1980 might have very different causes.[15] The accelerated decline in union membership rates fits well with the starting point of job polarization. Job polarization, and to a lesser extent also wage polarization can be observed in the U.S. and several European countries at least since the 1980s. Additionally, Dinlersoz and Greenwood (2016) document that the steep decline in union membership

[14]See, for example, Oh (1989) and Troy and Sheflin (1985).
[15]For data on union membership rates see Hirsch and Macpherson (2003).

rates that began in the late 1970s followed the emergence and diffusion of early advanced technologies.

Moving to cross-sectional evidence, the degree of unionization and the decline in union membership rates is on average more pronounced in countries with larger degrees of job and wage polarization. This is visible when comparing the U.S. to Europe, but also within the group of European countries. The Nordic countries, which experienced upgrading rather than polarization, exhibit constant or even increasing union membership rates.

Figure 2: Polarization and Collective Bargaining Coverage across Countries, 2004

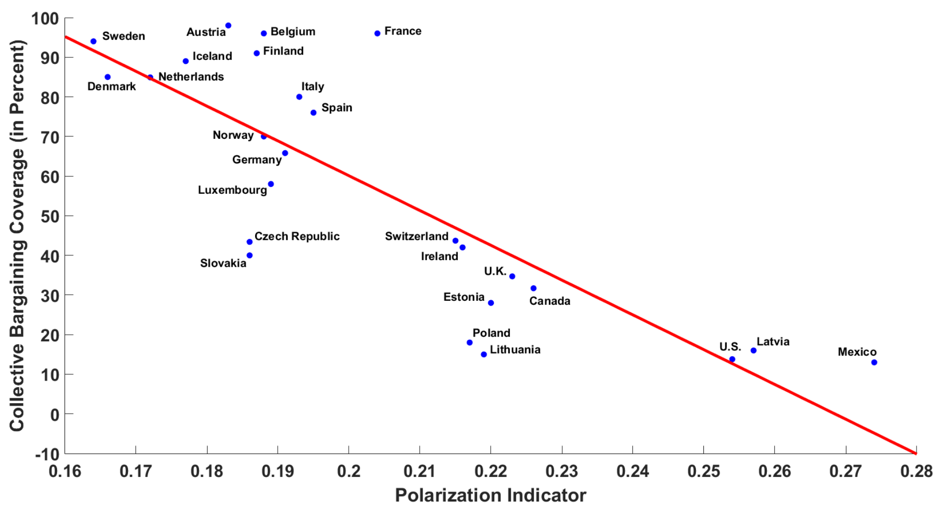


Figure 2 plots the polarization indicator developed in Duclos et al. (2004) against the collective bargaining coverage for the U.S., Canada, Mexico, and several European countries. Country selection is based on data availability. For all countries the polarization indicator is calculated for the year 2004. The collective bargaining coverage is the share of employed workers covered by a collective bargaining agreement in 2004 from the OECD data. The red line is the result of an OLS regression of the polarization indicator on the collective bargaining coverage. R^2 is 0.66.

Figure 2 plots the polarization indicator developed in Duclos et al. (2004), which evaluates the distance between and the distinction of income groups, against the collective bargaining coverage for the U.S., Canada, Mexico, and several European countries.[16] Despite the small sample size, the negative coefficient in the OLS regression of the polarization indicator on the collective bargaining coverage is statistically significant at the 0.1%-level.

The evidence presented in this section motivates us to develop a joint theory of polarization and deunionization. The prevalent explanation for polarization is the routinization hypothesis, which states that machines or computers replace middle-wage workers in occupations performing routine tasks.[17] The non-routine nature of tasks performed by low-wage and high-wage workers means that their jobs are more difficult to automate. In contrast to job polarization, no consensus has yet emerged regarding the source of deunionization.[18] We adopt the theoretical framework of Albertini et al. (2017), who develop a multi-sectoral search and matching model with an occupational choice, to examine the impact of routine-biased technical change on both polarization and deunionization.[19]

This paper is the first to theoretically evaluate how routine-biased technical change affects union membership decisions. Until now, technical change as a cause for deunionization has received only limited attention in the the-

[16] In contrast to the U.S., the differences between union membership rates and the percentage of workers covered by a collective bargaining agreement are large for most of the European countries. Thus, when looking at union influence, the share of workers covered by a collective bargaining unit seems to be more appropriate. The results also hold when exchanging the collective bargaining coverage for union density. The results are very similar when using changes in collective bargaining coverage instead of collective bargaining coverage.

[17] See, for example, Autor et al. (2003), Autor et al. (2006), Autor and Dorn (2013), Michaels et al. (2014), and Feng and Graetz (2015).

[18] For example, Ortigueira (2013) proposes the interplay between fiscal and technological links among different types of workers, Acemoglu et al. (2001) a rising skill premium and a decline in the manufacturing sector, and Scruggs and Lange (2002) globalization.

[19] Unions are not included in the model by Albertini et al. (2017).

oretical literature.[20] Acemoglu et al. (2001) show that skill-biased technical change can trigger deunionization by increasing the outside option of skilled workers. In their model, deunionization is entirely driven by quitting high-skilled workers: skill-biased technical change weakens the incentives for skilled workers to join the unionized sector, which they interpret as the manufacturing industry. Thus, in contrast to our model, deunionization works entirely through between-industry shifts. However, Baldwin (2003) finds that more than 80% of the decrease in union membership rates between 1977 and 1997 is accounted for by within-industries changes in unionization rates. Finally, the lower share of high-skilled workers in the unionized sector in Acemoglu et al. (2001) implies declining union wage premia and less skilled union members over time.

Açıkgöz and Kaymak (2014) study deunionization in a search and matching framework with endogenous union membership. In their model it is a rise in the skill premium that encourages the most skilled workers to leave the union, while unions themselves decide to get rid of the least skilled workers. This contrasts with the idea of an industrial union that covers workers of different skills, and with evidence in Baccaro and Locke (1998) and Checchi et al. (2010) who argue that disillusion about potential wage growth is the main driving force behind declining union membership rates among the least-skilled workers. In our model, low-skilled workers endogenously decide to vote against union coverage based on economic incentives.

Dinlersoz and Greenwood (2016) focus on the connection between technology, unionization, and inequality. In a general equilibrium model of union-

[20]Empirical contributions include von Brasch et al. (2018) and Meyer (2017).

ization with heterogeneous firms, skilled, and unskilled labor, they show that when the productivity of unskilled labor is high, the union decides to organize a lot of firms and demands generous wages for its members. Union members are only drawn from the low-skilled workers in Dinlersoz and Greenwood (2016). However, the inclusion of union members of other skill types would, as in Acemoglu et al. (2001) and in basically any model of skill-biased technical change, lead to both falling union wage premia and to union members becoming less skilled over time.

Thus, all three papers have trouble explaining two important empirical observations. First, the increasing relative skill of union members documented in Farber et al. (2018), and second the constant union wage premia over time documented in Hirsch and Schumacher (2004), Bryson (2002), and Farber et al. (2018). Both of these observations can be rationalized in a model with routine-biased technical change. Furthermore, wage changes caused by skill-biased technical change imply upgrading rather than polarization. As we have shown above, countries that exhibit upgrading tend to display both a smaller decline in and a larger degree of collective bargaining coverage.

3. Unions in the U.S.

This section provides a brief overview of how labor unions work in the U.S. These institutional features will be used when setting up the model in Section 4.

In the U.S., unions base their right to represent workers through collective bargaining on the voting decision of a so called bargaining unit. The National Labor Relations Act (NLRA) specifies the structure through which union organization and legal recognition takes place. This structure focuses on a system of petitions and elections to determine whether a majority of employees in the workplace wants to be represented by a union. The union then becomes the exclusive representative of all employees in the bargaining unit, whether they are union members or not.[21] If a majority of the employees votes against union representation, the unit is not represented by the union, no matter if workers individually choose to be union members or not. In the event of a lawfully-called strike, unions are allowed under the NLRA to fine members that still decide to work.

The NLRA stipulates that only a union that demonstrates majority support in an appropriate bargaining unit can be certified as the collective bargaining representative. An appropriate bargaining unit is a group of employees in a workplace that meets the legal test of sufficient community of interest to be represented by the union, whereby managers and supervisors are excluded from any bargaining unit. According to the National Labor Relations Board (NLRB), professional employees who engage in predominantly intellectual and not in routine mental, manual, or mechanical work are excluded from bargaining units with manual and routine workers, since they do not share a community of interests.[22]

The structure of bargaining in the U.S. is highly decentralized, with the

[21] In contrast to most European countries, the difference between the union membership rate and the share of workers covered by a collective bargaining agreement is small in the U.S. and behaves very similarly over time.

[22] Furthermore, the unionization rate for high-skilled abstract workers has stayed roughly constant over the last decades, while estimates of the union wage premium for these workers tend to be close to zero or even negative. As pointed out by Checchi et al. (2010), the reason for union membership among the highest-skilled are mostly non-monetary and related to their normative views on inequality.

estimated number of separate collective bargaining agreements ranging between 170,000 and 190,000 according to the Bureau of Labor Statistics. With regard to the prevelant union type in the U.S., Oh (1989) documents a steady decrease in the importance of craft unions and an increase in the importance of industrial unions. While the former is mostly limited to workers of a specific craft (and therefore of a specific skill group), the latter aims at including all workers employed in certain industries (and therefore covers workers of different skill groups). Moreover, most collective bargaining in the private sector takes place at the level of the individual firm.[23]

4. The Model

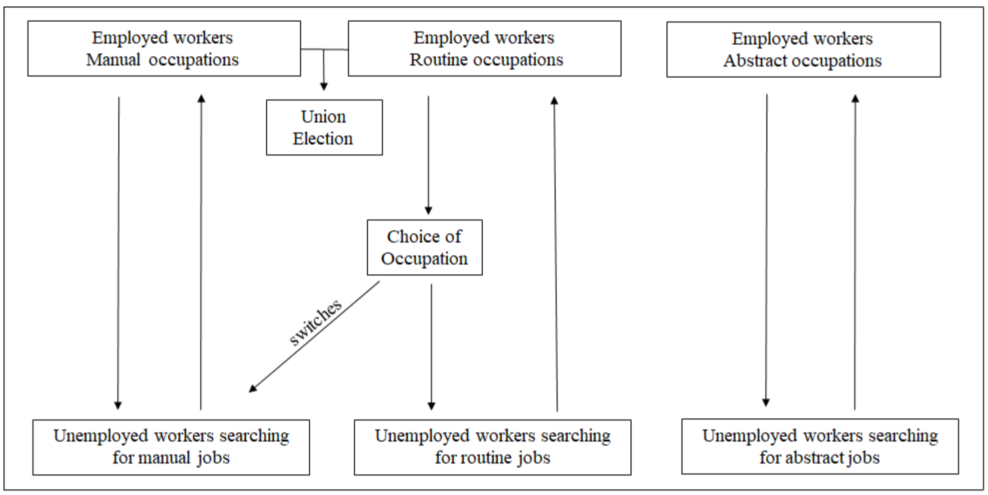
In this section, we present a discrete time search and matching model with an occupational choice and endogenous union formation. Workers are heterogeneous and differ with respect to their ability η, which is uniformly distributed across workers. For each ability level there is a continuum of workers. As depicted in Figure 3, workers can be specialized in manual, routine or abstract tasks. Upon becoming unemployed, workers previously employed in routine tasks can choose to switch occupations and join the unemployment pool of manual workers.[24] In line with Smith (2013), who

[23]See, for example, Traxler (1994) and Nickell and Layard (1999).

[24]To ease notation, and in line with the empirical evidence in Smith (2013), we abstract from other switches. Thus, in our model there will be 'overqualified' routine workers in manual occupations but we rule out the case of 'underqualified' manual workers in routine occupations. Neither the results on deunionization nor the results on polarization depend on the assumption that manual workers are unable to switch to routine occupations. Note, that because of falling prices for computer capital, the relative demand for manual workers increases. Thus, switches from manual to routine occupations would only occur whenever the job-finding rate for routine workers is larger than the job-finding rate for manual

shows that the increase in abstract employment is mainly driven by increased educational attainment and not by occupational switches, labor supply of abstract workers is assumed to increase exogenously.

Figure 3: Graphical Representation of the Model



In our model, unions arise endogenously through elections within firms.[25] When a simple majority of the respective bargaining unit votes in favor of a union, wages are bargained collectively between the respective firm and the union. The collective bargaining agreement covers all workers in the bargaining unit, regardless of the individual voting decision.[26]

workers in a unionized environment. These inefficient switches would only increase the speed with which deunionization occurs.

