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ARTICLES

JOB COMPETITION, CROWDING OUT, AND UNEMPLOYMENT FLUCTUATIONS

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This paper attempts to determine the factors generating the persistence of unemployment over the business cycle. The observations show that the total unemployment rate is highly persistent, and that the persistence of the unemployment rate of unskilled workers is higher than that of skilled workers. To account for these observations, the paper develops a framework that features search frictions. Individuals are either high educated or low educated, and firms post two types of vacancies: the complex, which can be matched with the high educated, and the simple, which can be matched with the high and the low educated. On-the-job search for a complex occupation is undertaken by the high educated in simple occupations. A negative aggregate technological shock induces the high educated unemployed to compete with the low educated by increasing their search intensity for simple vacancies. As the high educated occupy simple vacancies, they crowd out the low educated into unemployment. This downgrading of jobs in a cyclical downturn, or the increase in the labor input of the high educated in simple occupations, and the subsequent crowding out of the low educated into unemployment, provide a possible explanation for unemployment persistence.

Keywords: Unemployment, Business Cycle, Search and Matching

1. INTRODUCTION

This paper attempts to determine the factors generating the persistence of unemployment over the business cycle. To this end, the paper derives a set of stylized facts that capture not only the high persistence of the total unemployment rate, but also the higher persistence of the unemployment rate of unskilled workers compared to that of skilled workers. In addition, the observations capture the cyclical allocation of labor input in a labor market with heterogeneous agents across educational levels. These additional observations reflect a lagged cyclical upgrading of jobs by the college-educated, or a lagged cyclical increase in their labor input from jobs that do not require college education to ones that do. This provides a possible explanation for unemployment persistence, as in a cyclical

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downturn the skilled workers compete with the unskilled workers for unskilled jobs, and thus crowd out the unskilled into unemployment. This intuition, based on job competition across skills and the consequent crowding out of the unskilled into unemployment, is used to develop a model that is capable of reproducing the observed unemployment persistence.

Using the Outgoing Rotation Group of the Current Population Survey for the period from 1979 to 2008, the participants are divided into those employed and those unemployed. The two groups are further divided into those high and low educated, where the former are those with at least some college education. The employed types are further divided into those working in complex and in simple occupations, where the former are jobs that require at least some college education. Therefore, a monthly data set is compiled, including measures of employment and total hours of the high educated in complex and in simple occupations and employment and total hours of the low educated in simple occupations, besides the unemployment rates of the high and the low educated, as well as a measure of the crowding out of the low educated by the high educated in occupying simple jobs. The observations suggest that an economic expansion is accompanied contemporaneously by an increase in the employment and total hours of all labor types employed in simple occupations, followed with a lag by an increase in the employment and total hours of those employed in complex occupations and a decrease in the unemployment of the two types of labor, and the crowding-out effect. These observations reflect possible lagged cyclical upgrading of jobs by the high educated, through increasing their level of employment and their hours of work in complex occupations. This also implies a lagged downgrading of jobs and a consequent crowding out of the low educated into unemployment after an adverse shock, which provides a possible explanation for the persistence of unemployment.

The paper develops a model to identify the underlying market interactions that are critical in generating the observed behavior along the lines of this intuition. These interactions are captured in a dynamic stochastic general equilibrium model that features search frictions. Households are divided into high educated and low educated workers. Firms post two types of vacancies: the complex, which can be matched with the high educated, and the simple, which can be matched with both the high and the low educated. The high educated in simple occupations are allowed to search on the job for a complex occupation. An adverse aggregate technological shock induces the high educated unemployed to compete with the low educated, as they increase their search intensity for simple vacancies. As the high educated occupy simple vacancies, they crowd out the low educated into unemployment. This downgrading of jobs, or the increase in the labor input of the high educated in simple occupations, and the subsequent crowding out of the low educated into unemployment, provide a possible explanation for unemployment persistence.

