Firm Hiring Behavior in a Polarizing Labor Market

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April 24, 2014

PRELIMINARY AND INCOMPLETE
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Abstract

In recent decades, the U.S. labor market has experienced a disappearance of middle-skilled jobs as innovations in technology allow firms to shift production away from these workers towards capital or cheaper labor abroad. To better understand the implications of this polarization on aggregate conditions of the labor market, I develop an equilibrium search and matching model where firms take into account the comparative advantage of workers for a particular task. Specifically, there are three types of workers, low-, middle-, and high-skilled, and a continuum of firms that vary in the complexity of the task that needs to be completed to generate positive production. The key difference in my model is that firms are selective in their hiring decision. In particular, they post vacancies that can only be filled by a certain type of worker. Thus, the firms are able to direct their hiring efforts by varying the distribution of vacancies across worker types, allowing them to directly manipulate the effective match probabilities. Given this setup, it is now possible to analyze how the hiring decisions of firms change as middle-skilled workers lose their comparative advantage in production. After calibrating the model to the U.S. economy, I find that when the comparative advantage of high-skilled workers over middle-skilled workers increases and the comparative advantage of middle-skilled workers over low-skilled workers decreases, the distribution of vacancies posted for middle-skilled workers shifts towards less complex tasks. Not only does this polarize the skill composition of jobs, but the aggregate unemployment rate and wage inequality increase.

*I greatly appreciate the advice and support of John M. Abowd, Karel Mertens, and Victoria Prowse. All mistakes herein are my own. Contact: nlz6@cornell.edu

1 Introduction

Over the last several decades, a vast literature has developed documenting the changes in the distribution of earnings and the returns to college in the United States. It started with the observation that the returns to skill, usually measured by the relative wages of college graduate workers to high school graduates, has shown a tendency to increase over multiple decades despite the large secular increase in the relative supply of college educated workers.[1] Many researchers believe that this has been a result of the demand of skilled labor increasing faster than supply, resulting in a sharp rise in the inequality of wages.

While this rising inequality in wages is still quite evident, the change has been notably non-monotone. Specifically, over the last two decades, the growth of wages by earnings percentile has been U-shaped, or polarized, indicating a simultaneous growth of high and low wages relative to the middle.[2] A second, more recent trend, is the polarization of employment opportunities in the United States. The expanding job opportunities in both high-skill, high-wage occupations and low-skill, low-wage occupations has been coupled with the contracting opportunities in middle-wage, middle-skill white-collar and blue-collar jobs.[3] Specifically, as noted by Autor (2010), employment and earnings are rising in both high-education professional, technical, and managerial occupations and, since the late 1980s, in low-education food service, personal care, and protective service occupations. Conversely, job opportunities are declining in both middle-skill, white-collar clerical, adminitrative, and sales occupations and in middle-skill, blue-collar production, craft, and operative occupations. The literature has identified the following culprits responsible for this hollowing out of the middle: changes in technology, international trade, and the international offshoring of jobs.[4] All of these factors affect the availability of employment opportunities and the demand for skilled workers.

The objective of this paper is to analyze the mechanism through which changes in comparative advantages of different types of workers affects the hiring behavior of firms that ultimately results in job polarization. I find that this change in technology will cause workers to shift their hiring effor from middle-skilled workers to the tails. This hollowing out of the types of employment opportunities available in the labor market is what will result in job polarization. Unemployment among middle-skilled workers will increase, and since these workers account for a little over 50% of employment, the overall unemployment rate will also rise. While the analysis here will focus on a steady state equilibrium, understanding how job polarization is linked to unemployment can help shed light on the recent sluggish recoveries researchers have observed after recent recessions. Figure 1 plots the unemployment rate before and after the end of recent recessions, highlighting the jobless recovery phenomenon that has characterized the last three downturns. Specifically, in

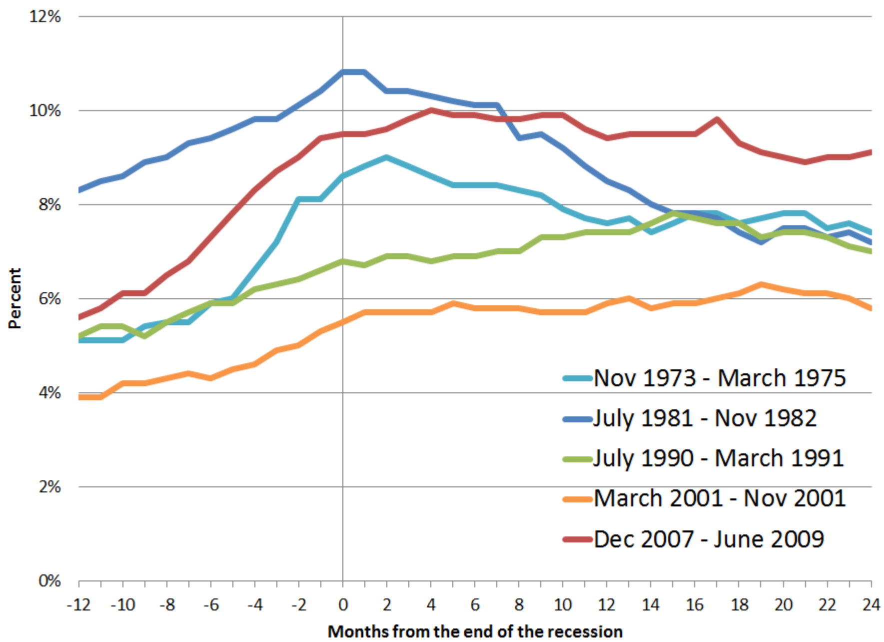
[1] See, for example, Davis (1992); Katz and Murphy (1992); Autor, Katz and Krueger (1998); Card and Lemieux (2001).

[2] See, for example, Autor, Katz and Kearney (2006, 2008).

[3] See Autor, Katz and Kearney (2006, 2008); Autor (2010); and Acemoglu and Autor (2011).

[4] See Autor, Katz and Kearney (2006, 2008); Autor, Dorn and Hanson (2013); Acemoglu, Gancia and Zilibotti (2012); Krugman (2008); Autor (2010); Acemoglu and Autor (2011).