[25]As the production function features constant returns to scale, in contrast to Taschereau-Dumouchel (2017), firms have no incentive to overhire high-wage and low-wage, and underhire middle-wage workers in our model.

[26]In the simulation the bargaining unit will, as depicted in Figure 3, consist of all manual and routine workers. This is consistent with the legal framework in the U.S. described in Section 3. However, the general model setup presented here allows for a wide range of different bargaining units.

4.1. Labor Market Frictions

The labor market is characterized by search and matching frictions à la Mortensen and Pissarides (1994). Search is directed, as there are labor sub-markets for each of the three occupations. Within each pool, vacancies and unemployed workers are matched randomly in any period and firms learn about the ability level of a worker upon matching. Given the number of vacancies v_i posted and the share of unemployed workers u_i for every occupation i, the number of matches is determined by the following Cobb-Douglas matching technology with matching efficiency Ψ_i

$$m_i = \Psi_i v_i^{\psi} u_i^{1-\psi} \text{ where } 0 < \psi < 1 \text{ and } i = a, r, m,$$

where a, r, and m refer to abstract, routine, and manual occupations, respectively. A vacancy is filled with probability $q_i = \frac{m_i}{v_i}$ and the job finding probability is $f_i = \frac{m_i}{u_i}$. The labor market tightness is defined as the ratio $\theta_i \equiv \frac{v_i}{u_i}$. When the labor market is tight, many firms compete for few unemployed workers. The job finding probability is high, but the job filling rate is low.

4.2. Occupational Choice

Workers can either be employed in abstract, routine, or manual occupations. Existing jobs are destroyed at the exogenous rates s_i, with $i = a, r, m$. The value function for unionized manual workers is given by

$$\begin{aligned} W_m^u(\eta) = w_m^u(\eta) + \beta[(1 - s_m)\big(\mathbb{1}_{u,+1} W_{m,+1}^u(\eta) + (1 - \mathbb{1}_{u,+1}) W_{m,+1}^n(\eta)\big) \\ + s_m U_{m,+1}(\eta)], \end{aligned}$$

where β is the discount factor and $w_m^u(\eta)$ denotes the wage received by a manual union worker with ability η. $\mathbb{1}_u$ is an indicator function with $\mathbb{1}_u = 1$ if and only if the worker is a union member. Thus, the term $\mathbb{1}_{u,+1}$ indicates whether a worker in the firm is covered by a collective bargaining regime in the next period.

In turn, the non-union manual workers' value function is given by

$$W_m^n(\eta) = w_m^n(\eta) + \beta[(1 - s_m)\big(\big(\mathbb{1}_{u,+1}W_{m,+1}^u(\eta) + (1 - \mathbb{1}_{u,+1})W_{m,+1}^n(\eta)\big) + s_m U_{m,+1}(\eta)],$$

where $w_m^n(\eta)$ is the wage received by a manual non-union worker with ability η.

When unemployed, workers lose their union membership.[27] Therefore, the union and non-union value functions for an unemployed manual worker are identical and given by

$$U_m(\eta) = z_m(\eta) + \beta[(1 - f_m)U_{m,+1} + f_m\big(\mathbb{1}_{u,+1}W_{m,+1}^u(\eta) + (1 - \mathbb{1}_{u,+1})W_{m,+1}^n(\eta)\big)],$$

where $z_m(\eta)$ denotes the unemployment benefits received from the government by a manual worker with ability η.

[27] This is in line with Lewis (1989) who finds that unions are not perceived to represent the interests of the unemployed.

For abstract workers the respective value functions are

$$\begin{aligned}
W_a^u(\eta) &= w_a^u(\eta) + \beta[(1-s_a)\big(\mathbb{1}_{u,+1}W_{a,+1}^u(\eta) + (1-\mathbb{1}_{u,+1})W_{a,+1}^n(\eta)\big) \\
&\quad + s_a U_{a,+1}(\eta)], \\
W_a^n(\eta) &= w_a^n(\eta) + \beta[(1-s_a)\big(\mathbb{1}_{u,+1}W_{a,+1}^u(\eta) + (1-\mathbb{1}_{u,+1})W_{a,+1}^n(\eta)\big) \\
&\quad + s_a U_{a,+1}(\eta)], \\
U_a(\eta) &= z_a(\eta) + \beta[(1-f_a)U_{a,+1} + f_a\big(\mathbb{1}_{u,+1}W_{a,+1}^u(\eta) \\
&\quad + (1-\mathbb{1}_{u,+1})W_{a,+1}^n(\eta)\big)].
\end{aligned}$$

Analogously, the value functions for routine workers are

$$\begin{aligned}
W_r^u(\eta) &= w_r^u(\eta) + \beta\left[(1-s_r)\big(\mathbb{1}_{u,+1}W_{r,+1}^u(\eta) + (1-\mathbb{1}_{u,+1})W_{r,+1}^n(\eta)\big)\right] \\
&\quad + \beta s_r \max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\}, \\
W_r^n(\eta) &= w_r^n(\eta) + \beta\left[(1-s_r)\big(\mathbb{1}_{u,+1}W_{r,+1}^u(\eta) + (1-\mathbb{1}_{u,+1})W_{r,+1}^n(\eta)\big)\right] \\
&\quad + \beta s_r \max\{U_{r,+1}(\eta), U_{m,+1}(\eta)\}, \\
U_r(\eta) &= z_r(\eta) + \beta[(1-f_r)\max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\} + f_r\big(\mathbb{1}_{u,+1}W_{r,+1}^u(\eta) \\
&\quad + (1-\mathbb{1}_{u,+1})W_{r,+1}^n(\eta)\big)].
\end{aligned}$$

Here, the term $\max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\}$ governs the occupational choice of routine workers when unemployed in the next period. Whenever the value of being an unemployed manual worker is larger than the value of being an unemployed routine worker, the worker switches occupations.

4.3. Firms

The model features a continuum of final good firms and intermediate firms. As the setup admits the presence of a representative firm on each level, firm indices are dropped. The good-producing firm uses three homogeneous intermediate goods, Z_a, Z_r, and Z_m, as input factors to produce the final product Y. Intermediate goods are acquired at their competitive factor prices.[28] Z_a is produced with abstract jobs L^a, Z_r with computer technology K and routine workers $L^r(\eta)$, and Z_m with manual jobs $L^m(\eta)$. Routine workers and computer technology K are close substitutes, whereas abstract workers are complementary to routine tasks. The maximization problem of the good-producing firm is given by[29]

$$\Pi = \max_{Z_a, Z_r, Z_m} \{Y - p_{Z_a} Z_a - p_{Z_r} Z_r - p_{Z_m} Z_m\}$$
$$\text{s.t. } Y \leq [(A Z_a^{\alpha} Z_r^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho},$$

where $0 < \alpha < 1$, $-\infty < \rho < 1$, A, and A_m are parameters of the production function.

Intermediate firms maximize profits by choosing employment next period and the number of vacancies to be posted, subject to the firm-level employment constraint. Job creation comes at a flow cost of c_a, c_r, and c_m. The behavior of the intermediate firm in producing the intermediate good Z_a,

[28] This production structure is chosen in order to facilitate representation, as it allows for solving the maximization problems of the good-producing firm and the intermediate firms consecutively. The job-creation conditions are identical if we instead assume that the good-producing firm directly uses manual, routine, and abstract workers as input factors.

[29] This nested production function is chosen in order to allow for larger complementarity in production between abstract and routine than between routine and manual tasks.

which is paid at price p_{Z_a}, is described by

$$\Pi^{Z_a} = \max_{L_a, v_a} \left\{ p_{Z_a} Z_a - \mathbb{1}_u w_a^u L_a - (1 - \mathbb{1}_u) \, w_a^n L_a - c_a v_a + \beta \Pi_{+1}^{Z_a} \right\}$$

$$\begin{aligned} \text{s.t. } & Z_a \leq L_a \\ & L_{a,+1} = (1 - s_a) L_a + q_a v_a, \end{aligned}$$

where $L_{a,+1}$ denotes the total abstract workforce next period. $\mathbb{1}_u$ is again the indicator function with $\mathbb{1}_u = 1$ indicating if the workforce in the firm is covered by a collective bargaining regime.

The behavior of the firm producing the intermediate good Z_r, which is paid at price p_{Z_r}, is described by

$$\begin{aligned} \Pi^{Z_r} = \max \Big\{ & p_{Z_r} Z_r - p_K K - \mathbb{1}_u \int_{\eta_m}^{\bar{\eta}} w_r^u(\eta) L_r(\eta) \, \mathrm{d}\eta \\ & - (1 - \mathbb{1}_u) \int_{\eta_m}^{\bar{\eta}} w_r^n(\eta) L_r(\eta) \, \mathrm{d}\eta - c_r v_r + \beta \Pi_{+1}^{Z_r} \Big\} \end{aligned}$$

$$\begin{aligned} \text{s.t. } & Z_r \leq \left[\left((1 - \mu) \int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta) \, \mathrm{d}\eta \right)^{\sigma} + (\mu K)^{\sigma} \right]^{\frac{1}{\sigma}} \\ & L_{r,+1} = (1 - s_r) L_r + q_r v_r \end{aligned}$$

where where $0 < \mu < 1$ and $-\infty < \sigma < 1$ are production parameters, $\bar{\eta}$ denotes the exogenous ability threshold between workers in routine and abstract tasks, and η_m the endogenous ability threshold between manual and routine workers. Workers with an ability level greater than η_m but smaller than $\bar{\eta}$ work in routine occupations. Following Albertini et al. (2017), firms can freely choose their desired level of computer capital K at the price p_K.

The behavior of the intermediate firm in producing the intermediate good Z_m, which is paid at price p_{Z_m}, is described by

$$\Pi^{Z_m} = \max \left\{ p_{Z_m} Z_m - \mathbb{1}_u w_m^u L_m - (1 - \mathbb{1}_u) w_m^n L_m - c_m v_m + \beta \Pi_{+1}^{Z_m} \right\}$$

$$\text{s.t. } Z_m \leq L_m$$

$$L_{m,+1} = (1 - s_m) L_m + q_m v_m.$$

Workers with an ability level lower than η_m work in manual occupations. As in Autor and Dorn (2013), workers in manual occupations are homogenous with respect to their productivity in performing manual tasks.[30] The first order conditions and the job-creation conditions are derived in Appendix A and Appendix B.

4.4. Wage Bargaining Regimes

Since we focus on the U.S., we want our union framework to be as close as possible to the institutional framework presented in Section 3. Workers can decide to form a union on the level of the good-producing firm, which bargains with the firm and distributes the surplus according to a union wage schedule. Once new workers are hired, all manual and routine workers vote to decide whether to form a union or not. Abstract workers are excluded from the

[30]This is in line with the idea that skill differences play a larger role for workers on the assembly line compared to, for example, cleaners.

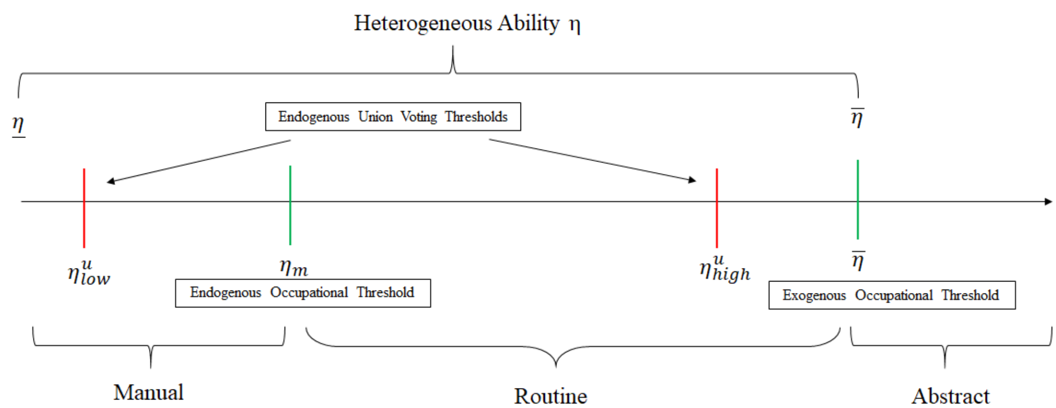
collective bargaining unit. If a union is established, the collective bargaining agreement covers all manual and routine workers, regardless of whether or not the individual worker voted in favor of the union.[31] The voting decision of an individual worker is endogenously determined and depends directly upon the potential union wage premium. Workers vote in favor of a union if the value of being a worker in a unionized firm is higher than the value of being a worker in a non-unionized firm

$$W_i^u(\eta) > W_i^n(\eta), \text{ with } i = r, m.$$

There are two ability thresholds in the model arising endogenously from the union voting decision of workers. These thresholds are denoted by η_{low}^u and η_{high}^u (with $\eta_{high}^u > \eta_{low}^u$). All workers with ability levels between these two thresholds receive a positive union wage premium and decide to vote in favor of the union. Thus, whether a union is established or not depends crucially on the composition of the workforce in a firm. It follows that the model is characterized by the two types of time-variant thresholds depicted in Figure 4: one concerning the occupational choice of workers and one concerning the union membership decision. If the majority of the bargaining unit votes against a collective bargaining agreement, manual and routine workers are not represented by the union and wages are negotiated individually. Union and non-union wages are both determined by generalized Nash bargaining over the match surplus. However, the surplus that is bargained over differs

[31] The wages of abstract workers will always be bargained individually between these workers and the firm.