This paper adopts a different approach than previous studies that attempted to explain the persistence of unemployment. For instance, Esteban-Pretel (2005) and Esteban-Pretel and Faraglia (2005) include the aspect of skill loss by the high educated if unemployed for an extended period of time, in order to explain the persistence of unemployment. When the economy suffers an adverse shock, unemployment increases and the creation of vacancies declines, thus lengthening unemployment spells. The increase in the duration of unemployment causes workers to lose their skills, which leads to an increase in the unemployment of the unskilled. The increase in the unemployment of the unskilled, who have a lower probability of finding a job, raises the average duration of unemployment in the economy, and accordingly the persistence of unemployment. In addition, Pries (2004) argues that even though unemployed workers find jobs quickly, due to the high job-finding rate, following a shock that triggers a burst of job loss, the newly found jobs often last only a short time. After initial job loss, a worker may experience several short-lived jobs before settling into more stable employment. This recurring job loss contributes to the persistence of unemployment. Eriksson and Gottfries (2005) argue that employers use information on whether the applicant is employed or unemployed as a hiring criterion, because the perceived productivity of an unemployed worker may be lower than that of an employed worker, as human capital is lost in unemployment. This ranking of job applicants by employment status increases the level and persistence of unemployment. Eriksson (2006) extends this framework to argue that long-term unemployed workers do not compete well with other job applicants because they have lost the abilities that employers find attractive. In a model with short-term and long-term unemployed workers, firms prefer to hire the unemployed who have not lost their human capital. This ranking of job applicants results in a lengthy adjustment process and is capable of generating persistence after an adverse shock.

This paper, however, argues that unemployment persistence can be reproduced in a model without the aspects of skill loss, recurring job loss, or ranking of job applicants. The success of this model is attributed to the additional dynamics that it introduces, such as competition between those distinguished by their educational levels for a job with a particular educational requirement, the crowding out of the unsuccessful by the successfully matched, and the possibility of a mismatch between the educational level of the successful and the educational requirements of the job they occupy. This downgrading of jobs can explain unemployment persistence.

The remainder of the paper is organized as follows: Section 2 presents the stylized facts, Section 3 develops the model, Section 4 discusses the calibration, Section 5 analyzes the results and the sensitivity analysis, and Section 6 concludes. The Appendix includes the data and derivations.

2. OBSERVATIONS

To derive the business cycle patterns of labor market variables that reflect agent heterogeneity in educational levels and the educational requirements of jobs they are occupying, a time series is compiled from the Outgoing Rotation Group of the Current Population Survey CPS.[1] This Survey provides monthly information from January 1979 until December 2008 on the participants' employment status, level of education, type of occupation, and hours of work.

To compile a time series out of this survey, the labor market participants in each monthly file are divided into those employed and those unemployed. Each group is further divided into those high and low educated, where the former are those who obtained at least some college education. Each of the two employed groups is further divided into those working in a complex occupation and those working in a simple occupation, where the former is a job that requires at least some college education. This provides four employed and two unemployed types: the high educated employed in a complex occupation, the high educated employed in a simple occupation, the high educated unemployed, the low educated employed in a complex occupation, the low educated employed in a simple occupation, and the low educated unemployed. The low educated employed in a complex occupation are dropped from the sample due to their insignificant proportion out of all the low educated, and out of all those employed in complex occupations. Levels of employment are calculated for the three employed types, and levels of unemployment are calculated for the two unemployed types. Using the weighted average weekly hours of work of each group and the level of employment, the total hours of each group are derived. The proportion of each unemployed type out of the total sample is also calculated. Finally, a crowding-out variable is defined as the proportion of the total hours of the high educated among the total hours of all those employed in simple occupations, such that its increase reflects an increase in the crowding-out of the low educated by the high educated in occupying this type of job.

Therefore, the variables compiled and used in the analysis are (1) the employment level, the average weekly hours, and the total hours of the high educated employed in complex occupations, (2) the employment level, the average weekly hours, and the total hours of the high educated employed in simple occupations, (3) the employment level, the average weekly hours, and the total hours of the low educated employed in simple occupations, (4) the proportion of the high educated unemployed, (5) the proportion of the low educated unemployed, and (6) the crowding-out effect. This monthly time series is transformed into quarterly data by taking three-month averages. The data average during the period under study of the proportion of the high educated in complex occupations out of the total labor force is 0.23, and that of the high educated in simple occupations is 0.25, whereas that of the low educated in simple occupations is 0.46. The data average of the proportion of the high educated unemployed is 0.02, and that of the low educated unemployed is 0.04, which gives a total unemployment rate of 6%.