Figure 1: Unemployment Rates after Recent Recessions



Source: Bureau of Labor Statistics, series LNS14000000

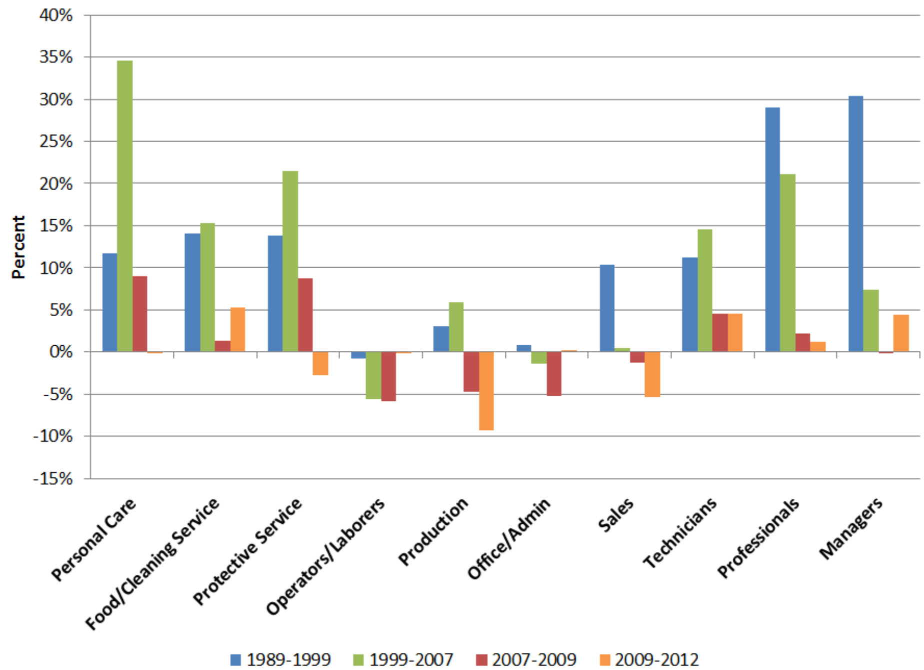
the 1973 and 1981 recessions, the unemployment rate steadily falls as the economy is in recovery. However, in the 1990, 2001, and 2007 recessions, the unemployment rate stays persistently high, even increasing, months after the end of the recession. Further, as seen in figure 2, the middle-skill occupations were hit particularly hard in the Great Recession.

The remainder of the paper is organized as follows. Section 2 looks at the recent literature on the polarization of the labor market. Section 3 presents the model. Section 4 goes over how the parameters of the models will be calibrated. Section 5 presents the estimated steady state and analyzes how the equilibrium changes under job polarization. Finally, section 6 concludes.

2 Related Literature

Since the 1990s, the U.S. labor market that has seen a disappearance of jobs traditionally held by middle-skilled workers. During the 1980s, employment growth by occupation is approximately monotone in skill level with occupations below the median skill level declining as a share of employment and those above the median rising as a share of employment. However, in the subsequent decade, this monotone relationship gave way to a distinct pattern of polarization: relative employment growth was most rapid for high-skill occupations, modestly positive for low-skill occupations, and modestly negative for middle-skill occupations. But, in the most recent decade, employment growth was heavily concentrated among the low-skill occupations, while it was negative for the middle-skill occupations. Thus, the disproportionate growth of low education, low-wage occupa-

Figure 2: Employment Growth by Occupational Groups



Source: Current Population Survey, March Supplement, 1989-2012

tions became evident in the 1990s and accelerated thereafter.

Using data from the Current Population Survey (CPS) March Supplement from 1989-2012, I classify employment into 10 major occupational groups encompassing all U.S. non-agricultural employment as in Acemoglu and Autor (2011).[5] Figure 2 plots the percentage point changes in employment levels for various time intervals. The 10 occupations divide neatly into three groups, with task complexity generally increasing as one moves right along the horizontal axis. The first three columns depict employment trends in service occupations: protective services, food preparation and cleaning services, and personal care. The majority of workers in service occupations have no post-secondary education. Further, the average hourly wages in service occupations are in most cases below the other seven occupations categories. The next four columns display employment growth in "middle-skill occupations:" sales; office and administrative support; production, craft, and repair; and operator, fabricator, and laborer. The first two are middle-skilled, white-collar occupations that are disproportionately held by women with a high school degree or some college. The latter two categories are a mixture of middle- and low-skilled blue-collar occupations that are disproportionately held by males with a high school degree or lower education. The last three columns are highly educated and highly paid occupations: managers, professionals, and technicians.

Cumulatively, the rapid employment growth in both low and high education jobs have substantially reduced the share of employment accounted for by middle-skill workers. In other words,

[5]See appendix section A for specific details of what occupations are encompassed in each group.

while the number of people employed in these middle-skill occupations rose in each period between 1989-2007, their growth rate lagged the economy-wide average and generally slowed across decades. These occupations were hit particularly hard during the 2007-2009 recession, with absolute declines in employment ranging from 7% to 17%. In contrast, the employment growth in low- and high-skill occupations has been robust throughout the three decades. In particular, despite their low educational requirements and low pay, employment growth in service occupations has been relatively rapid over the past three decades. Even in the deep recession of 2007 through 2009, during which the number of employed U.S. workers fell by approximately 8 million, low- and high-skill occupations experienced almost no absolute decline in employment. Notably, employment growth in service occupations during the Great Recession was modestly positive—more so, in fact, than the three high-skilled occupations. Thus, while the Great Recession dramatically reduced overall employment in the U.S. economy, it did not fundamentally change the trend of job polarization prevailing throughout this period.

Autor, Levy and Murnane (2003) link job polarization to rapid improvements in the productivity and the decline in the real price of information and communications technologies. They emphasize that the impacts of this technological innovation are two-fold. First, the rapid, secular price decline in the real cost of computing technology creates enormous incentives for employers to substitute expensive labor with information technology for certain workplace tasks. Simultaneously, it creates significant advantages for workers whose skills are complementary to these new innovations. However, as powerful as computers are, they cannot replace all workers. Autor, Levy and Murnane (2003) note that computers are particularly well-suited to replace what they call "routine" tasks: tasks that are highly procedural and rule-based. Routine tasks are characteristic of many middle-skilled jobs, such as book-keeping, clerical work, repetitive production, and monitoring jobs. Acemoglu and Autor (2011) conclude that the substantial declines in clerical and administrative occupations are likely a consequence of the falling price of machine substitutes for these tasks. The process of automation and offshoring of routine tasks, in turn, raises relative demand for workers who can perform complementary non-routine tasks. Thus, the displacement of jobs that are intensive in routine tasks may have contributed to the polarization of employment by reducing job opportunities in middle-skilled clerical, administrative, production and operative occupations. Jobs that are intensive in either non-routine abstract or non-routine manual tasks, however, are much less susceptible to this process due to the demand for problem-solving, judgment and creativity in the former case, and flexibility and physical adaptability in the latter. Since these jobs are found at opposite ends of the occupational skill spectrum, the consequence may be a partial "hollowing out" of employment opportunities.

Jaimovich and Siu (2012), motivated by the same empirical evidence that middle-skill occupations were particularly hard hit in this last recessions, analyze the link between job polarization and jobless recoveries. Specifically, they extract the cyclical component of aggregate per capita employment for each of the three occupational groups (non-routine manual, routine, and non-routine cognitive) and find that during the recessions of the 1970s and 1980s, while routine occupations did experience clear contractions in these downturns, they made full recoveries. On the other hand, in the last three recessions, no severe contractions were observed, but the routine occupations show no recoveries. The authors develop a Diamond-Mortensen-Pissarides search and matching model with occupational choice and learning-by-doing. In their model, there are three types of workers: high-skilled, middle-skilled, and low-skilled. When the middle-skilled workers are confronted with routine-biased technological innovation, they are faced with the following decision as they exit the routine market: (i) enter the switching market where, if they are employed for one period, learn to be a high-skilled worker or (ii) enter the low-skill market. They find that not only can this model generate jobless recoveries, but also that a recession accelerates polarization. Unlike the model in Jaimovich and Siu (2012) that generates job polarization through workers' decision to obtain skills, I focus on the firms' vacancy posting and hiring behavior. It is the firms that are adopting new technologies and substituting away from workers. Thus, understanding the link between technological innovations, changes in labor demand, job polarization, and unemployment is important.[6]

3 Task-Based Search and Matching

In this section, I develop a model of random search with heterogeneous workers and firms and on-the-job search to analyze the impact of job polarization on the aggregate labor market. Using the sequential auction search and matching model of Postel-Vinay and Robin (2002) as a starting point, this model extends the theory to allow for a hiring decision of the firm that takes into account the comparative advantages of each worker's type. Specifically, I extend their model to include the task-based framework of Acemoglu and Autor (2011), where any type of worker can complete any type of task. However, it is the comparative advantage of a worker in completing a task of a certain complexity that determines what workers are assigned to which tasks.