Figure 4: Occupational and Union Membership Choice



between the two bargaining regimes. Non-union workers bargain individually over their marginal product. The union bargains over the entire match surplus of all manual and routine workers, with surpluses accruing to the matched parties being split according to a rule that maximizes the weighted average of the respective surpluses.

Individual Bargaining

If a majority of the manual and routine workers votes against a union, each worker bargains individually with the firm. Denoting the worker's weight in the bargaining process by $\gamma^i \in [0, 1]$, this implies the following sharing rule for individual bargaining

$$W_i^n(\eta) - U_i(\eta) = \frac{\gamma^i}{1-\gamma^i} J_i^n(\eta),$$

with $i = a, r, m$,

where $W_i^n(\eta)$ is the asset value of employment for non-union members, $U_i(\eta)$ is the value of being unemployed, and $J_i^n(\eta)$ is the value of the marginal non-union worker of type i and ability η to the firm. This results in the wage schedules for the three occupational types given below.[32]

Abstract Jobs:

$$w_a^n = \gamma^a p_{Z_a} + \gamma^a c_a \theta_a + (1 - \gamma^a)\, z_a(\eta) \tag{1}$$

Routine Jobs:

$$w_r^n(\eta) = \gamma^r p_{Z_r} y_r(\eta) + \gamma^r c_r \theta_r + (1 - \gamma^r)\, z_r(\eta) \tag{2}$$

Manual Jobs:

$$w_m^n = \gamma^m p_{Z_m} + \gamma^m c_m \theta_m + (1 - \gamma^m)\, z_m(\eta) \tag{3}$$

It follows that the wages resulting from individual bargaining are given by the sum of the marginal productivity of every η worker in every occupation, the search returns, and the outside option. This result is identical to the Nash-bargained wage in a standard Mortensen-Pissarides search and matching model.

[32] See Appendix C for a detailed derivation of the wage schedules.

Collective Bargaining

We consider a union which negotiates wages on behalf of all manual and routine workers within a firm and thus bargains over the total surplus S^u of all union members. We make the following assumptions based on the union framework in the U.S. outlined in Section 3:

Assumption 1. *All manual and routine workers in a unionized firm are union members.*

Assumption 2. *The union can force all of its members to strike.*

Under these assumptions, if no agreement on wages can be reached, all manual and routine workers in the unionized firm go on a strike and the firm can only produce using abstract workers and computer capital.

With risk-neutral heterogeneous workers, our approach only pins down the total share of the surplus going to the workers, not how it is shared among them. It is well established in the literature that unions induce wage compression and that individual union wage premia decrease in the skill level of the worker.[33] To keep the degrees of freedom in choosing the wage schedule small, we assume the simplest wage schedule that is in line with

[33] See, for example, Card et al. (2004).

both observations: unions set a constant wage for all workers[34]

$$w^u = \frac{S^u}{L_m + L_r}. \tag{4}$$

This is also in line with Fitzenberger et al. (2006) who show that unions tend to prefer wage equality over higher average wages.[35]

Under collective bargaining, the outside option of a union member is not the value of being unemployed, but the value of being a union member during a strike.[36] Therefore, denoting the union's weight in the bargaining process by $\gamma^u \in [0,1]$, the following surplus sharing rule holds in the case of collective bargaining

$$\begin{aligned}\max_{w_i^u} & \left(\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta)\left[W_i^u(\eta) - W_i^{u,s}(\eta)\right] \mathrm{d}\eta\right)^{\gamma^u} \\ & \left(\sum_i \left\{p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\, \mathrm{d}\eta\right\}\right)^{1-\gamma^u} \\ & \text{with } i = r, m,\end{aligned}$$

where $W_i^u(\eta)$ is the asset value of employment for union members with pro-

[34]The results are robust to other wage schedules. In particular, the evaluation in Appendix G establishes that the main mechanism behind falling union membership rates in our model holds for all union wage schedules that imply higher wages for routine compared to manual workers and a larger average union wage premium for manual workers compared to routine workers. Thus, the results in this paper hold for all wage schedules that are in line with empirical evidence.

[35]Recent examples of unions that negotiated across-the-board percentage wage increases for all their members in particular firms include, among others, Communications Workers of America, United Auto Workers, and United Food and Commercial Workers.

[36]Since a match between a union-worker and a firm always generates a positive bilateral surplus, the possibility of a strike is zero.

ductivity η and $W_i^{u,s}(\eta)$ is the value of being a union member during a strike.[37] Z_i is again the production of each of the three intermediate goods and Z_i' is the production in each of the three sectors when manual and routine workers are on a strike, which is compensated at price p'_{Z_i}.

It follows that the total surplus received by the union S^u is given by [38]

$$S^u = \gamma^u \sum_i (p_{Z_i} Z_i - p'_{Z_i} Z_i') + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w^{u,s} \, \mathrm{d}\eta \quad (5)$$

$$\text{with } i = r, m,$$

where $w^{u,s}$ denotes the wage received by a union worker during a strike, regardless of occupation and ability. The total surplus of the union is a function of the abilities of all manual and routine workers, while the non-union wage is a function of the individual ability of the respective worker. Under individual bargaining, every worker with ability η behaves as if he is the last hired worker. In contrast, under collective bargaining the union bargains over the production of all workers.

4.5. Households, Government Expenditures, and Transfers

In the model there is one household for each occupation and for each employment status, e.g. employed and unemployed. Households own the firm and consume the final good Y. There are no savings. For each worker

[37] The value of being a union member during a strike differs from the value of being a union member since wages are replaced by potential strike money.

[38] See Appendix D for a detailed derivation.

the budget constraint is given by

$$C = I$$

with $I \in \{w_a^n, w_r^n(\eta), w_r^u, w_m^n, w_m^u, z_a(\eta), z_r(\eta), z_m(\eta)\}$.

Since the government pays out unemployment benefits, government expenditures are

$$G = \int_{\underline{\eta}}^{\bar{\eta}} (z_a(\eta)u_a + z_r(\eta)u_r + z_m(\eta)u_m) \, \mathrm{d}\eta.$$

Firms can generate profits, which are given by

$$\Omega = \Pi^{Z_a} + \Pi^{Z_r} + \Pi^{Z_m}.$$

Therefore, the transfers received by households are

$$\Gamma = -G + \Omega.$$

Total Consumption in the economy is then given by the sum of individual consumption in addition to the transfers.[39]

4.6. Equilibrium

With the model completely described, we define the equilibrium.

Definition 1. *An equilibrium is defined as a set of i) firms' policy functions; ii) households' policy functions; iii) a union wage schedule; iv) prices; and*

[39]This allows us to abstract from the distribution of transfers to households. The results remain unchanged when lump-sum transfers are assumed instead.

v) a law of motion for the aggregate states, such that: i) the firm's policies satisfy the firms' first order conditions and the job-creation conditions; ii) households' policy functions satisfy the households' first order conditions; iii) the wage is determined through individual or collective bargaining; iv) the choices given the aggregate states clear the markets; v) the law of motion for aggregate states is consistent with individual decisions and with the process for computer capital prices.

5. Routine-biased Technical Change

In Section 6 we simulate the model in order to quantify the effects of routine-biased technical change, in the form of an exogenous drop in the price of computer capital relative to the price of consumption, on occupational decisions and on union formation. It is well established in the literature, that routine-biased technical change generates polarization in models of the labor market.[40] In our model, polarization is driven by occupational switches from previous routine workers to manual occupations. This result is formalized in Proposition 1.

Proposition 1. *Routine-biased technical change increases the incentives for previous routine workers to switch to manual occupations if* $\sigma > 0$ *and* $\sigma > (1-\alpha)\rho$.

Proof. See Appendix G for a proof of Proposition 1. □

Routine-biased technical change, by increasing the capital stock, raises the productivity of manual workers by more compared to the productivity

[40] See, for example, Autor and Dorn (2013) or Albertini et al. (2017).

of routine workers. This leads to higher relative wages and job-finding rates for manual workers. Thus, the incentives for previous routine workers to switch to manual occupations increase. We add to this well-known result by demonstrating that routine-biased technical change additionally leads to deunionization. Proposition 2 summarizes the main mechanism.

Proposition 2. *Routine-biased technical change reduces the incentive for unionized manual workers to vote in favor of union coverage if $\rho > 0$.*

Proof. See Appendix G for a proof of Proposition 2. □

Intuitively, falling computer capital prices imply lower marginal costs of production. The demand for manual, routine, and abstract workers increases due to the scale effect. Because of the complementarity of computer capital and routine workers in production, there is a negative substitution effect that reduces the demand for routine workers. Their marginal productivity increase by less compared to the marginal productivity of manual workers. Thus, due to the demand effect, the non-union wages of manual workers increase by more compared to the non-union wages of routine workers. The increasing relative demand for manual workers in response to the drop in the price of computer capital increases the size of the share of the surplus the union can extract, while the negative substitution effect on the relative demand for routine workers tends to work in the opposite direction. Since unions set identical wages for manual and routine workers, routine workers benefit from the higher relative demand for manual workers while manual workers suffer from the lower relative demand for routine workers. This directly implies that non-union wages for manual workers grow by more than union wages. Furthermore, the increase in the amount of capital used in production lowers the implicit bargaining power of unions, as a potential strike becomes less harmful for the firm. This additionally dampens union wage growth compared to non-union wage growth. Thus, the incentives to unionize decrease unambiguously for manual workers.

The effect of routine-biased technical change on the voting incentives for routine workers is ambiguous and depends on the larger union wage growth due to the relatively larger productivity growth of manual workers and the lower union wage growth due to the larger amount of capital. In the simulation, the incentives for routine workers to vote in favor of a collective bargaining agreement decrease as well. However, even if the incentives were to increase for routine workers, manual workers would still drive deunionization, as polarization implies that they make up an increasing share of the bargaining unit over time.

6. Quantitative Analysis

In this section all the parameters discussed above are calibrated to match different aspects of U.S. data for 1977, the date from which on both polarization and deunionization can be observed in our dataset. In line with empirical data, we let capital prices fall by 50% up to 2005.[41] We use the calibrated model to quantify the effects on the occupational choice of workers and on union elections. For the simulation we choose a setting with heteroge-

[41] 2005 is chosen as the endpoint for two reasons. First, 2005 marks the endpoint of the dataset compiled in Autor and Dorn (2013). Second, Beaudry et al. (2016) documents a reversal in the demand for cognitive skills since the early 2000s. Accounting for this reversal goes beyond the scope of our analysis.

neous unions that differ with respect to their bargaining power. We consider an economy that consists of a number N of independent islands, representing firms from different industries. All islands are identical except for the bargaining power of the potential union. The performance of the model is evaluated along several dimensions, especially with regard to the empirical evidence on deunionization in the U.S.[42]

6.1. Calibration

The model is calibrated to quarterly frequencies. Target values pertain to economy-wide averages. Table 1 lists the exact parameter values as well as the source that encourages the specific choice. We first calibrate the discount factor β and the labor market variables. For the separation rates of manual and routine workers, we choose conventional values of $s_m = s_r = 0.1$. Following Albertini et al. (2017), we set the separation rate of abstract workers to $s_a = 0.05$. The matching efficiencies are calibrated in order to match the targeted number of employed workers in 1977 and the average quarterly job-finding rate of 0.66 between 1967 and 1977 in Shimer (2005).[43] Different matching efficiencies for routine workers in unionized and non-unionized firms are chosen in order to ensure that the quarterly job-finding rate for union and non-union members always stays in the interval between zero and one. Vacancy posting costs are chosen to correspond on average to 35% of a workers quarterly steady state wage, which lies well in the range of values

[42]The complete set of equations used to derive the steady states is given in Appendix H. We focus on steady states as we are mainly interested in the long-run effect of routine-biased technical change on the economy and on the wage bargaining regimes. Analysing the transitional dynamics is an interesting task for future research.