The cross-correlation coefficients between real gross domestic product in period t and each of these variables in lag and lead periods are displayed in Table 1. These patterns demonstrate that the employment level and average hours of the high educated in complex occupations are procyclical with a lag. Therefore, the total hours of the high educated in complex occupations are procyclical and lags

TABLE 1. CPS data moments: standard errors in () calculated by bootstrapping

	Cross correlations of output(t) and $x(t+i)$								
x	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$
N^{hc}	−0.2205	−0.1480	−0.0998	0.0040	0.1765	0.2597	0.3318	0.4606	0.4457
	(0.1018)	(0.1083)	(0.1051)	(0.1201)	(0.1182)	(0.1158)	(0.1189)	(0.0956)	(0.0830)
H^{hc}	0.2239	0.2248	0.2508	0.1995	0.2147	0.2369	0.2296	0.2106	0.1279
	(0.0944)	(0.0830)	(0.0843)	(0.0782)	(0.0793)	(0.0745)	(0.0853)	(0.0834)	(0.0877)
TH^{hc}	−0.0524	0.0044	0.0552	0.1083	0.2522	0.3290	0.3833	0.4742	0.4203
	(0.1032)	(0.0960)	(0.1043)	(0.1126)	(0.1035)	(0.1051)	(0.0931)	(0.0827)	(0.0805)
N^{hs}	0.2647	0.3276	0.3631	0.4659	0.4425	0.3636	0.1838	0.0413	−0.1498
	(0.1017)	(0.1004)	(0.1030)	(0.0826)	(0.0971)	(0.1054)	(0.1272)	(0.1185)	(0.1019)
H^{hs}	0.2933	0.3717	0.4844	0.4621	0.4685	0.3868	0.2853	0.1393	0.0670
	(0.1077)	(0.0896)	(0.0793)	(0.0832)	(0.0770)	(0.0804)	(0.0926)	(0.1000)	(0.0896)
TH^{hs}	0.3342	0.4177	0.4958	0.5655	0.5483	0.4509	0.2673	0.0916	−0.0904
	(0.1074)	(0.0955)	(0.0891)	(0.0764)	(0.0870)	(0.0988)	(0.1186)	(0.1167)	(0.1031)
N^{ls}	0.0431	0.1551	0.3693	0.5344	0.6503	0.6463	0.5712	0.4324	0.3193
	(0.0845)	(0.0923)	(0.0821)	(0.0713)	(0.0585)	(0.0612)	(0.0731)	(0.0831)	(0.0819)
H^{ls}	0.2517	0.3409	0.4690	0.5102	0.5755	0.4731	0.3691	0.2622	0.1088
	(0.0990)	(0.0926)	(0.0812)	(0.0772)	(0.0643)	(0.0661)	(0.0785)	(0.0820)	(0.0915)
TH^{ls}	0.1193	0.2392	0.4538	0.5991	0.7105	0.6726	0.5777	0.4332	0.2921
	(0.0887)	(0.0923)	(0.0810)	(0.0714)	(0.0519)	(0.0591)	(0.0774)	(0.0867)	(0.0847)

TABLE 1. Continued.

x	Cross correlations of output(t) and $x(t+i)$								
	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$
U^h	−0.0218	−0.1453	−0.3026	−0.4691	−0.6046	−0.6275	−0.5871	−0.5065	−0.4072
	(0.0671)	(0.0699)	(0.0659)	(0.0554)	(0.0494)	(0.0431)	(0.0516)	(0.0570)	(0.0733)
U^l	−0.1957	−0.3722	−0.5563	−0.7624	−0.8877	−0.8391	−0.6954	−0.4990	−0.2834
	(0.0917)	(0.0875)	(0.0768)	(0.0461)	(0.0242)	(0.0363)	(0.0590)	(0.0875)	(0.1032)
U	−0.1957	−0.3722	−0.5563	−0.7624	−0.8877	−0.8065	−0.6990	−0.5396	−0.3602
	(0.0861)	(0.0813)	(0.0742)	(0.0460)	(0.0359)	(0.0363)	(0.0513)	(0.0750)	(0.0891)
Crowding	0.2032	0.1731	0.0390	−0.0175	−0.1472	−0.2097	−0.2927	−0.3164	−0.3549
	(0.0914)	(0.0861)	(0.0999)	(0.0818)	(0.0923)	(0.0939)	(0.0947)	(0.0826)	(0.0840)