3.1 The Environment

Assume that time is discrete and that all agents are risk neutral and live forever, discounting the future at a rate r. Workers and firms are heterogeneous with i denoting the type of the worker and j denoting the type of the firm. To better understand the direct consequences of job polarization on the conditions of the aggregate labor market, the analysis will focus on the steady state equilibrium.

[6] Katz (2010) notes that firms appear to increasingly use downturns to improve organizational efficiency and productivity. This reduces the need to hire new workers for some time. Daly, Hobijn and Kwok (2009) notice a change in the cyclicality of the inflow rate—the pace at which workers move into unemployment—and the outflow rate—the pace at which they move out of unemployment. Flow behavior changed noticeably in the 1990 and 2001 recessions. During both of these recessions, the main factor behind the rising unemployment rate was a decline in the outflow rate. Further, as the economy moved into recovery, the outflow rate stayed persistently low, moving back to its normal pre-recessionary levels relatively slowly. This dominance of the outflow rate is noted by Hall (2005) and ?Shimer (2012).

Workers Consider an economy populated by a continuum of workers, who differ by skill level. Assume that there are three types of workers: low-skilled (L), middle-skilled (M) and high-skilled (H) workers. Let π^i denote the proportion of workers of type i, where $\pi^i \geq 0$ and $\pi^L + \pi^M + \pi^H = 1$.

Workers can either be unemployed or matched to a firm and producing. When unemployed, workers receive unemployment benefit b^i. Let u^i be the measure of type i workers who are unemployed, where $i \in \{L, M, H\}$. Then the total measure of unemployed workers is:

$$u = \sum_i u^i \tag{1}$$

Both unemployed and employed workers participate in search, but with different degrees of search efforts.

Firms There is also a continuum of infinitely-lived, risk neutral firms. Firms are heterogeneous along a single dimension that is indexed by $j \in [0, 1]$. This index can be thought of as representing the complexity of a task that needs to be completed for production with higher j's representing more complex tasks. These firms have access to a production technology $y^i(j)$ and seek to maximize the discounted stream of expected profits. Each period, firms engage in recruiting new workers by posting vacancies $v^i(j)$ at convex flow recruiting cost $c(v^i(j))$. Notice that unlike other search and matching models, the firms here can direct their search efforts to a particular type of worker. In other words, a firm will choose the measure of vacancies to post to low-, middle-, and high-skilled workers and these will become productive matches only if they encounter the correct type. Firms can compete with other firms through Bertrand competition for workers who are already in a productive match. Thus, firms can both poach other workers with new vacancy postings and counter a current employee's outside offer to retain the match.

Matches Once a match (i, j) forms, a flow output of $y^i(j)$ is produced. For a firm j, any type of worker can be hired to complete the task and produce output. However the comparative advantage of skill groups differ across tasks. Specifically, I assume that productivity across skill types has the following structure:

$$\frac{\partial y^H(j)}{\partial j} > \frac{\partial y^M(j)}{\partial j} > \frac{\partial y^L(j)}{\partial j} \quad \forall j \in [0, 1] \tag{2}$$

In other words, there is positive assortative matching in the economy.

Matches are destroyed exogenously at a rate δ. The aggregate number of meetings between vacancies and searching workers is determined through a standard meeting function $M(\cdot, \cdot)$ that takes the total amount of effective job searchers and the total number of vacancies as inputs.

Total Surplus Let $W^i(w, j)$ be the value of being employed at wage w for a worker of type i at firm j. Let B^i denote the value of unemployment for a worker of type i. Let $\Pi^i(w, j)$ denote the expected profit to a firm j employing worker of type i at wage w. Assume free entry so the value of a vacancy to a firm is zero. Thus, total surplus of a match is defined as follows:

$$S^i(w,j) = W^i(w,j) - B^i + \Pi^i(w,j) \tag{3}$$

Under the assumption of transferable utility, the wage does not affect the size of the surplus: $S^i(w,j) \equiv S^i(j)$.

3.2 Wage Determination

Wage Negotiation with Unemployed Workers When an unemployed worker matches with a vacancy, the firm offers wage $w = \phi_0^i(j)$ such that the worker is made indifferent between taking the job and being unemployed:

$$W^i(w,j) - B^i = 0 \tag{4}$$

In other words, for new matches, the firm receives all of the surplus.[7]

Wage Renegotiation: Poaching Workers are allowed to search while employed and the incumbent employers respond to outside offers. Suppose the worker finds another match (i,j'). Depending the total surplus this new match can generate, the worker could have the opportunity to renegotiate his wage. There are three cases that need to be considered.

First, if the surplus of this new job is greater than his current job, $S^i(j') > S^i(j)$, the worker moves to the poaching firm and is paid a wage $w' = \phi_1^i(j',j) = \phi_1^i(j,j)$ such that

$$W^i(w',j') - B^i = S^i(j) \tag{5}$$

In other words, he is paid the wage that would make him indifferent between staying with his current employer j or moving to the new firm j'.

Second, if the surplus at the poaching firm is less than the surplus at his current employer but greater than the worker's value of the current job, $W^i(w,j) - B^i \leq S^i(j') \leq S^i(j)$, the worker will use the outside offer to negotiate up his wage to $w' = \phi_1^i(j,j') = \phi_1^i(j',j')$ such that

$$W^i(w',j) - B^i = S^i(j') \tag{6}$$

Once again, the worker is paid a wage that makes him indifferent between quitting and staying. In this case, it is the total surplus of the poaching firm. Notice that in the above two cases, the worker matches with the higher surplus job and uses the lower surplus job as the outside option

[7] This is equivalent to saying that the wage is determined through Nash bargaining with the worker's bargaining power set to zero. The model could be extended to allow for bargaining as in Cahuc, Postel-Vinay and Robin (2006).

when bargaining. This means that the worker will receive the entire surplus from the lower surplus match.

Lastly, if the surplus at the poaching firm is less than the worker's value of the current job, $S^i(j') < W^i(w,j) - B^i$, the worker does not have a credible threat to leave, so the wage does not change.

3.3 Labor Market Flows

Meeting Technology All workers participate in search with effort varying across employment states. Specifically, s_0 and s_1 are the relative search efforts of unemployed and employed workers, respectively. Together they produce effective search effort N. Further, firms post vacancies that aggregate to V.

$$N \equiv \sum_i \left[s_0 u^i + s_1 \int_0^1 n^i(j)\mathrm{d}j \right] \tag{7}$$

$$V \equiv \sum_i \left[\int_0^1 v^i(j)\mathrm{d}j \right] \tag{8}$$

Finally, following the literature, assume that the aggregate meeting function is Cobb-Douglas:

$$M = M(N,V) = \min\{\omega N^{\gamma} V^{1-\gamma}, N, V\} \tag{9}$$

where $\omega > 0$ and $\gamma \in [0,1]$.