[43]Under this calibration the job-finding rates increase with the skill level.

found in the literature.[44] Unemployment benefits and strike pay are both set to zero.[45]

Table 1: Calibrated Parameters

Symbol	Interpretation	Value	Source
β	Discount factor	0.99	Annual interest rate of 4%
c_m	Manual recruiting costs	0.3	35% of wages
c_r	Routine recruiting costs	0.3	35% of wages
c_a	Abstract recruiting costs	0.5	35% of wages
Ψ_m	Manual matching efficiency	0.35	Job-finding rate 0.66
Ψ_r^n	Routine matching efficiency	0.33	Job-finding rate 0.66
Ψ_r^u	Routine matching efficiency unionized	0.25	Job-finding rate 0.66
Ψ_a	Abstract matching efficiency	0.98	Job-finding rate 0.66
ψ	Unemployment-elasticity of matching	0.5	Petrongolo and Pissarides (2001)
s_m	Manual eparation rate	0.1	Garín (2015)
s_r	Routine separation rate	0.1	Garín (2015)
s_a	Abstract separation rate	0.05	Albertini et al. (2017)
γ^m	Manual Worker's bargaining power	0.5	Midpoint of literature values
γ^r	Routine Worker's bargaining power	0.5	Midpoint of literature values
γ_a	Abstract Worker's bargaining power	0.8	Wage premium 1977
γ^u	Union bargaining power	0.725 - 0.96	Union data
A	Productivity routine and abstract input	3.4	Occupational shares in 1977
A_m	Productivity of manual input	0.71	Occupational shares in 1977
α	Marginal return to abstract labor	0.4	Occupational shares in 1977
ρ	Production parameter	0.65	Occupational shares in 1977
σ	Production parameter	0.74	Albertini et al. (2017)
μ	Production parameter	0.5	Albertini et al. (2017)
$\underline{\eta}$	Lower bound on skill	0.48	Occupational shares in 1977
$\overline{\eta}$	Upper bound on routine skill	1.44	Occupational shares in 1977
g_{L_a}	Growth rate of abstract employment	0.0175	Abstract employment in 2005
g_K	Growth rate of computer capital prices	-0.024	Investment prices in 2005

All production and skill specific parameters are set in order to match data on employment shares in 1977 (31.9% manual, 38.2% routine, and 29.9% abstract workers), as well as the abstract employment share of 40.9% in 2005. This leaves manual and routine employment shares in 2005 as an untargeted moment to gauge the performance of the model. The growth rates of computer capital prices g_K and abstract employment g_{L_a} are calibrated to match a drop in computer capital prices by 50% and an increase in the

[44]See, for example, Garín (2015) and Michaillat (2012).
[45]The results are robust to alternative parameter choices.

abstract employment share of 11 percentage points.

Depending on birth cohort, age group, and survey data, the difference in wages between high school graduates and college graduates amounts to 10%-29%. The average Mincer college wage premium - over age groups, birth cohorts, and survey data - amounts to roughly 15% to 20% in the U.S. in 1977.[46] Setting the bargaining power of abstract workers, γ_a^n, to 0.8 yields a college wage premium of 17% in the model in 1977 while leaving the average worker bargaining power in the standard range between 0.4 and 0.6.[47]

Table 2: Union Calibration, 1977

	Model	Target Value	Source
Overall Membership Rate	23.3%	22.1%	Hirsch and Macpherson (2003)
Manual Membership Rate	33.3%	35.5%	Hirsch and Macpherson (2003)
Routine Membership Rate	33.3%	35.5%	Hirsch and Macpherson (2003)
Union Wage Premium	0%	0%	Bryson et al. (2016) and DiNardo and Lee (2004)
Vote Share Won Elections	64.6%	70.0%	Frandsen (2012)

The union bargaining power of the potential unions is equally distributed on the interval between 0.725 and 0.96.[48] This range is chosen to match sev-

[46] See, for example, Ashworth and Ransom (2018). Mincer college wage premium refers to a wage premium that is adjusted for observable skills using the model proposed by Mincer (1974). Typically, the Mincer wage premium is roughly half the size of the raw wage premium.

[47] The college wage premium can be calculated when assuming that the skill η refers to the educational attainment of otherwise identical workers. If we further assume that manual workers have high school education, abstract workers a college degree, and routine workers some college or an associates degree, than the college wage premium is given by the ratio of abstract to manual wages in the model.

[48] The large differences between the union bargaining powers and the individual bargaining power of a worker are due to the fact that under collective bargaining workers are not lost to the firm when bargaining breaks down. If we instead assume that the firm loses its workforce when no agreement is reached, the calibration target for the union bargaining powers would be substantially lower than under individual bargaining. The reason behind this is that the union bargains over the average product of all workers in the bargaining unit, while each individual workers only bargains over his or her marginal product. The results are robust to alternative intervals of the union bargaining power.

eral aspects of the data, including pro-union vote share in elections, union membership rates in 1977, and the union wage premium.[49] The target values and their model equivalents are given in Table 2. Estimates of the average union – non-union wage differential across workers range from close to zero in Bryson (2002), DiNardo and Lee (2004), Booth and Bryan (2004), and Frandsen (2012) to 25% in Hirsch and Schumacher (2004). Generally, more recent studies tend to find only very small wage premia on average. Additionally, Streeck (2005) argues that because of its structure, industrial unions tend to exhibit lower wage premia on average compared to craft unions.

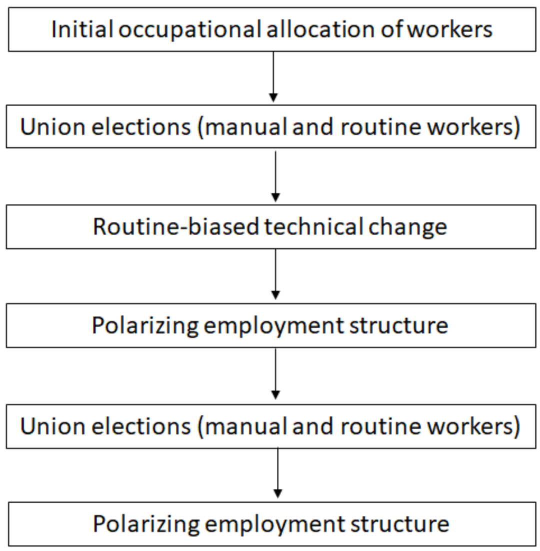
6.2. Simulation Results

The timing of events is depicted in Figure 5. First, given the initial calibration, the occupational thresholds are determined. Afterwards, union elections take place and all islands with a union bargaining power above $\gamma^u = 0.88$ are unionized. Capital prices fall, the amount of computer capital used in production increases, and occupational thresholds in non-unionized firms change with former routine workers switching to manual occupations. A union election takes place in every period and unions failing to gain majority support are terminated. Occupational shifts occur in the previously unionized firms, which amplifies the initial polarization.

An overview of our main results is given in Figure 6, which is the model equivalent to Figure 1. The relative price of the investment good drops by 50% between 1977 and 2005. The share of routine workers drops by 10 per-

[49]Since in our simple model either all or none of the manual workers are in favor of a union, the pro-union vote share in won elections is chosen as a target value over the overall pro-union vote share.

Figure 5: Timing of Events



centage points from 38% in 1977 to 28% in 2005 and the union membership rate by 15.5 percentage points for 23.3% to 7.8%.[50] The model is also able to capture the observation that the decrease in the union membership rate has flattened out since the early 1990s.[51]

6.2.1. Deunionization

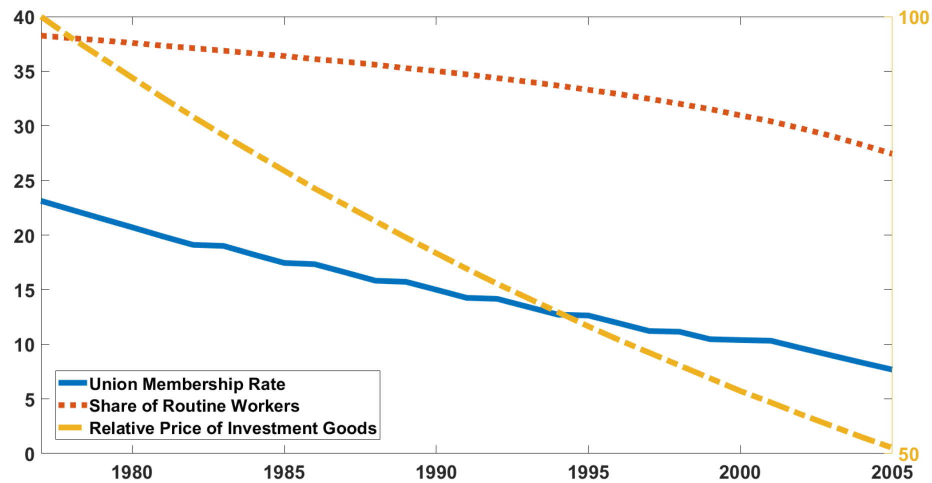
As capital prices fall, in the subsequent elections, the unions with the lowest bargaining power fail to gain majority support and are terminated.[52]

[50]In the model the union membership rate is defined as the ratio of union members to total employment across islands.

[51]As employment shares only adjust in non-unionized firms, firms on some islands will deunionize and then unionize again after employment has adjusted. This reunionization slows down the decline in the union membership rate. Nevertheless, indefinitely falling capital prices will eventually lead to a union membership rate of zero in the model.

[52]This model prediction is supported by evidence in the 2004 NLRB Performance and Accountability Report. Going from 1994 to 2004, the number of filed representation petitions has dropped by 25%, but the share of won elections has increased by over five percentage points.

Figure 6: Polarization and Deunionization – Simulated Model



Note: The number of islands is set to $N = 100$ for the plot. The relative price of investment is plotted as an index with 1977 = 100.

Our model performs well in generating declining union membership rates between 1977 and 2005. The predicted and actual changes in membership rates are given in Table 3. The overall union membership rate falls by 15.5 percentage points from 23.3% to 7.8% in the model compared to a drop of 14.2 percentage points in the data. For manual workers, the union membership rate falls by 20.5 percentage points in the model and by 22.5 percentage points in the data. For routine workers, the union membership rate falls by 19.8 percentage points in the model and by 22.4 percentage points in the data.[53] In Appendix E we consider an extension of the model that includes a

[53]Using data for all wage and salary workers (including the public sector), the overall union membership rate drops by 11.3 percentage points from 23.8% in 1977 to 12.5% in 2005. The slower decrease is driven by increasing union membership rates in the public sector between 1977 and 2005.

union for abstract workers. In line with the data, the union membership rate of abstract workers decreases only slightly over the considered time period.

Table 3: Declining Union Membership Rates: Model versus Data

Union Membership	Data 1977	Model 1977	Data 2005	Model 2005
Overall	22.1%	23.3%	7.9%	7.8%
Manual Workers	35.5%	33.3%	13.0%	13.2%
Routine Workers	35.5%	33.3%	13.1%	13.5%

Note: Data for the union membership rates are taken from the U.S. union database constructed by Hirsch and Macpherson (2003) and include all private sector nonagricultural workers. For the membership rates for routine and manual workers in 1977 we use data on the union density of private construction workers (manual) and private manufacturing workers (routine). More detailed data on the union membership rates of workers in manual and routine occupations is only available since 1983. From 1983 onwards, union density for all manual workers and for construction workers as well as union density of all routine workers and manufacturing workers behave very similarly in terms of absolute values and changes over time.

Claim 1. *The drop in overall union membership rates between 1977 and 2005 is mainly driven by decreasing membership rates within occupations and not by changing employment shares.*

In our model deunionization does not only, by construction, work entirely through changes within industries, but also mainly through changes within rather than between occupations. Baldwin (2003) conducts a decomposition exercise for the time period between 1977 and 1997 and finds that the within-industries contribution to falling unionization rates in the U.S. is, depending on the exact specification, at least 82%. Adopting the approach used in Baldwin (2003), we estimate the within-occupations component of the decline in the U.S. union membership rate between 1983 and 2005 to be 81.1%.[54]

[54] See Appendix F for a detailed account of the decomposition analysis.

Consistently, 83% of the falling union membership rate is explained by the within-occupations component in our model and only 17% by the changing employment shares.