Notes: TH^{hc}: total hours of the high educated in complex occupations; TH^{hs}: total hours of the high educated in simple occupations; TH^{ls}: total hours of the low educated in simple occupations.

the cycle by three quarters, as the cross-correlation coefficient with output reaches 0.4742, which is statistically significant with a p-value of zero. The employment level and average hours of the high and low educated employed in simple occupations are procyclical. Thus, the total hours of the high and the low educated in simple occupations are positively correlated with contemporaneous output, with cross-correlation coefficients of 0.5483 and 0.7105, respectively, that are statistically significant with p-values of zero. The proportion of the high educated unemployed is countercyclical and lags the cycle, with a cross-correlation coefficient with output that reaches -0.6275 and is statistically significant, whereas the proportion of the low educated unemployed is counter-cyclical with a cross-correlation coefficient with output of -0.8877 that is also statistically significant. The total unemployment rate is countercyclical, with a cross-correlation coefficient of -0.8877 that is statistically significant. Finally, the crowding-out effect is countercyclical with a lag, as the fourth lagged cross-correlation coefficient of -0.3549 is statistically significant. These patterns are summarized as follows:

(1) The employment level of the high educated in complex occupations is procyclical with a lag.
(2) The average hours of the high educated in complex occupations are procyclical with a lag.
(3) The total hours of the high educated in complex occupations are procyclical with a lag.
(4) The employment level of the high educated in simple occupations is procyclical.
(5) The average hours of the high educated in simple occupations are procyclical.
(6) The total hours of the high educated in simple occupations are procyclical.
(7) The employment level of the low educated in simple occupations is procyclical.
(8) The average hours of the low educated in simple occupations are procyclical.
(9) The total hours of the low educated in simple occupations are procyclical.
(10) The unemployment rate of the high educated is countercyclical with a lag.
(11) The unemployment rate of the low educated is countercyclical.
(12) The total unemployment rate is countercyclical.
(13) The crowding-out effect is countercyclical with a lag.

Table 2 shows the cyclical patterns of the aggregate unemployment rate and hours of work extracted from the Bureau of Labor Statistics (BLS). The observations show that the unemployment rate is countercyclical, and the hours of work are procyclical. These observations are consistent with those on the disaggregated data extracted from the Current Population Survey (CPS).

Table 3 displays the serial correlations of the total unemployment rate, and of the unemployment rates of the high and the low educated. The observations from the CPS data show the high persistence of total unemployment, and that the persistence of the unemployment of the low educated is higher than that of the high educated. The persistence of the aggregate unemployment rate from the BLS data is similar to that from the CPS data.

The approach of this paper is the use of the cyclical behavior of the variables pertaining to the allocation of labor input to ascertain intuitively the factors behind

TABLE 2. BLS data moments: standard errors in () calculated by bootstrapping

	Cross correlations of output(t) and $x(t+i)$								
x	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$
Agg$U$	−0.1571	−0.3422	−0.5419	−0.7514	−0.8834	−0.8505	−0.7265	−0.5477	−0.3328
	(0.0889)	(0.0838)	(0.0724)	(0.0436)	(0.0248)	(0.0314)	(0.0548)	(0.0803)	(0.0972)
Agg$H$	0.3447	0.4666	0.6075	0.7164	0.7379	0.5256	0.2534	0.0282	−0.1919
	(0.0880)	(0.0856)	(0.0628)	(0.0414)	(0.0434)	(0.0756)	(0.1076)	(0.1069)	(0.1086)

Notes: Agg$U$: aggregate unemployment rate; Agg$H$: aggregate weekly hours of work.