Effective Matching Probabilities Workers and firms meet according to the aggregate meeting function $M(N,V)$. Consistent with the random matching assumption, every unemployed worker has the same probability of meeting a vacancy, regardless of his type. Similarly, this is also true of employed workers and vacancies. Therefore, define $\lambda_0 = \frac{s_0 M}{N}$ as the probability an unemployed worker contacts a vacancy and $\lambda_1 = \frac{s_1 M}{N}$ as the probability an employed worker contacts a vacancy. And let $q = \frac{M}{V}$ be the probability per unit of recruiting effort $v^i(j)$ that a firm contacts a worker. However, workers are only suitable for working in jobs posted for his skill group. Thus, the effective probabilities of a worker of type i meeting a vacancy posted by firm j are:

$$\text{(Unemployed worker } i\text{):}\ \lambda_0 \cdot \frac{v^i(j)}{\sum_i v^i(j)} \cdot \frac{\sum_i v^i(j)}{V} = \lambda_0 \left(\frac{v^i(j)}{V} \right)$$

$$\text{(Employed worker } i\text{):}\ \lambda_1 \cdot \frac{v^i(j)}{\sum_i v^i(j)} \cdot \frac{\sum_i v^i(j)}{V} = \lambda_1 \left(\frac{v^i(j)}{V} \right)$$

Notice that Shimer (2012) finds that since 1987, ninety percent of the fluctuation in the unemployment rate can be attributed to movements in the job finding probability. In other words, recessions are times characterized by the increased difficulty of workers in general to find a job.

Laws of Motion Firms hire unemployed workers at their reservation wage, counter outside offers of employed workers, and renegotiate the wages of current matches that lie outside the bargaining set. Thus, the law of motion of unemployment is:

$$\delta\left(\int n^i(j)\mathrm{d}j\right) = \lambda_0\left(\frac{\int v^i(j)\mathrm{d}j}{V}\right)u^i \tag{10}$$

The above equation states that in steady state, the flows into unemployment (left-hand side) must be equal to the flows out of unemployment (right-hand side). This equality must for for each type i of workers.

Similarly, the law of motion of employment is:

$$\begin{aligned}\lambda_0\left(\frac{v^i(j)}{V}\right)\mathbb{1}\{S^i(j)\geq 0\} + \lambda_1\left(\frac{v^i(j)}{V}\right)\int \mathbb{1}\{S^i(j) > S^i(j')\}n^i(j')\mathrm{d}j \\ = \delta n^i(j) + \int \lambda_1\left(\frac{v^i(j)}{V}\right)\mathbb{1}\left\{S^i(j') > S^i(j)\right\}n^i(j)\mathrm{d}j'\end{aligned} \tag{11}$$

The left-hand side is the flows into employment. The first term is the measure of new workers of type i hired by firm j from unemployment. The second term is the number of type i workers poached away from firm j'. The right-hand side is the flows out of employment. The first term is the measure of matches that are destroyed exogenously. The second term is the measure of workers that are poached away.

3.4 Value Functions

Value of Unemployment Let B^i be the value of unemployment for a worker of type i, and let $W^i(w,j)$ be the value of employment for a worker of type i matched to firm j, being paid a wage w. Then, the value of unemployment B^i solves the following Bellman equation:

$$B^i = b^i + \frac{1}{1+r}\left\{\left[1-\lambda_0\left(\frac{\int v^i(j)\mathrm{d}j}{V}\right)\right]B^i + \int\lambda_0\left(\frac{v^i(j)}{V}\right)\max\left[W^i(\phi_0^i(j),j),B^i\right]\mathrm{d}j\right\}$$

An unemployed worker i receives nonlabor income b^i from home production and the expected discounted value of his payoff tomorrow. In the next period, the worker can either meet a suitable vacancy and choose whether or not to match with the firm or he can not find a job opening and remains unemployed. The first term in the expectation captures the situation where the worker does not meet a suitable vacancy for his skill type i and continues to be unemployed in the next period. The second term captures the situation where the worker meets a vacancy from some firm j and must choose whether to accept or reject this offer. If the match is productive, the worker enters and employment contract with firm j.

Recall that when a worker is hired from unemployment, the firm receives the entire surplus of the new match. This means that the worker is paid a wage $w = \phi_0^i(j)$ such that $W^i(\phi_0^i(j), j) - B^i = 0$. Using this relationship, the above equation simplifies to:

$$
\begin{aligned}
B^i &= b^i + \left(\frac{1}{1+r}\right) B^i \\
B^i &= \left(\frac{1+r}{r}\right) b^i
\end{aligned}
\tag{12}
$$

Value of Employment The value of employment $W^i(w, j)$ for a worker of type i employed by a firm of type j, paid wage w satisfies the following Bellman equation:

$$
\begin{aligned}
W^i(w,j) = w + \frac{1}{1+r}\Bigg\{\delta B^i + (1-\delta)\Bigg[&\int_{\{j':S^i(j')>S^i(j)\}} \lambda_1\left(\frac{v^i(j')}{V}\right) W^i(\phi_1^i(j',j),j')\mathrm{d}j' \\
&+ \int_{\{j':S^i(j)\geq S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right) W^i(\phi_1^i(j,j'),j)\mathrm{d}j' \\
&+ \left(1 - \int_{\{j':S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\mathrm{d}j'\right) W^i(w,j)\Bigg]\Bigg\}
\end{aligned}
$$

In a period, this worker of type i at firm j is paid his wage and the expected discounted value of his payoff in the next period. The first term is the case where the match exogenously dissolves and the worker enters unemployment. If the match continues, then the worker can receive an outside offer that induces a wage change. In particular, he can either be poached away by a competing firm or renegotiate his wage at his current firm because his threat to quit is now credible. In the last term, the worker does not receive a vacancy that will induce a wage change so he just simply continues with his current match.

Subtracting B^i from both sides and using equation 12, the Bellman equation for the value of employment simplifies to:

$$
\begin{aligned}
W^i(w,j) - B^i = w - b^i + \frac{1-\delta}{1+r}\Bigg\{&\int_{\{j':S^i(j')>S^i(j)\}} \lambda_1\left(\frac{v^i(j')}{V}\right) S^i(j)\mathrm{d}j' \\
&+ \int_{\{j':S^i(j)\geq S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right) S^i(j')\mathrm{d}j' \\
&+ \left(1 - \int_{\{j':S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\mathrm{d}j'\right)\left[W^i(w,j) - B^i\right]\Bigg\}
\end{aligned}
\tag{13}
$$

Value of a Filled Job Assuming that the firm receives no value from posting a vacancy, the value of a filled job $\Pi^i(w,j)$ at firm j, employing worker i at wage w satisfies:

$$\begin{aligned}\Pi^i(w,j) = y^i(j) - w + \frac{1}{1+r}\Bigg\{\delta\cdot 0 + (1-\delta)\Bigg[&\int_{\{j':S^i(j')>S^i(j)\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\cdot 0\mathrm{d}j' \\ &+ \int_{\{j':S^i(j)\geq S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\Pi^i(\phi_1^i(j,j'),j)\mathrm{d}j' \\ &+ \left(1-\int_{\{j':S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\mathrm{d}j'\right)\Pi^i(w,j)\Bigg]\Bigg\}\end{aligned}$$

In a period, the firm receives the profits from the match with worker i: the output produced from the match net the wage paid to the worker. In the next period, the match could dissolve because of exogenous separation, as captured in the first term or the match can continue. If the match survives, then one of the following three situations could occur. First, the worker could receive an outside offer such that he is poached away by a competing firm. In this case, the match at firm j dissolves and the firm receives nothing. Second, the worker could receive an outside offer such that firm j must increase the worker's wage to convince him to stay in the match. Third, the worker does not meet a vacancy that can induce a wage change so the match continues unchanged.