Claim 2. *Despite falling union membership rates, the average union wage premium stays roughly constant between 1977 and 2005.*

As highlighted in Farber et al. (2018), existing models of union formation have trouble explaining the observation of a constant union wage premium in times of rapidly declining union membership rates. The increased use of capital and high-skilled workers reduces the value of low-skilled workers for the firm and thus depresses the implicit bargaining power of unions. A similar effect is at work in our model, as the increased use of capital in production lowers the value of routine workers for the firm. However, since our model predicts that the unions with the lowest bargaining power will be the ones that are terminated, union termination in the model is associated with increasing average union bargaining power. In contrast to the predictions of existing models, these countervailing effects imply relatively constant union wage premia despite a sharp decline in union membership rates.

Claim 3. *Deunionization increases the relative skill level of union members between 1977 and 2005.*

Existing models of union formation mostly rely upon declining membership rates among the highest-skilled workers in order to explain deunionization. This stands in sharp contrast to the membership data in Hirsch and Macpherson (2003). In our model, since either all or none of the non-abstract workers on an island are unionized, deunionization does not influence the relative skill level of union members compared to the non-unionized non-abstract workforce. Consider an increase in the skill level of a worker and how this affects his or her probability of being a union member. In Appendix E we show that, in line with the data, the union membership rate of abstract workers decreases only slightly in our model. Thus, an increase in the skill level of a worker decreases the probability of being a union member by less in 2005 compared to 1977. Evidence on the effect of educational attainment on the union status of workers in Farber et al. (2018) points in the same direction. The reason is that the union membership rate of abstract workers decreases by less compared to the union membership rates of the less-skilled manual and routine workers, both in the data and in our model.

6.2.2. Polarization

Due to the falling capital prices employment on the non-unionized islands adjusts, with the lowest-skilled routine workers deciding to switch to manual occupations upon becoming unemployed. Since, the unions with the lowest bargaining power fail to gain majority support employment adjusts in the deunionizing firms identical to the non-unionized firms. The employment shares in the model and in the data are given in Table 4. The share of manual workers decreases from 31.9% to 31.1% in the data and 31.6% in the model between 1977 and 2005, while the employment share of routine workers decreases from 38.2% to 28.0% in the data and 27.5% in the model. Figure 7 displays the respective percentage point changes in the employment share for each occupation.[55]

Table 4: Employment Shares in 1977 and 2005: Model versus Data

Employment Shares	Data 1977	Model 1977	Data 2005	Model 2005
Manual	31.9%	31.9%	31.1%	31.6% (30.0%)
Routine	38.2%	38.2%	28.0%	27.5% (29.1%)
Abstract	29.9%	29.9%	40.9%	40.9% (40.9%)

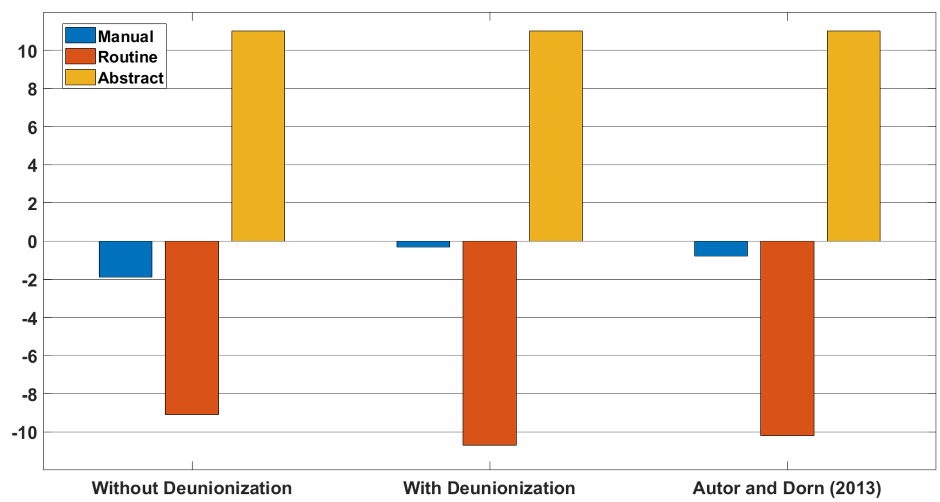
The share of workers in each occupation is constructed using the dataset and the occupational classification from Autor and Dorn (2013). The employment shares in a model without deunionization are given in round brackets.

In our model polarization does not occur in unionized firms, as the lowest-skilled unionized routine workers have no incentive to switch to manual jobs as long as wages for manual and routine workers grow equally. Thus, the increase of workers employed in manual occupations is smaller compared to a model without unions. In Appendix G, we provide an evaluation of this result along with a range of wage schedules for which the result holds. While there is no direct evidence on the polarization of the employment structure in unionized versus non-unionized firms, our model prediction is supported by two strands of the literature. First, Calmfors et al. (2001) and Rogers and Streeck (1995) argue that in many countries the management is under the obligation to at least consult with the relevant unions over restructuring and layoff plans. In these cases union officials tend to prefer policies that favor those workers who are most likely to be union members in order to improve their chances in future elections. Thus, unions will likely

[55] Since the model is calibrated to match employment shares in 1977, a model version without unions corresponds to the case of complete deunionization. Such a model would substantially overpredict employment changes. For the counterfactual scenario without deunionization, union elections are abolished, which fixes the share of unionized islands at the level of 1977.

oppose plans that reinforce polarization. Second, Connolly et al. (1986), Hirsch and Link (1987), and more recently Bradley et al. (2015) argue that unions have detrimental effects on innovation and technology adaption. As technical change is the most important driving force behind polarization, less innovation is likely to be accompanied by less polarization. This implies, as our model predicts, that deunionization amplifies polarization.

Figure 7: Percentage Point Changes in Employment Shares, 1977 – 2005: Model versus Data



Note: The share of workers in each occupation is calculated across islands. The share of workers in each occupation is constructed using the dataset and the occupational classification from Autor and Dorn (2013). For the counterfactual scenario without deunionization, union elections are abolished, which fixes the share of unionized islands at the level of 1977.

The untargeted changes in employment shares for manual and routine workers are both close to the changes reported in Autor and Dorn (2013), Jaimovich and Siu (2012), and Albertini et al. (2017). Even though the manual employment share remains roughly unchanged, there has been substantial employment reallocation with more than 14% of all routine workers in 1977 deciding to switch to manual occupations. Over 20% of the changes in manual and routine employment in our model are triggered by the termination of unions. While the model, in line with the empirical literature, predicts routine-biased technical change to be the main explanation for job market polarization, deunionization plays an important role in amplifying employment changes.

We additionally check the performance of the model with respect to matching the evolution of the unemployment rate. Our model predicts an average unemployment rate of 7.86% in 1977, with lower job-finding rates and slightly larger unemployment on unionized islands. Going to 2005, the average unemployment rate drops to 5.7%. The average unemployment rate estimated by the BLS for the time periods between 1974 to 1980 and 2002 to 2008 is 7% and 5.5%, respectively. In line with the data, the unemployment rate in our model decreases in the skill level.

The changes in employment and unemployment are accompanied by changes in wages for workers in all three occupations. The model predicts wages for abstract workers to grow by close to 20%. Wages for manual and routine workers grow by 13% and 11%, respectively. These untargeted wage changes are reasonably close to the wage growth of 16% for manual, 11% for routine, and 25% for abstract workers reported in Autor and Dorn (2013) for the time period between 1980 and 2005.

6.2.3. Inequality

In contrast to the large effect on employment changes, deunionization has only modest effects on wage changes. Income inequality, as measured by the Gini index in wages, is roughly 40% higher in 1977 in a model without unions.[56] Going from 1977 to 2005, the Gini index in our model increases by 13% compared to an increase of 15% for U.S. data. However, since union wage premia are small on average and the unions with the lowest bargaining power are terminated, this increase in inequality is almost entirely driven by increasing relative wages for abstract workers. The small overall effects of deunionization on wage inequality in our model accord with the empirical findings in DiNardo et al. (1996), Frandsen (2012), and Farber et al. (2018).

However, the effects of deunionization for those groups that traditionally receive a high union wage premium, the low- to middle-skilled workers, are substantial. For previous union members, e.g. those workers that lose their union wage premium going from 1977 to 2005, the wage growth would be 25% larger if they were covered by one of the existing unions. Furthermore, for those low- to lower middle-skilled workers still covered by a union in 2005, over one third of their total wage growth is due to collective bargaining.

7. Policy Experiments and Implications

While routine-biased technical change hurts middle-wage workers, job market polarization per se, in the sense of changing employment shares, does not. In the model, the possibility to switch occupations allows labor supply to adjust to the changes in labor demand and thereby to partly offset the wage effects of routine-biased technical change. As shown by Kambourov and Manovskii (2009), Gathmann and Schönberg (2010) and Cortes and Gallipoli (2017), occupational switching costs are large. Therefore, as proposed for example in Autor et al. (2003), policies that simplify job switches or that

[56] The Gini index is computed in our model using wage deciles.

aim at making them less costly for workers could serve to dampen income inequality caused by routine-biased technical change.

Our analysis has shown that while the overall effect of deunionization on income inequality is small, there are large effects for low- to lower middle-skilled workers. Taking into account evidence from Frandsen (2012), who reports that most union elections are very closely contested, even very small policy changes in favor of unions or union workers could lead to large effects on income inequality for these workers.

We briefly consider the effects of three policies in our model that aim at preventing deunionization and increasing equality. The first policy simply abolishes union elections after the first election in 1977 and maintains the established unions regardless of worker preferences. While this approach prevents deunionization, it also prevents efficient deunionization in the sense that even unions generating a negative average wage premium would be maintained. The second policy lowers the necessary voting threshold for unions. For specific voting thresholds, this policy achieves the same results as the former policy with identical downsides. However, such an intervention is not well suited to stop the overall trend of declining union membership rates, as the threshold would have to be regularly adjusted to changes in the economy. Furthermore, low threshold values, apart from being difficult to justify, could in principle lead to the founding of further inefficient unions. The third policy aims at increasing the bargaining power of unions by increasing political support.[57] Consider, for example, a scenario in which the bargaining power

[57] A recent example is the Protecting the Right to Organize Act introduced by Rep. Robert Cortez Scott.

of all established unions is set to $\gamma^u = 0.96$, the bargaining power of the most powerful union. In addition to at least delaying deunionization, this policy also raises wages for low-wage and middle-wage workers and reduces inequality. However, as with the policy lowering the voting threshold, deunionization would eventually occur if the trend of falling computer capital prices continues.

In our simulation, deunionization can always be prevented by adjusting the union wage schedule towards less equality inside the unionized firms.[58] However, empirical evidence suggests that rigid organizational structures partly prevent unions from meeting today's challenges. Waddington (2005) contends that trade union practices are perceived as formal and old-fashioned and that the representative structures inside unions are often inappropriate for the participation of all members. Bryson et al. (2016) argue that union representatives have very long tenure and tend to become less representative of the membership over their term of office. While membership rates decline across all age groups, according to data from the Bureau of Labor Statistics, membership rates for workers aged between 16 and 24 declined at twice the rate of overall membership between 2002 and 2012. Data on the evolution of the median age of union members points in the same direction. Dunn and Walker (2016) stress that over half of all U.S. union members are between 45 and 64 years of age. Thus, it seems that unions are mostly controlled and influenced by older members that might display a tendency to stick to

[58]This of course abstracts from workers voting against the union simply because they are dissatisfied with the changes in the wage structure, as our analysis soley focuses on monetary incentives.

established practices. Bryson et al. (2016) argue that the decline in union membership rates across countries is negatively related to the degree of progressiveness of the unions. One straightforward policy suggestion would be restricting the tenure of union representatives to ensure that union officials are drawn from the current membership.

8. Conclusion

This paper explores how routine-biased technical change affects both the occupational and the union-membership choice of workers. To do so we develop a model that endogenizes both decisions in a search and matching framework.

We provide analytical results and use the calibrated model to show that routine-biased technical change, represented by a sharp drop in computer capital prices, not only generates employment and wage polarization but also deunionization. The drop in computer capital prices reduces the demand for routine workers, while abstract and manual workers are in great demand. The changing demand structure influences the surplus the union can extract and thereby also the individual union wage premium of workers. Manual workers, who benefit from the changing demand structure, are discouraged from voting in favor of a collective bargaining agreement. The wage gains for manual workers, that would be distributed equally between manual and routine workers by the union, lead to the least skilled workers being better off when bargaining individually with the firm. Former routine workers, when faced with lower wages compared to manual workers, decide to switch occupations.

We demonstrate that this effect can lead to a change in the voting outcome, with the majority of the workforce of previously unionized firms now voting against unionization and in favor of individual bargaining. In an economy in which unions differ with respect to their bargaining power, routine-biased technical change leads to a large decrease in union membership, as those unions with the lowest bargaining power are terminated. This contributes substantially to employment polarization. While overall effects on income inequality are small, low- to middle-skilled previously unionized workers are severely affected.