TABLE 3. Unemployment serial correlations

	Variable	$\rho(x_t, x_{t-1})$	$\rho(x_t, x_{t-2})$	$\rho(x_t, x_{t-3})$	$\rho(x_t, x_{t-4})$	$\rho(x_t, x_{t-5})$
CPS data	U_t	0.870	0.695	0.492	0.299	0.101
BLS data	U_t	0.878	0.691	0.480	0.266	0.085
Benchmark	U_t	0.922	0.868	0.800	0.724	0.646
No-crowding	U_t	0.952	0.891	0.823	0.749	0.673
No-skills	U_t	0.942	0.878	0.809	0.738	0.665
CPS data	U_t^h	0.796	0.643	0.504	0.338	0.118
Benchmark	U_t^h	0.908	0.761	0.646	0.553	0.472
No-crowding	U_t^h	0.950	0.886	0.818	0.744	0.669
CPS data	U_t^l	0.855	0.649	0.432	0.229	0.038
Benchmark	U_t^l	0.871	0.753	0.647	0.550	0.462
No-crowding	U_t^l	0.952	0.892	0.823	0.749	0.673

the business cycle pattern of unemployment and its persistence. For instance, the lagged increase in the total hours of the high educated in complex occupations reveals a possible lagged procyclical upgrading of jobs they are occupying. Evidence on the cyclical upgrading of jobs is provided by Devereux (2000, 2004), who used the Panel Study of Income Dynamics for the period 1976–1992 and found that in a recession the skilled occupy jobs that would normally be occupied by the unskilled. Thus, in a downturn, as the high educated compete with the low educated in occupying simple jobs, they crowd out the low educated into unemployment, which contributes to the persistence of total unemployment, and the higher persistence of the unemployment of the low educated compared to that of the high educated.

3. MODEL

Consider an economy where time is infinite and discrete. The population is of measure 1, and there is a constant fraction δ of households that are ex ante high educated and $(1-\delta)$ that are low educated. The representative firm posts complex and simple vacancies. The complex vacancies are matched with the high educated only, whereas the simple vacancies are matched with both the high and the low educated. The firm also chooses the proportion of simple vacancies directed toward the high educated and that directed toward the low educated. An explanation could be that there are different newspapers for the high educated and for the low educated, so that companies can direct their advertisements about available vacancies to particular newspapers. A high educated worker in a simple occupation is allowed to continue searching on the job for a complex occupation. This is justified, as the two types of vacancies differ according to their creation costs, and these costs generate rents that give rise to equilibrium wage differentials between occupation types.

The model is an extension of Gautier (2002) in a general equilibrium framework, and focuses on the dynamics of the model to explain some aspects of the business cycle. This paper extends that framework into one where employment is considered in the intensive and extensive margins. The paper uses the observed cyclical behavior of the variables pertaining to the allocation of labor input to ascertain intuitively the factors behind the business cycle pattern of unemployment and its persistence. Accordingly, the Gautier (2002) framework is extended to a dynamic stochastic general equilibrium framework that incorporates the aspects of job competition between workers of different education levels on jobs of different educational requirements. In this framework, the matching process determines the level of employment in every occupation, and the hours of work are determined endogenously. This allows the endogenous determination of labor input, which generates the crowding out of the low educated by the high educated in simple jobs in a downturn. Therefore, it is the intuition derived from the observations that justifies the deviation from the Gautier (2002) framework. The other deviation from the Gautier (2002) framework is that directed search is assumed in the model, instead of random search, to capture the distinction between the creation of simple vacancies for the high educated and the low educated. This clarifies the dynamics of job competition and crowding out. As the proportion of jobs created for the high educated increases, the crowding-out effect increases. In this context, we expect the proportion of vacancies directed to the high educated to increase in a downturn, and to decrease in an economic expansion due to the cyclical upgrading of jobs. The matching in Gautier (2002) is between one firm and one worker, whereas this paper departs from this assumption to allow complementarities in the production function.