Simplifying the above equation gives us:

$$\begin{aligned}\Pi^i(w,j) = y^i(j) - w + \frac{1-\delta}{1+r}\Bigg\{&\int_{\{j':S^i(j)\geq S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\left[S^i(j)-S^i(j')\right]\mathrm{d}j' \\ &+ \left(1-\int_{\{j':S^i(j')\geq W^i(w,j)-B^i\}} \lambda_1\left(\frac{v^i(j')}{V}\right)\mathrm{d}j'\right)\Pi^i(w,j)\Bigg\}\end{aligned} \quad (14)$$

Total Surplus Combining equations 13 and 17 results in the following equation for total surplus:

$$\begin{aligned}S^i(j) &= W^i(w,j) - B^i + \Pi^i(w,j) \\ &= y^i(j) - b^i + \left(\frac{1-\delta}{1+r}\right)S^i(j)\end{aligned}$$

Thus, given a worker of type i and a firm j, we can already deduce the optimal behavior of match formation:

$$S^i(j) = \left(\frac{1+r}{r+\delta}\right)\left[y^i(j) - b^i\right] \quad (15)$$

3.5 Vacancy Posting

While allowing firms to direct their vacancy postings to particular workers does not distort a worker's decision to accept or reject a match, it does change the probability that a worker meets an opening. In particular, notice that the effective meetings rates in the model depend directly on

$v^i(j)$. This means that the firm can now directly manipulate the meeting rate through its vacancy posting decision. Since vacancies do not have a continuation value, as in they only last one period, the firm's vacancy posting problem becomes the following:

$$\max_{v^i(j)} \Bigg\{ -\sum_i c(v^i(j)) + \sum_i q v^i(j) \Bigg(\frac{\lambda_0 \left(\frac{v^i(j)}{V}\right) u^i}{M} \max\{S^i(j), 0\} \\ + \int \frac{\lambda_1 \left(\frac{v^i(j)}{V}\right) n^i(j')}{M} \max\{\Pi^i(\phi_1^i(j,j'), j), 0\} \mathrm{d}j' \Bigg) \Bigg\}$$

where $c(v^i(j))$ is the convex cost the firm must pay to post vacancies, with $c(0) \geq 0$, $c'(\cdot) > 0$, $c'(0) = 0$, and $c''(\cdot) > 0$.

Recall that if a firm hires a worker from unemployment, then the firm receives the entire surplus. However, if a firm manages to poach an already employed worker, then the worker uses his previous job as an outside option and receives a wage such that he receives the total surplus of his previous job. Thus, the above problem simplifies to:

$$\max_{v^i(j)} \Bigg\{ -\sum_i c(v^i(j)) + \sum_i q v^i(j) \Bigg(\frac{\lambda_0 \left(\frac{v^i(j)}{V}\right) u^i}{M} \max\{S^i(j), 0\} \\ + \int \frac{\lambda_1 \left(\frac{v^i(j)}{V}\right) n^i(j')}{M} \max\{S^i(j) - S^i(j'), 0\} \mathrm{d}j' \Bigg) \Bigg\} \tag{16}$$

Define $J^i(j)$ as the expected value of a new match with worker i:

$$J^i(j) = \frac{\lambda_0 \left(\frac{v^i(j)}{V}\right) u^i}{M} \max\{S^i(j), 0\} + \int \frac{\lambda_1 \left(\frac{v^i(j)}{V}\right) n^i(j')}{M} \max\{S^i(j) - S^i(j'), 0\} \mathrm{d}j' \tag{17}$$

Notice that unlike previous equilibrium search and matching models, $J^i(j)$ depends on $v^i(j)$. In particular, the firm can manipulate the value of a new match through changing the effective probability that a vacancy meets a worker.

Since the total surplus function does not depend on the distribution of vacancy postings (see equation 15), this means that $J^i(j)$ depends on $v^i(j)$ ***only*** through its impact on the effective probability that a vacancy meets a worker. The firm will post vacancies $v^i(j)$ up to the point where the marginal vacancy makes zero expected profit. In other words, the optimal number of vacancies $v^i(j)$ firm j posts for workers of type i solves:

$$c'(v^i(j)) = q \left[J^i(j) + v^i(j) \frac{\partial J^i(j)}{\partial v^i(j)} \right] \tag{18}$$

where

$$\frac{\partial J^i(j)}{\partial v^i(j)} = \frac{\lambda_0 u^i}{VM}\max\{S^i(j),0\} + \int \frac{\lambda_1 n^i(j')}{VM}\max\{S^i(j)-S^i(j'),0\}\mathrm{d}j' \tag{19}$$

Assume that the flow cost of posting vacancies is assumed to have the following functional form:

$$c^i(v^i(j)) = \frac{c_0^i v^i(j)^{1+c_1^i}}{1+c_1^i} \tag{20}$$

with $c_0^i > 0$ and $c_1^i > 0$. Thus, we can rewrite equation 18 as:

$$c_0^i v^i(j)^{c_1^i} = q_t\left[J^i(j) + v^i(j)\frac{\partial J^i(j)}{\partial v^i(j)}\right] \tag{21}$$

4 Calibration

Given the properties of the surplus function, the steady state equilibrium in this environment can be solved in two stages:

1. For given home production and value added technologies b^i and $y^i(j)$, discount rate r, and exogenous job destruction rate δ, the surplus function $S^i(j)$ is sufficient to determine all decisions regarding worker transitions between unemployment and employment and movements between jobs. It is defined by the unique solution to the functional equation 15.
2. For a given vacancy cost function $c(v^i(j))$, and meeting technology $M(N,V)$, we can solve for a unique distribution of unemployed workers, matches, and vacancy postings:

$$u^i, \{n^i(j)\}_{j=0}^1, \{v^i(j)\}_{j=0}^1, \quad \forall i \in \{L,M,H\}$$

The distributions can be found by using the surplus function and iterating on the first order condition of the vacancy posting decision and the laws of motion until the distributions of unemployment, matches, and matches converge to the stationary distributions.

4.1 Parametric Specification

To fully specify the model, there are still several functional form assumptions that need to be made explicit. Specifically, I need to specify the functional forms for both home production and the value added technologies of matches.

Following Lise and Robin (2013), I will approximate the production technology of the firm by a second order Taylor series in worker and firm type:

$$y^i(j) = y_0 + y_1\cdot i + y_2\cdot j + y_3\cdot i^2 + y_4\cdot j^2 + y_5\cdot ij$$

Each worker type $i \in \{L, M, H\}$ will be associated with a productivity level. For simplicity, I assume that they are three equally separated points on the unit interval.[8] The comparative advantage assumption implies that $y_6 > 0$.[9] Similarly, home production will also be approximated by a polynomial:

$$b^i = b_0 + b_1 \cdot i + b_2 \cdot i^2$$

For completeness, recall that the aggregate meeting technology is assumed to be Cobb-Douglas:

$$M = M(N, V) = \min\{\omega N^{\gamma} V^{1-\gamma}, N, V\}$$

where $\omega > 0$ and $\gamma \in [0, 1]$. Both unemployed and employed workers can participate in search. Thus, I assume that the effective amount of worker search effort is a weighted average of unemployed and employed worker search:

$$N \equiv \sum_i \left[s_0 u^i + s_1 \int_0^1 n^i(j) \mathrm{d}j \right]$$

where $s_0 > 0$ and $s_1 > 0$.