References

Acemoglu, D., Aghion, P., Violante, G.L., 2001. Deunionization, technical change and inequality. Carnegie-Rochester Conference Series on Public Policy 55, 229–264.

Açıkgöz, O.T., Kaymak, B., 2014. The rising skill premium and deunionization. Journal of Monetary Economics 63, 37–50.

Albertini, J., Hairault, J.O., Langot, F., Sopraseuth, T., 2017. A tale of two countries: A story of the French and US polarization. IZA Discussion Papers No. 11013.

Ashworth, J., Ransom, T., 2018. Has the college wage premium continued to rise? evidence from multiple U.S. surveys. IZA Discussion Papers No. 11657.

Autor, D.H., Dorn, D., 2013. The growth of low-skill service jobs and the polarization of the US labor market. American Economic Review 103, 1553–1597.

Autor, D.H., Katz, L.F., Kearney, M.S., 2006. The polarization of the U.S. labor market. American Economic Review 96, 189–194.

Autor, D.H., Levy, F., Murnane, R.J., 2003. The skill content of recent technological change: An empirical exploration. Quarterly Journal of Economics 118, 1279–1333.

Baccaro, L., Locke, R., 1998. The end of solidarity? the decline of egalitarian wage policies in Italy and Sweden. European Journal of Industrial Relations 4, 283–308.

Baldwin, R., 2003. The decline of US labor unions and the role of trade. Peterson Institute for International Economics.

Beaudry, P., Green, D.A., Sand, B.M., 2016. The great reversal in the demand for skill and cognitive tasks. Journal of Labor Economics 34, S199–S247.

Booth, A., Bryan, M.L., 2004. The union membership wage-premium puzzle: Is there a free rider problem? International Labor Relations Review 57, 402–421.

Bradley, D., Kim, I., Tian, X., 2015. Do unions affect innovation? *Management Science*, Forthcoming.

von Brasch, T., Gjelsvik, M.L., Sparrman, V., 2018. Deunionization and job polarization – a macroeconomic model analysis for a small open economy. Economic Systems Research 30, 380–399.

Bryson, A., 2002. The union membership wage premium: An analysis using propensity score matching. CEP Discussion Papers No. 530.

Bryson, A., Dale-Olsen, H., Nergard, K., 2016. Gender differences in the union membership wage premium? a comparative case study. IZA Discussion Papers No. 10435.

Calmfors, L., Booth, A., Burda, M., Checchi, D., Naylor, R., Visser, J., 2001. The Role of Unions in the Twenty-First Century: A Report for the Fondazione Rodolfo Debenedetti. Oxford University Press. chapter 1. pp. 1–158.

Card, D., Lemieux, T., Riddel, C.W., 2004. Unions and wage inequality. Journal of Labor Research 25, 519–559.

Checchi, D., Visser, J., van de Werfhorst, H.G., 2010. Inequality and union membership: The influence of relative earnings and inequality attitudes. British Journal of Industrial Relations 48, 84–108.

Connolly, R.A., Hirsch, B.T., Hirschey, M., 1986. Union rent seeking, intangible capital, and market value of the firm. Review of Economics and Statistics 68, 567–577.

Cortes, G.M., Gallipoli, G., 2017. The cost of occupational mobility: An aggregate analysis. Journal of the European Economic Association 16, 275–315.

DiNardo, J., Fortin, N.M., Lemieux, T., 1996. Labor market institutions and the distribution of wages, 1973-1992: A semiparametric approach. Econometrica 64, 1001–1044.

DiNardo, J., Lee, D.S., 2004. Economic impacts of new unionization on private sector employers: 1984-2001. Quarterly Journal of Economics 119, 1383–1441.

Dinlersoz, E., Greenwood, J., 2016. The rise and fall of unions in the United States. Journal of Monetary Economics 83, 129–146.

Duclos, J.Y., Esteban, J., Ray, D., 2004. Polarization: Concepts, measurement, estimation. Econometrica 72, 1737–1772.

Dunn, M., Walker, J., 2016. BLS spotlight on statistics: Union membership in the United States. U.S. Department of Labor, Bureau of Labor Statistics.

Farber, H.S., Herbst, D., Kuziemko, I., Naidu, S., 2018. Unions and inequality over the twentieth century: New evidence from survey data. NBER Working Papers No. 24587.

Feng, A., Graetz, G., 2015. Rise of the machines: The effects of labor-saving innovations on jobs and wages. CEP Discussion Papers No. dp1330.

Fitzenberger, B., Kohn, K., Lembcke, A., 2006. Union density and varieties of coverage: The anatomy of union wage effects in Germany. International Labor Relations Review 66, 169–197.

Frandsen, B.R., 2012. Why unions still matter: The effects of unionization of the distribution of employee earnings. Working Paper.

Garín, J., 2015. Borrowing constraints, collateral fluctuations, and the labor market. Journal of Economic Dynamics and Control 57, 112–130.

Gathmann, C., Schönberg, U., 2010. How general is human capital? a task-based approach. Journal of Labor Economics 28, 1–49.

Goos, M., Manning, A., 2007. Lousy and lovely jobs: The rising polarization of work in Britain. Review of Economics and Statistics 89, 118–133.

Goos, M., Manning, A., Salomons, A., 2009. Job polarization in Europe. American Economic Review 99, 58–63.

Hirsch, B.T., Link, A.N., 1987. Labor union effects on innovative activity. Journal of Labor Research 8, 323–331.

Hirsch, B.T., Macpherson, D.A., 2003. Union membership and coverage database from the current population survey: Note. Industrial and Labor Relations Review 56, 349–354.

Hirsch, B.T., Schumacher, E.J., 2004. Match bias in wage gap estimates due to earnings imputation. Journal of Labor Economics 22, 689–722.

Jaimovich, N., Siu, H.E., 2012. The trend is the cycle: Job polarization and jobless recoveries. NBER Working Papers No. 18334.

Kambourov, G., Manovskii, I., 2009. Occupational specificity of human capital. International Economic Review 50, 63–115.

Lewis, P., 1989. The unemployed and trade union membership. Industrial Relations Journal 20, 271–279.

Meyer, B., 2017. Financialization, technological change, and trade union decline. Socio-Economic Review .

Michaels, G., Natraj, A., Reenen, J.V., 2014. Has ICT polarized skill demand? evidence from eleven countries over twenty-five years. Review of Economics and Statistics 96, 60–77.

Michaillat, P., 2012. Do matching frictions explain unemployment? not in bad times. American Economic Review 102, 1721–1750.

Mincer, J., 1974. Schooling, experience, and earnings. Columbia University Press, NY.

Mortensen, D.T., Pissarides, C.A., 1994. Job creation and job destruction in the theory of unemployment. Review of Economic Studies 61, 397–415.

Nickell, S., Layard, R., 1999. Labor market institutions and economic performance. Handbook of Economics 3, 3029–2084.

Oh, W., 1989. Craft versus Industrial Unions: Union Organization Within the Work Place. Ph.D. thesis. The Ohio State University.

Ortigueira, S., 2013. The rise and fall of centralized wage bargaining. Scandinavian Journal of Economics 115, 825–855.

Petrongolo, B., Pissarides, C.A., 2001. Looking into the black box: A survey of the matching function. Journal of Economic Literature 39, 390–431.

Post, C., 2017. The roots of trumpism. Cultural Dynamics 29, 100–108.

Rogers, J., Streeck, W., 1995. Works councils: Consultation, representation, and cooperation in industrial relations. National Bureau of Economic Research, Inc.

Scruggs, L., Lange, P., 2002. Where have all the members gone? globalization, institutions, and union density. The Journal of Politics 64, 126–153.

Shimer, R., 2005. The cyclical behavior of equilibrium unemployment and vacancies. American Economic Review 95, 25–49.

Smith, C.L., 2013. The dynamics of labor market polarization. Finance and Economics Discussion Series 2013-57, Board of Governors of the Federal Reserve System (U.S.).

Streeck, W., 2005. The Sociology of Labor Markets and Trade Unions. In: N.J. Smelser and R.Swedberg *The Handbook of Economic Sociology*. Princeton University Press. pp. 254–283.

Taschereau-Dumouchel, M., 2017. The union threat. Working Paper.

Traxler, F., 1994. Collective bargaining: Levels and coverage. Employment Outlook 1994, OECD, 167-194.

Troy, L., Sheflin, N., 1985. U.S. union sourcebook. Industrial Relations Data and Information Services, West Orange, New Jersey.

Waddington, J., 2005. Trade union membership in Europe: The extent of the problem and range of union responses. Host publication.

Waddington, J., Whitston, C., 1997. Why do people join unions in a period of membership decline? British Journal of Industrial Relations 35, 515–546.

Appendix

Appendix A. First Order Conditions of Firms

Defining the value of a marginal worker in an abstract non-routine cognitive occupations for a firm as J_a, the first-order conditions for hiring and for vacancy posting are given by

$$c_a = \mu_a q_a,$$
$$\mu_a = \beta J_{a,+1},$$

where μ_a is the Lagrange-multiplier on the employment constraint for workers in abstract occupations. The corresponding value of a marginal worker in abstract non-routine cognitive occupations is given by

$$J_a = p_{Z_a} - \mathbb{1}_u w_a^u - (1 - \mathbb{1}_u) w_a^n + (1 - s_a)\beta J_{a,+1}.$$

Defining the value of a marginal worker with ability η in a routine occupation for a firm as $J_r(\eta)$, the first-order conditions for hiring workers in routine tasks and for vacancy posting are given by

$$c_r = \mu_r q_r$$
$$\mu_r = \beta J_{r,+1},$$

where μ_r is the Lagrange-multiplier on the employment constraint for a worker in routine occupations. The corresponding value of a marginal worker with ability η in routine occupations is given by

$$J_r = p_{Z_r}\overline{y_r} - \mathbb{1}_u \overline{w_r^u} - (1 - \mathbb{1}_u)\overline{w_r^n} + (1 - s_r)\beta J_{r,+1},$$
$$\text{with } y_r(\eta) = \frac{\partial Z_r}{\partial L_r(\eta)} = \eta(1-\mu)^\sigma \left[(1-\mu)^\sigma + (\mu k)^\sigma\right]^{\frac{1}{\sigma}-1} \text{ and } k \equiv \frac{K}{\int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta)\,\mathrm{d}\eta},$$

where $\overline{y_r}$ is the expected marginal product of a routine worker, $\overline{w_r^u}$ is the expected union wage, and $\overline{w_r^n}$ the expected non-union wage.

Defining the value of a marginal worker with ability η in a non-routine manual occupation for a firm as J_m, the first-order conditions for hiring workers in manual tasks and for vacancy posting are given by

$$c_m = \mu_m q_m,$$
$$\mu_m = \beta J_{m,+1},$$

where μ_m is the Lagrange-multiplier on the employment constraint for worker in manual occupations. The corresponding value of a marginal worker with ability η in manual occupations is given by

$$J_m = p_{Z_m} - \mathbb{1}_u w_m^u - (1 - \mathbb{1}_u) w_m^n + (1 - s_m)\beta J_{m,+1}.$$

Appendix B. Job Creation Conditions

The job creation conditions are given by

$$\frac{c_i}{q_i} = \beta J_{i,+1}$$

$$\text{with } i = a, r, m,$$

Together with the values of marginal workers for firms, it follows that

$$\frac{c_a}{q_a} = \beta\left[p_{Z_a} - \mathbb{1}_{u,+1} w_a^u - (1 - \mathbb{1}_{u,+1})\, w_a^n + (1 - s_a)\frac{c_a}{q_{a,+1}}\right],$$

$$\frac{c_r}{q_r} = \beta\left[p_{Z_r}\overline{y_r} - \mathbb{1}_{u,+1}\overline{w_r^u} - (1 - \mathbb{1}_{u,+1})\,\overline{w_r^n} + (1 - s_r)\frac{c_r}{q_{r,+1}}\right],$$

$$\frac{c_m}{q_m} = \beta\left[p_{Z_m} - \mathbb{1}_{u,+1} w_m^u - (1 - \mathbb{1}_{u,+1})\, w_m^n + (1 - s_m)\frac{c_m}{q_{m,+1}}\right].$$

As we are mainly interested in the long-run effect of routine-biased technical change on the economy and on the wage bargaining regimes, we focus on the steady state of the economy. The steady state job creation conditions are given by

$$\frac{c_a}{q_a} = \beta \left[p_{Z_a} - \mathbb{1}_u w_a^u - (1 - \mathbb{1}_u)\, w_a^n + (1 - s_a) \frac{c_a}{q_a} \right], \tag{B.1}$$

$$\frac{c_r}{q_r} = \beta \left[p_{Z_r} \overline{y_r} - \mathbb{1}_u \overline{w_r^u} - (1 - \mathbb{1}_u)\, \overline{w_r^n} + (1 - s_r) \frac{c_r}{q_r} \right], \tag{B.2}$$

$$\frac{c_m}{q_m} = \beta \left[p_{Z_m} - \mathbb{1}_u w_m^u - (1 - \mathbb{1}_u)\, w_m^n + (1 - s_m) \frac{c_m}{q_m} \right]. \tag{B.3}$$

A firm hires workers of each type and each ability level η until the costs of labor are equal to the discounted expected marginal product. Here the costs consist of the vacancy posting costs and the discounted expected wage minus the discounted cost of hiring next period.