Finally, I will assume that the cost of posting a vacancy does not vary with worker type:

$$c(v^i(j)) = \frac{c_0 v^i(j)^{1+c_1}}{1 + c_1}$$

where $c_0 > 0$ and $c_1 > 0$.

From the above parameterization this results in 20 parameters that need to be calibrated:

$$\{\omega, \gamma, s_0, s_1, c_0, c_1, \delta, \pi^L, \pi^M \pi^H, b_0, b_1, b_2, y_0, y_1, y_2, y_3, y_4, y_5, r\}$$

I will set $\gamma = \frac{1}{2}$.[10] The discount rate is set to five percent annually, $r = 0.05$. I will normalize $s_0 = 1$ and estimate the relative search effort of employed workers to unemployed workers. Finally, given the identity, $\pi^L + \pi^M + \pi^H = 1$, I only need to set two of three parameter values. This leaves 16 parameters that still need to be pinned down. Some of these parameters will be calibrated externally, while others will be calibrated internally by matching moments from the model to moments in the data.

I will set the productivity of workers to be three equally spaced points on the unit interval: $\{0, 0.5, 1\}$. This is not a restrictive assumption because the parameters of home production and

[8] All of the grids in the estimation procedure do not fully cover the unit interval. This is to avoid problems at the boundary. Therefore, to calibrate the model, worker productivity is set such that $i^L = 0.002$, $i^M = 0.500$, and $i^H = 0.998$. Firm productivity is similarly defined as 75 equidistant points in the interval $[0.002, 0.998]$.

[9] This is not a binding constraint since the calibration is done without imposing this condition and the parameter estimates are such that $y_6 > 0$ holds. Therefore, this means that the comparative advantage assumption is not restrictive, and that some degree of assortative matching is observed in the labor market.

[10] This is following much of the equilibrium search literature, for example Shimer (2005) and Lise and Robin (2013).

the production function should be flexible enough to capture the variation in productivity across these three groups. Firm complexity will also be a grid of 50 linearly spaced points on the unit interval.[11]

4.2 Externally Calibrated Parameters

Three of the remaining 13 parameters will be calibrated outside of the model. First, π^L, π^M, and π^H are the fractions of the workforce that is low-, middle-, and high-skilled, respectively. Using the same data from the Current Population Survey (CPS) as discussed above, I group the 10 broad occupational categories into three that to represent the cognitive non-routine workers (H), the routine workers (M), and the non-cognitive non-routine workers (L). I match the average fraction of employment in each of these three categories from 1989-1999 to calibrate π^L, π^M, and π^H. About 14% of workers are in the low-skilled category, 53% in the middle-skilled category, and 33% in the high-skilled category. Finally, in this steady state model, matches can only dissolve exogenously. Thus, the exogenous separation rate, δ, is calibrated to match the average quarterly transition rate from employment to unemployment of 0.0254.

4.3 Internally Calibrated Parameters

The remaining 13 parameters will be calibrated to match a set of moments from the data. See Table 1 for a full list of moments. Unlike the exogenous separation rate, these moments do not match one-to-one to parameters in the model. Therefore, each moment will help pin down several parameters in the model. The first set of moments (the mean unemployment rate and transition rates) will help pin down the parameters in the matching function and the cost function. The cost function is a key component in determining the optimal vacancy posting decision of the firms, which, in turn, will determine the number of matches that can form. The job-to-job transition rate will help identify the relative search intensity of employed workers as compared to unemployed workers. The remaining moments capture the wage distribution for each type of worker and for the overall economy. One of the features of this model is that even in a steady state equilibrium, there is wage dispersion. Workers of a particular type will all enter employment contracts under the same wage (their reservation wage). However, once employed, the path of wages for an individual is dependent on the history of employers the worker manages to meet. Consider a worker of type i at firm j. It can be shown that the worker will be paid a wage w such that:

$$w^i(j) = \begin{cases} y^i(j') & \text{if the worker received an offer from firm } j' \text{ that could induce a wage change} \\ b^i & \text{if the worker has not received an offer that can induce a wage change} \end{cases}$$

[11]The grids are trimmed by 0.002.

Table 1: Targeted Moments

Moments		Data	Before	After
	$\mathbb{E}(U)$	0.0562	0.0683	0.0686
	$\mathbb{E}(U2E)$	0.4376	0.4010	0.2051
	$\mathbb{E}(J2J)$	0.0273	0.0209	0.0212
	Wage Distributions			
aggregate	P90(w)	3.4122	3.3990	3.4357
	P50(w)	2.5635	2.3071	2.2147
	P10(w)	1.6633	0.9175	0.8075
low-skilled	P90(w^L)	3.0119	2.4763	2.4763
	P50(w^L)	2.1133	1.8235	1.8235
	P10(w^L)	1.2843	0.5428	0.5428
middle-skilled	P90(w^M)	3.2247	2.4547	2.4129
	P50(w^M)	2.4606	2.1123	1.9767
	P10(w^M)	1.6456	0.9175	0.8075
high-skilled	P90(w^H)	3.6662	3.4839	3.4839
	P50(w^H)	2.9087	3.2727	3.2406
	P10(w^H)	2.0671	2.1294	2.1294

Notes: The transition moments are taken from Lise and Robin (2013) who use data from BLS and CPS from 1951q1 to 2007q4. The remaining moments are calculated from the CPS March Supplement from 1989-1999 for individuals between the age of 16 and 64. The parameter values are calibrated to match the moments listed in the 'Data' column. The moments predicted by the standard steady state equilibrium model is listed under the column labeled 'Before.' Using the same parameter estimates, the column labeled 'After' lists the same moments calculated in the new steady state after job polarization.

Therefore, the wage distribution within and between worker types will help set the parameters in home production and the value-added technologies.

Given an initial guess for the parameters, I will solve for the steady state equilibrium. Since there is no analytical solution for the equilibrium distribution of wages, I then simulate the model for 500 workers to get the statistics I need from the wage distribution. The parameters are then updated and the moments recalculated until the following objective function is minimized:

$$\min_{p} \left[m_M(p) - m_D\right]^\top \left[m_M(p) - m_D\right] \tag{22}$$

where $m_M(p)$ is a vector of moments from the model that are a function of the vector of parameters p and m_D is the vector of the same moments calculated from the data. There are 15 moments used to estimate 13 parameters. Table 2 lists all of the parameter estimates. The resulting moments under this parameterization is reported in the second column of table 1. The model seems to do a decent job matching the aggregate moments, but falls short of matching the wage distributions within each skill group.