Appendix C. Derivation of Wages

This section derives the non-union wages in the model. The first order conditions are given by

$$W_i^n(\eta) - U_i(\eta) = \frac{\gamma^i}{1 - \gamma^i} J_i^n(\eta),$$
$$\text{with } i = a, r, m.$$

Abstract Workers

After replacing the value function, the Nash sharing rule for abstract workers is given by

$$
\begin{aligned}
&w_a^n + \beta\left[(1-s_a)W_a^n + s_a U_a\right] - z_a(\eta) - \beta[(1-f_a)U_a^n + f_a W_a^n\} \\
&= \frac{\gamma^a}{1-\gamma^a}\left[p_{Z_a} - w_a^n + (1-s_a)\beta J_a^n\right].
\end{aligned}
$$

After some rearrangement, we have

$$
\begin{aligned}
w_a^n &= \gamma^a p_{Z_a} + (1-\gamma^n) z_a(\eta) + \gamma^a (1-s_a)\beta J_a^n \\
&\quad + (1-\gamma^a)\beta\left[f_a\left(W_a^n - U_a^n\right) - (1-s_a)\left(W_a^n - U_a^n\right)\right].
\end{aligned}
$$

By using the job creation condition (B.1) and $\frac{c_a}{q_a)} = \beta J_{a,+1}^n$ as well as the first order condition resulting from the Nash sharing rule:

$$
(1-\gamma^a)\left(W_a^n - U_a^n\right) = \gamma^a J_a^n = \gamma^a \frac{c_a}{\beta q_a}
$$

we obtain the following wage equation

$$
w_a^n = \gamma^a p_{Z_a} + \gamma^a c_a \theta_a + (1-\gamma^a) z_a(\eta).
$$

Routine Workers

After replacing the value function, the Nash sharing rule for routine workers of ability level η is given by

$$
\begin{aligned}
&w_r^n(\eta) + \beta\left[(1-s_r)W_r^n(\eta) + s_r U_r(\eta)\right] - z_r(\eta) - \beta[(1-f_r)U_r^n(\eta) + f_r W_r^n(\eta)\} \\
&= \frac{\gamma^r}{1-\gamma^r}\left[p_{Z_r} y_r(\eta) - w_r^n(\eta) + (1-s_r)\beta J_r^n\right].
\end{aligned}
$$

After some rearrangement, we have

$$
\begin{aligned}
w_r^n(\eta) &= \gamma^r p_{Z_r} y_r(\eta) + (1-\gamma^r) z_r(\eta) + \gamma^r (1-s_r)\beta J_r^n \\
&\quad + (1-\gamma^r)\beta \left[f_r \left(W_r^n(\eta) - U_r^n(\eta) \right) - (1-s_r) \left(W_r^n(\eta) - U_r^n(\eta) \right) \right].
\end{aligned}
$$

By using the job creation condition (B.2) and $\frac{c_r}{q_r(\eta)} = \beta J_r^n(\eta)$ as well as the first order condition resulting from the Nash sharing rule:

$$
(1-\gamma^r)\left(W_r^n(\eta) - U_r^n(\eta) \right) = \gamma^r J_r^n(\eta) = \gamma^r \frac{c_r}{\beta q_r}
$$

we obtain the following wage equation

$$
w_r^n(\eta) = \gamma^r p_{Z_r} y_r(\eta) + \gamma^r c_r \theta_r + (1-\gamma^r) z_r(\eta).
$$

Manual Workers

After replacing the value function, the Nash sharing rule for manual workers is given by

$$
\begin{aligned}
& w_m^n + \beta \left[(1-s_m) W_m^n + s_m U_m \right] - z_m(\eta) - \beta [(1-f_m) U_m^n + f_m W_m^n \} \\
&= \frac{\gamma^m}{1-\gamma^m} \left[p_{Z_m} - w_m^n + (1-s_m)\beta J_m^n \right].
\end{aligned}
$$

After some rearrangement, we have

$$
\begin{aligned}
w_m^n &= \gamma^m p_{Z_m} + (1-\gamma^m) z_m(\eta) + \gamma^m (1-s_m)\beta J_m^n \\
&\quad + (1-\gamma^m)\beta \left[f_m \left(W_m^n - U_m^n \right) - (1-s_m) \left(W_m^n - U_{m,+1}^n \right) \right].
\end{aligned}
$$

By using the job creation condition (B.3) and $\frac{c_m}{q_m)} = \beta J_m^m$ as well as the first order condition resulting from the Nash sharing rule:

$$(1-\gamma^m)(W_m^n - U_m^n) = \gamma^m J_m^n = \gamma^m \frac{c_m}{\beta q_m}$$

we obtain the following wage equation

$$w_m^n = \gamma^m p_{Z_m} + \gamma^m c_m \theta_m + (1-\gamma^m) z_m(\eta).$$

Appendix D. Union Surplus

This section derives the union surplus. The first order condition in the collective bargaining problem is given by

$$\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) \left[W_i^u(\eta) - W_i^{u,s}(\eta)\right] \mathrm{d}\eta$$
$$= \frac{\gamma^u}{1-\gamma^u} \sum_i \left\{ p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta \right\},$$

with $i = r, m$.

After replacing the value function and using the job creation conditions (B.1) - (B.3), the Nash sharing rule is given by

$$\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) \left[w_i^u(\eta) - w_i^{u,s}(\eta)\right] \mathrm{d}\eta$$
$$= \frac{\gamma^u}{1-\gamma^u} \sum_i \left\{ p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta \right\}.$$

After some rearrangement, we have

$$\gamma^u \sum_i \left(p_{Z_i} Z_i - p'_{Z_i} Z'_i\right) + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u,s}(\eta)\, \mathrm{d}\eta$$
$$= \gamma^u \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u}(\eta)\, \mathrm{d}\eta + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u}(\eta)\, \mathrm{d}\eta.$$

Thus, the total union surplus is given by

$$S^u = \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u}(\eta)\, \mathrm{d}\eta$$
$$= \gamma^u \sum_i \left(p_{Z_i} Z_i - p'_{Z_i} Z'_i\right) + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u,s}(\eta)\, \mathrm{d}\eta$$

with $i = r, m$.

Appendix E. A Union for Astract Workers

In this section we introduce a union for abstract workers into the model setup described in Section 4. As stated in Section 3, the NLRB stipulates that abstract workers are excluded from bargaining units with manual and routine workers. Thus, in the extended model there will be two potential unions on each island – one for manual and routine workers, and one for abstract workers. The rest of the model setup is left unchanged and the collective wage bargaining described in Subsection 4.4 also applies to the unions for abstract workers.

It follows that the total surplus of the abstract union is given by

$$S_a^u = \gamma_a^u \left(p_{Z_a} Z_a - p'_{Z_a} Z'_a\right) + (1-\gamma_a^u) L_a w_a^{u,s},$$

where γ_a^u is the bargaining power of the potential union. As for the union for manual and routine workers, we assume that the union for abstract workers pays the same wage rate for all covered workers. Union wages for abstract workers are therefore given by

$$w_a^u = \frac{S_a^u}{L_a},$$

and abstract workers vote in favor of a union whenever the value of being a union member is larger than the value of being a non-union worker.

The bargaining power of the potential unions for abstract workers is equally distributed across islands. The upper bound of the union bargaining power interval is set to one. The lower bound is calibrated to 0.834, to match the abstract union membership rate in 1983.[59]

The change in the union membership rate between 1983 and 2005 is reported in Table E.5.[60] In the data, the union membership rate for abstract workers drops by 1.8 percentage points from 10.7% to 8.5%. In the model, the membership rate drops by 1.1 percentage points from 10.7% to 9.6%. Both in the model and in the data, the union membership rate for abstract workers decreases by less than the membership rates for manual or routine workers.

The higher marginal productivity of abstract workers due to technical

[59]We choose 1983 instead of 1977 here, as occupational data is only available from the U.S. union database by Hirsch and Macpherson (2003) from 1983 onwards. Following Autor and Dorn (2013), we classify workers in management, business, and financial, as well as in professional, technical and related occupations as abstract workers.

[60]As the presence of a union for abstract workers does neither affect the occupational nor the union membership decision of non-abstract workers, we only focus on the union membership rate of abstract workers in this section.

Table E.5: Declining Union Membership Rates for Abstract Workers: Model versus Data

Union Membership	Data 1983	Model 1983	Data 2005	Model 2005
Abstract Workers	10.7%	10.7%	8.5%	9.6%

Note: Data for the union membership rates are taken from the U.S. union database constructed by Hirsch and Macpherson (2003). Workers in management, business, and financial, as well as in professional, technical and related occupations are classified as abstract workers.

change effects union and non-union wages for these workers similarly. However, under individual bargaining the higher demand for abstract workers increases the cost of hiring a worker in the next period. The outside option under collective bargaining, e.g. a strike of abstract workers, is associated with the same costs as before. Thus, the incentives to unionize decrease slightly for abstract workers, but by less compared to manual and routine workers.

Appendix F. Decomposition Analysis of Deunionization

In this section we apply the methodology used in, among others, Baldwin (2003) to decompose changes in union membership rates to occupations. We use this decomposition to assess the relative importance of each component for deunionization.

The within-occupation component measures the effect of a change in the membership rate for a specific occupational group, keeping the employment share of that group constant. The between-occupation component measures the effect of a change in the employment share of a specific occupational group, keeping the membership rate constant. Summing up both components over all occupational groups yields the estimated overall change in the union membership rate.

Table F.6: CHANGES UNION MEMBERSHIP RATES – DATA, 1983 – 2005

	Percentage Point	Share
Total Change	-11.01	100%
Within-occupations	-8.93	81.11%
Between-occupations	-2.08	18.89%

Note: Data for occupational employment shares and union membership rates are taken from the U.S. union database constructed by Hirsch and Macpherson (2003).

For the estimation we use data on occupation specific union membership rates provided in the U.S. union database described in Hirsch and Macpherson (2003). Occupations are classified into six major occupational groups: management, business, and financial; professional, technical and related; service; sales and related; construction and extraction; production; transportation and material moving. As occupation specific data is only available from 1983 onwards in the U.S. union database, we calculate the within- and between-occupations components for the time period between 1983 and 2005.

Table F.7: CHANGES UNION MEMBERSHIP RATES – MODEL, 1983 – 2005

	Percentage Point	Share
Total Change	-11.89	100%
Within-occupations	-10.3	86.63%
Between-occupations	-1.59	13.37%

Note: Data for occupational employment shares and union membership rates are taken from the U.S. union database constructed by Hirsch and Macpherson (2003).

81.1% of the changes in union membership rates are due to the within-occupational changes in unionization rates, while only 19.9% are due to changes in employment shares. We use the same methodology to calculate the within-occupations and between-occupations component for the three occupations in our model. In line with the data, 83% of the changes in union membership rates between 1983 and 2005 are driven by the within-occupations component.

Appendix G. Theoretical Evaluation of the Main Mechanisms

The arguments in this section proof Propositions 1 and 2, which state the main mechanisms in our paper. Appendix G.1 and Appendix G.2 provide interim results necessary for the proofs.

Appendix G.1. Employment Changes

This subsection establishes that in the absence of occupational switches, steady state employment levels for manual and routine workers stay constant over time in our model.

First, note that the model is calibrated to match abstract and non-abstract employment in 1977 and in 2005. Since non-abstract employment has been approximately constant over this time period, our calibration targets imply that $L_m + L_r$, the sum of employed manual and routine workers, is constant over the simulation period. Together with constant labor supply, this connotes that $u_m + u_r$, the sum of unemployed manual and routine workers, is also constant over time.

Second, in the steady state both conditions for the evolution of employment, $s_m L_m = h_m u_m$ and $s_r L_r = h_r u_r$, hold. Third, if there are no occupational switches, labor supply is also constant for each occupational group. This implies that $L_m + u_m$ and $L_r + u_r$ are constant over time.