Table 2: Parameter Estimates

Matching Function	ω	1.8940
$M = \min\{\omega N^{\gamma} V^{1-\gamma}, N, V\}$	γ	0.5000
Search Intensity	s_0	1.0000
	s_1	0.2220
Exogenous Separation	δ	0.0254
Vacancy Posting Costs	c_0	0.0550
$c(v^i(j)) = \frac{c_0}{1+c_1} v^i(j)^{1+c_1}$	c_1	1.1200
Worker Heterogeneity	π^L	0.1372
$\pi^L + \pi^M + \pi^H = 1$	π^M	0.5335
	π^H	0.3293
Home Production	b_0	0.5430
$b^i = b_0 + b_1 \cdot i + b_2 \cdot i^2$	b_1	-0.0950
	b_2	1.6880
Production Function	y_0	2.6120
$y^i(j) = y_0 + y_1 \cdot i + y_2 \cdot j + y_3 \cdot i^2 + y_4 \cdot j^2 + y_5 \cdot ij$	y_1	-1.1710
	y_2	-1.0240
	y_3	1.6500
	y_4	-2.5950
	y_5	3.0930
Discount Rate	r	0.0500

Notes: r is fixed at 0.05 annually and ω is fixed at 0.5; s_0 is normalized to 1; the worker heterogeneity parameters were set to match the proportion of jobs in three large occupational groups from CPS from 1989-1999; the exogenous separation rate is set to match the mean transition rate from employment to unemployment from Lise and Robin (2013); the remaining parameters are calibrated through minimum distance.

5 Steady State Equilibrium

Given these parameter estimates, figure 3 plots the resulting production function and total surplus function. Notice that for low values of task complexity, low skilled workers are actually more productive than middle-skilled workers. Further, figure **??** makes it clear exactly which matches the firms will consider. If the firm knows that certain matches will never generate positive surplus, the firm will not waste resources posting vacancies for those workers. Figure 4 plots the firms' vacancy posting decision and the resulting employment distribution for each type of worker. As expected, the firms with the highest level of task complexity are posting vacancies and hiring only high-skilled workers. However, most firms actually post vacancies for all three types of workers. In other words, firms will enter and post vacancies in any market where total surplus is positive because of the possibility of matching with a worker who will generate positive surplus. The employment distributions are also what would be expected. For all types of workers, the mass is concentrated at the complexity level that generates the most surplus. This peak moves to the right towards more complex tasks with skill level.

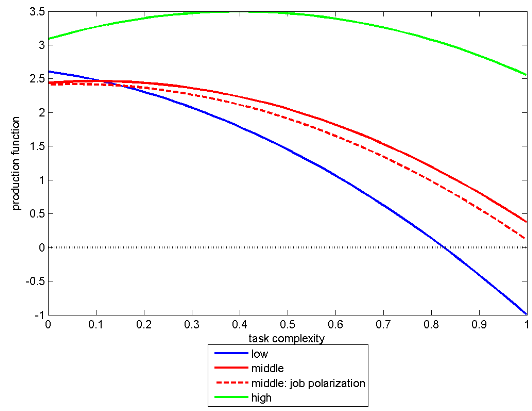
5.1 Job Polarization

To analyze the impact of job polarization, I assume a change in the comparative advantage of middle-skilled workers and analyze the effects this has on the new steady state equilibrium. Specifically, I assume that the comparative advantage of middle-skilled workers over low-skilled workers has declined and that the comparative advantage of high-skilled workers over middle-skilled workers has increased. Given the functional form assumption of the production technologies this can be easily accomplished through the assumption that middle-skilled workers become less productive in the polarized economy. Specifically, I assume that middle-skilled workers are 85% as productive as they used to be in the old steady state. Figures 3a and 3b graphically show the implications of this assumption on the comparative advantage of workers and the production technologies. The changes this will have on productive matches can be seen in figure 3c. Everything else in the economy remains the same, including the distribution of worker types, π^i for $i \in \{L, M, H\}$.[12]

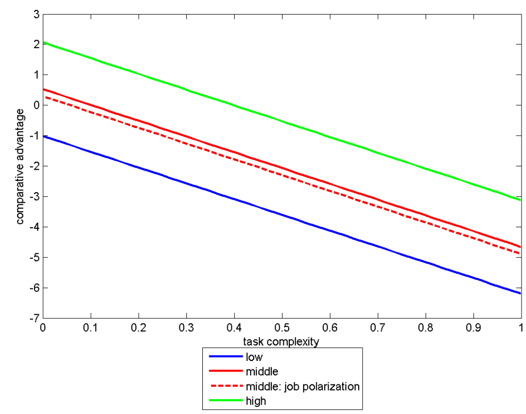
First, it is important to note that with this change in comparative advantage, the labor market does become more polarized in the new steady state. This can be seen in the last two columns of table 3. These two columns list the fraction of employment attributed to each skill group, before and after job polarization. Note that the fraction of jobs held by middle-skilled workers declines from 53.41% to 53.37%, while the fraction of jobs held by low- and high-skilled workers increases. To see where this polarization is coming from, see figure 4. Notice that in the polarized economy, the distribution of middle-skilled workers shifts left, towards less complex tasks. Since low- and high-skilled workers generate the same amount of surplus as before, the employment

[12] An interesting extension would be to endogenize the worker's human capital decision by allowing him to choose his skill type.

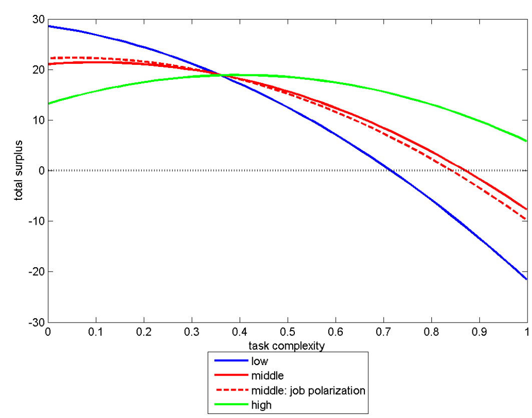
Figure 3: Production Functions and Total Surplus