Thus, if we assume that there are no occupational switches, we have a linear system of six equations to determine six steady state values. It immediately follows that there is a unique solution and employment levels for manual and routine workers are constant over time.

Appendix G.2. Occupational Switches

The previous subsection established that employment levels of manual and routine workers in our model are constant in the absence of occupational switches. In this subsection we deduce the range of union wage schedules under which there are no occupational switches (and therefore constant employment levels of manual and routine workers) in unionized firms.

Keep in mind that occupational switches occur whenever $U_r(\eta) < U_m(\eta)$, e.g. whenever the value of being an unemployed manual worker of ability η is larger than the value of being an unemployed routine worker of ability η. As long as union wages for routine workers are at least as high as union wages for manual workers, routine workers only have an incentive to switch occupations upon becoming unemployed when the job-finding rate for manual workers is sufficiently large compared to the job-finding rate of routine workers.

To asses the effect of an increase in union wages on the job-finding rates, we solve the job creation conditions of manual (B.3) and routine (B.2) workers for θ. For manual workers this gives

$$\theta_m = \left[\frac{(\frac{1}{\beta} - (1 - s_m))c_m}{\Psi(p_{Z_m} - w_m^u)}\right]^{\frac{1}{\psi - 1}}.$$

Next we calculate the elasticity of the job-finding rate for manual workers with respect to changes in the union wage of manual workers as

$$\epsilon^{f_m}_{w^u_m} = \epsilon^{f_m}_{\theta} \epsilon^{\theta_m}_{w^u_m} = -\frac{\psi}{\psi - 1} \frac{1}{\left(\frac{p_{Z_m}}{w^u_m} - 1\right)}.$$

Analogously, the elasticity of the job-finding rate for routine workers with respect to changes in the union wage of routine workers is

$$\epsilon^{f_r}_{w^u_r} = -\frac{\psi}{\psi - 1} \frac{1}{\left(\frac{p_{Z_r}\overline{y_r}}{w^u_r} - 1\right)}.$$

For both manual and routine workers, the effect of an increase in union wages on the job-finding rate is larger, the smaller the difference between marginal productivity and wages becomes.[61]

Under the calibration in Section 6, $\epsilon^{f_m}_{w^u_m} \approx \epsilon^{f_r}_{w^u_r} \approx -7$. Thus, a union wage premium of, for example, 5% decreases the job-finding rate of manual and routine workers by 35%. First, this implies that even a very small union wage premium might have large effects on the job-finding rate. Second, and of higher importance for the argument here, this implies that the effect of an increase in union wages is very similar for manual and for routine workers.

Finally, in the calibrated model the job-finding rates for manual and routine workers in non-unionized firms are basically identical. Taken together, this means that as long as union wages for routine workers are at least as large as union wages for manual workers, and the average union wage premium for routine workers is not larger than the average union wage premium for man-

[61] This holds as long the marginal productivity of a worker is larger than the wage.

ual workers, there will be no occupational switches and thus no employment changes in unionized firms.

Appendix G.3. Polarization

Routine-biased technical change is modeled as a drop in p_k, the relative price of computer capital. As we are concerned with the incentives of previous routine workers to switch to manual occupations, we consider the effects of a decrease in p_k before any switches occur. Thus, L_a, L_r, and L_m are constant.

Note, that the decrease in the relative price only affects the intermediate firm producing Z_r directly. From the first order condition with respect to computer capital

$$\frac{\partial Z_r}{\partial K} = \mu^\sigma \left[\left(\frac{1-\mu}{k} \right)^\sigma + \mu^\sigma \right]^{\frac{1}{\sigma}-1}$$

it follows that K increases if and only if computer capital and workers performing routine tasks are substitutes, e.g. if $\sigma > 0$.[62] The increasing computer capital stock increases production of the intermediate good Z_r.

Keep in mind that a previous routine worker switches occupations if $U_m(\eta) > U_r(\eta)$. Thus, given that unemployment benefits and separation rates are not affected by the drop in capital prices, the two variables driving changes in the incentives are wages and job-finding rates. From the wage equations and job creation conditions for both types of occupations it immediately follows that both variables of interest are driven by changes in the marginal productivity of the respective workers.

[62]Since the computer capital stock can be adjusted instantaneously and without frictions, an increase in K before occupational switches occur is in line with the model setup.

As the relevant elasticities (the elasticity of the wage with respect to productivity and labor market tightness, and the elasticity of the job-finding rate with respect to productivity and wages) are identical for both types of occupations, it remains to show that the marginal productivity of manual workers increases by more compared to the marginal productivity of routine workers due to routine-biased technical change.

The relative marginal productivity of routine workers compared to manual workers is given by

$$\frac{p_{Z_r} y_r(\eta)}{p_{Z_m}} = \eta(1-\alpha)(1-\mu)^{\sigma} \left(\frac{A^{1+\frac{1}{\rho}}}{A_m} \right)^{\rho} \left(\frac{Z_a^{\frac{\alpha\rho}{\rho-1}}}{Z_m} \right)^{\rho-1} \left((1-\mu) \int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta) \, \mathrm{d}\eta \right)^{\sigma-1} Z_r^{(1-\alpha)\rho-\sigma}.$$

Thus, the relative productivity of routine workers decreases in Z_r, if $\sigma > (1-\alpha)\rho$, which proofs Proposition 1. Intuitively, in order for routine-biased technical change to increase the incentives for occupational switches, capital and routine tasks need to be substitutes and they need to be better substitutes than routine and manual tasks in the production of the final good.

Appendix G.4. Voting Incentives

A manual worker inside a unionized firm votes in favor of collective bargaining coverage, if the value of being a manual worker in a unionized firm is larger than the value of being a worker in a non-unionized firm, e.g. if $W_m^u > W_m^n$. As in Appendix G.3, the relevant variables are again the wages and the job-finding rates. As the marginal productivity of a manual worker is independent of the union status of the firm, relative changes in the job-finding rates are entirely driven by relative wage changes. Thus, it suffices to show that the non-union wage rate for manual workers increases relative to the union wage rate.[63]

Using the equation for the union surplus (5), the union wage schedule (4), and the non-union wage for manual workers (3), the relative union wage for a manual worker is given by[64]

$$\frac{w_m^u}{w_m^n} = \frac{\left[\gamma^u(p_{Z_m}Z_m - p'_{Z_m}Z'_m) + \gamma^u(p_{Z_r}Z_r - p'_{Z_r}Z'_r)\right]/(L_m + L_r)}{\gamma^m p_{Z_m} + \gamma^m c_m \theta_m}.$$

Using the production functions, this expression can be rewritten as

$$\frac{w_m^u}{w_m^n} = \frac{\left[\gamma^u p_{Z_m}Z_m\right]/(L_m + L_r)}{\gamma_m p_{Z_m} + \gamma_m c_m \theta_m} + \frac{\left[\gamma^u(p_{Z_r}Z_r - p'_{Z_r}Z'_r)\right]/(L_m + L_r)}{\gamma_m p_{Z_m} + \gamma_m c_m \theta_m}. \quad \text{(G.1)}$$

First, following the arguments in Appendix G.3, routine-biased technical change implies an increase in Z_r and thus an increase in the marginal productivity of manual workers, p_{Z_m}. Second, note that the effect of routine-biased technical change on the first term only depends on the elasticity of this term with respect to p_{Z_m}. Combining the job creation condition (B.3) and the wage for manual workers (3) yields

$$((1/\beta) - 1 + s_m)c_m\Psi_m\theta_m^\eta + c_m\gamma^m\theta_m = (1-\gamma^m)p_{Z_m}.$$

[63]Note, that the positive effect of a wage increase on the value function is not offset by a decrease in the job-finding rate.

[64]Since w_i^u and $z_i(\eta)$ are both unaffected by routine-biased technical change and set to zero in the simulation, they are left out in order to facilitate representation.

From this expression it is easy to see that the elasticity of θ_m with respect to p_{Z_m} is larger than one. Next, we use that for two functions f and g the elasticity of $(g+f)$ is given by $\epsilon_{f+g} = \frac{f\epsilon_f + g\epsilon_g}{f+g}$ to establish that the elasticity of the non-union wage of manual workers is larger than one. As L_m is constant in unionized firms, this directly implies that the first term of equation (G.1) decreases in p_{Z_m}.

Intuitively, routine-biased technical change increases the productivity of and therefore the demand for manual workers. The non-union wage for manual workers increases as both the productivity and the labor market tightness increase. The union wage for manual workers increases by less, as the different outside options in the two bargaining regimes imply that the greater labor market tightness does not affect the collective bargaining.

For the second term in equation (G.1), note that

$$\frac{Z_r}{Z_r'} = \left[1 + \left(\frac{(1-\mu)\int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta)\,\mathrm{d}\eta}{\mu K}\right)^{\sigma}\right]^{\frac{1}{\sigma}}.$$

Thus, an increase in K due to routine-biased technical change reduces $\frac{Z_r}{Z_r'}$. After some rearrangement, $\frac{p_{Z_r} Z_r}{p'_{Z_r} Z' r}$ is given by

$$\frac{p_{Z_r} Z_r}{p'_{Z_r} Z_r'} = \frac{[(AZ_a^{\alpha} Z_r^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho} - 1}{[(AZ_a^{\alpha} (Z_r')^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho - 1}} \left(\frac{Z_r}{Z_r'}\right)^{(1-\alpha)\rho}.$$

Thus, using that $\frac{Z_r}{Z_r'}$ decreases with K, it is straightforward to show that an increase in K reduces $\frac{p_{Z_r} Z_r}{p'_{Z_r} Z' r}$ if routine and manual tasks are substitutes, e.g. if $\rho > 0$.

Taken together, routine-biased technical change reduces the union wage of manual workers relative to the non-union wage of manual workers, if $\rho > 0$. This proofs Proposition 2. Note, that the provided proof holds if we exchange the union wage of manual workers for the union surplus. Thus, as long as the union wage schedule is steady over time and satisfies the conditions in Appendix G.2, the mechanism driving deunionization in our model holds.

Appendix H. Steady State Equations

This section lists the equations used to calculate the steady state of the model economy.

$$Y = [(AZ_a^{\alpha} Z_r^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho}$$

$$Z_a = L_a$$

$$Z_r = \left[\left((1-\mu) \int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta) \, \mathrm{d}\eta \right)^{\sigma} + (\mu K)^{\sigma} \right]^{\frac{1}{\sigma}}$$

$$Z_m = L_m$$

$$s_i L_r = q_i v_i$$

with $i = a, r, m$

$$p_{Z_i} = \frac{\partial Y}{\partial Z_i}$$

with $i = a, r, m$

$$p_K = \frac{\partial Z_r}{\partial K}$$

$$\frac{c_a}{q_a} = \beta \left[p_{Z_a} - \mathbb{1}_u w_a^u - (1 - \mathbb{1}_u)\, w_a^n + (1 - s_a) \frac{c_a}{q_a} \right]$$

$$\frac{c_r}{q_r} = \beta \left[p_{Z_r} \overline{y_r} - \mathbb{1}_u \overline{w_r^u} - (1 - \mathbb{1}_u)\, \overline{w_r^n} + (1 - s_r) \frac{c_r}{q_r} \right]$$

$$\frac{c_m}{q_m} = \beta \left[p_{Z_m} - \mathbb{1}_u w_m^u - (1 - \mathbb{1}_u)\, w_m^n + (1 - s_m) \frac{c_m}{q_m} \right]$$

$$w_a^n = \gamma^a p_{Z_a} + \gamma^a c_a \theta_a$$

$$w_r^n(\eta) = \gamma^r p_{Z_r} y_r(\eta) + \gamma^r c_r \theta_r$$

$$w_m^n = \gamma^m p_{Z_m} + \gamma^m c_m \theta_m$$

$$y_r(\eta) = \frac{\partial Z_r}{\partial L_r(\eta)}$$

$$f_i = \Psi_i \theta_i^{\psi}$$
$$\text{with } i = a, r, m$$

$$W_m^n = W_r^n(\eta_m)$$

$$Y = \sum_i w_i L_i + \sum_i c_i v_i + \Gamma$$

with $i = a, r, m$

$$S^u = \gamma^u \sum_i (p_{Z_i} Z_i - p'_{Z_i} Z'_i)$$

with $i = r, m.$

$$w^u = S^u / (L_m + L_r)$$

$$W_m^u = W_m^n(\eta_{low}^u)$$

$$W_r^u = W_r^n(\eta_{high}^u) \text{ or } W_m^u = W_m^n(\eta_{high}^u)$$