(a) Production Function



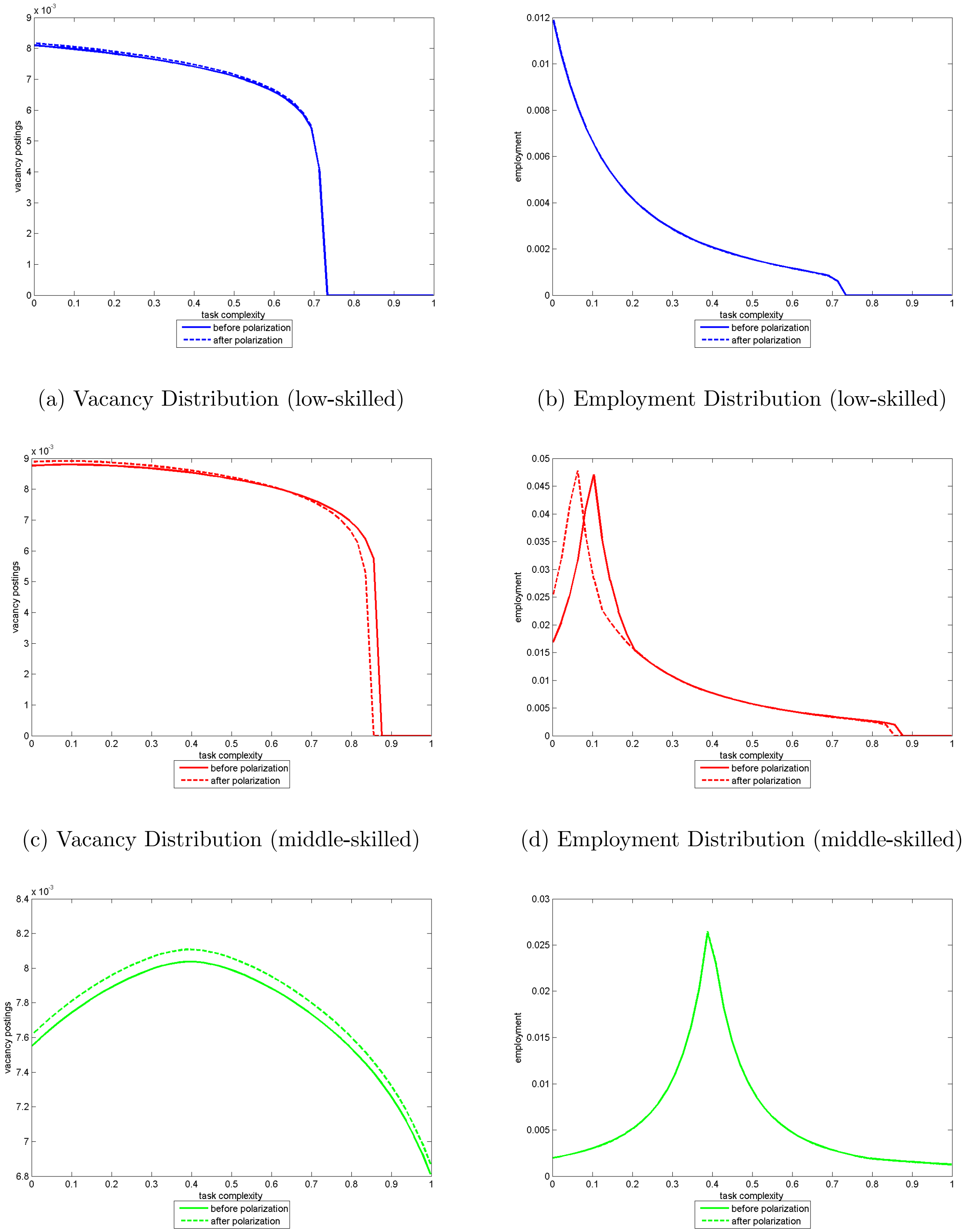
(b) Comparative Advantage



(c) Total Surplus

Notes: The top figure plots the resulting production function by skill type. The middle figure plots the derivative of each production function with respect to task complexity: $\partial y^i(j)/\partial j$. This is to check that the comparative advantage assumption holds. The bottom figure plots the total surplus function by skill type.

Figure 4: Steady State Equilibrium



(a) Vacancy Distribution (low-skilled)

(b) Employment Distribution (low-skilled)

(c) Vacancy Distribution (middle-skilled)

(d) Employment Distribution (middle-skilled)

(e) Vacancy Distribution (high-skilled)

(f) Employment Distribution (high-skilled)

Notes: The column on the left plots the steady state equilibrium vacancy distribution for each skill type. The column on the right plots the steady state equilibrium employment distribution for each skill type.

Table 3: Unemployment Rates and Vacancy Postings by Skill Type

	Unemployment Rate		**Vacancy Postings**		**Employment**	
	Before	*After*	*Before*	*After*	*Before*	*After*
aggregate	0.0683	0.0686	–	–	–	–
low	0.0885	0.0878	0.2615	0.2637	0.1342	0.1344
middle	0.0672	0.0682	0.3526	0.3471	0.5341	0.5337
high	0.0618	0.0613	0.3859	0.3892	0.3316	0.3319

Notes: The two columns under 'Unemployment Rate' list the unemployment rate before and after job polarization. The next two columns under 'Vacancy Postings' is the fraction of total vacancy postings that went to each skill type, before and after job polarization. The last two columns under 'Employment' lists the fraction of total employment that is attributed to each skill type, before and after job polarization. The columns under 'Vacancy Postings' and 'Employment' do not necessarily sum to 1 because of rounding. Job polarization here is defined as a shift in the comparative advantage of middle-skilled workers compared to low- and high-skilled workers. In this setup, this specifically amounts to midddle-skilled workers being 85% as productive as before in the polarized labor market. All other parameters remain the same.

distribution across task complexity for these workers does not really change, making it difficult to see the impact of job polarization. If we compare the unemployment rates within each skill type (see table 3), we can see the impact more clearly. The unemployment rate for middle-skilled workers increases from 6.83% to 6.86% and the unemployment rate for low- and high-skilled workers falls from 8.85% to 8.78% and from 6.18% to 6.13%, respectively. Since over half of the labor force is middle-skilled workers, the overall unemployment rate increases slightly from 6.72% to 6.82%. What is interesting to note is the vacancy posting decisions of the firms.

What is really clear in this model is that all of this change in employment is driven by labor demand. In this new economy, there is a mass of firms that used to post vacancies to middle-skilled workers, but now no longer do so. This is a direct consequence of middle-skilled workers becoming less productive than in the old steady state. However, in general equilibrium, this change in the productivity of middle-skilled workers also affects the vacancy posting decisions of firms for low- and high-skilled workers. Since the comparative advantage middle-skilled workers had over low-skilled workers has decreased, firms with low complexity tasks will post more vacancies for middle-skilled workers. At the same time, high-skilled workers, who used to be very attractive matches, have become even more attractive. Therefore, vacancy postings to hire high-skilled workers increases everywhere.

The last column of table 1 reports the estimates of the moments used to calibrate the model in the new steady state equilibrium after job polarization. These numbers should be compared to the second column, which are the same moments calculated before job polarization. One interesting thing to note is that at the aggregate level, there is an increase in wage inequality after the introduction of this technological innovation that triggers job polarization. This arises because while the wage distribution of low- and high-skilled workers has not changed, there is a downward shift in the wage distribution of middle-skilled workers.

6 Conclusion

This paper sets out to develop and estimate an equilibrium search and matching model where firms are able to direct their hiring efforts through their vacancy posting decision. The motivation for this extension is to provide insight into how changes in labor demand from polarizing technological innovation affect the aggregate conditions of the labor market. I find that as middle-skilled workers become less productive relative to high-skilled workers and lose their comparative advantage over low-skilled workers, firms shift their hiring efforts away from middle-skilled workers towards lows- and high-skilled workers. The result is an economy that experiences job polarization that is coupled with an increase in the overall unemployment rate and in wage inequality.

A Current Population Survey

Data on employment at the occupational group level from 1989 to 2012 is taken from the Current Population Survey (CPS) March Supplement from IPUMS-CPS. I use the 1990 Census Bureau occupational classification and collapse the three-digit codes into ten broad occupational categories following Acemoglu and Autor (2011):

11 Managers : 003-037, 303
12 Professionals: 043-200
13 Technicians: 203-235
21 Sales: 243-290
22 Office and administration: 308-391
23 Production, craft, and repair: 503-699
31 Operators, fabricators, and laborers: 703-890
32 Protective services: 415-427
33 Food preparation, buildings and grounds, and cleaning: 405-408, 434-444, 448-455, 486
34 Personal care and personal services: 445-447, 456-469
40 Agriculture: 473-485, 487-498

Following Jaimovich and Siu (2012), I classify workers in occupational groups (11), (12), and (13) to be non-routine cognitive workers, those in (21), (22), (23), and (31) are routine workers, and those in (32), (33), and (34) to be non-routine manual workers. I do not include the agriculture occupations (40) or the military in my analysis.

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