3.1. Households

In this context, the high and the low educated household members are divided into those employed and those unemployed as follows:

$$N_t^{hc} + N_t^{hs} + U_t^h = \delta, \tag{1}$$

$$N_t^{ls} + U_t^l = 1 - \delta, \tag{2}$$

where N_t^{ij} denotes the number of workers of education type i in occupation type j, where $i \in (h, l)$ for high and low educated workers, respectively, and $j \in (c, s)$ for complex and simple occupations, respectively. U_t^i denotes the number of the unemployed of type i. Time for all types is normalized to one. A high educated unemployed person uses a portion S_t^{hc} of its time to search for a complex occupation, a portion S_t^{hs} to search for a simple occupation, and $(1 - S_t^{hc} - S_t^{hs})$ for leisure. A low educated unemployed person uses a portion S_t^{ls} of its time to search for a simple occupation and $(1 - S_t^{ls})$ for leisure. A high educated worker in a complex occupation spends a portion H_t^{hc} hours at work and $(1 - H_t^{hc})$ at leisure. A high educated worker in a simple occupation spends a portion H_t^{hs} hours at work, a portion O_t to search on the job for a complex occupation, and $(1 - H_t^{hs} - O_t)$ for leisure. The low educated worker in a simple occupation spends a portion H_t^{ls} hours at work and $(1 - H_t^{ls})$ at leisure.

As different employment histories among members of a household can lead to heterogeneous wealth positions, we follow the literature in assuming that each household is thought of as an extended family whose members perfectly insure each other against variations in labor income due to employment or unemployment. Remaining within the confines of complete markets allows solving the program of a representative household, which chooses consumption and search intensities to maximize the expected discounted infinite sum of its instantaneous utility which is separable in consumption and leisure. Assuming the household has the value function $\Gamma_t^H = \Gamma^H(H_t^{hc}N_t^{hc}, H_t^{hs}N_t^{hs}, H_t^{ls}N_t^{ls})$, the optimization problem of the household can be written in the recursive form

$$\Gamma_t^H = \underset{\{C_t, S_t^{hc}, S_t^{hs}, O_t, S_t^{ls}\}}{\text{Max}} \left\{ \mho(C_t) + U_t^h \Omega_t^h + U_t^l \Omega_t^l + N_t^{hc}\Omega_t^{hc} + N_t^{hs}\Omega_t^{hs} + N_t^{ls}\Omega_t^{ls} + \beta E_t\left[\Gamma_{t+1}^H\right] \right\}, \quad (3)$$

where E_t is the expectation operator conditional on the information set available in period t, β is the discount factor, and $\mho(C_t)$ is the utility of period-t consumption of the household C_t. $\Omega_t^h = \Omega^h(1 - S_t^{hc} - S_t^{hs})$, and $\Omega_t^l = \Omega^l(1 - S_t^{ls})$ denote the utility of period-t leisure of the high and the low educated unemployed, respectively. $\Omega_t^{hc} = \Omega^{hc}(1 - H_t^{hc})$, $\Omega_t^{hs} = \Omega^{hs}(1 - H_t^{hs} - O_t)$, and $\Omega_t^{ls} = \Omega^{ls}(1 - H_t^{ls})$ denote the utility of period-t leisure of the employed types. This is subject to the budget constraint

$$C_t = N_t^{ls}H_t^{ls}W_t^{ls} + N_t^{hs}H_t^{hs}W_t^{hs} + N_t^{hc}H_t^{hc}W_t^{hc} + D_t, \quad (4)$$

where W_t^{ij} is the period-t wage for labor type ij, and D_t is the dividends distributed by firms. The households also take into consideration the employment dynamics of the three types of workers. The high educated workers in complex occupations in period $(t+1)$ are composed of those of that type who are not exogenously separated in period t according to the separation rate from complex occupations χ^{hc}, in addition to the new matches from the searchers pool, whether they are high educated unemployed or on-the-job searchers,

$$N_{t+1}^{hc} = (1 - \chi^{hc})N_t^{hc} + P_t^{hc}\left(S_t^{hc}U_t^h + O_t N_t^{hs}\right), \quad (5)$$

where $P_t^{hc} = M_t^{hc}/(S_t^{hc}U_t^h + O_t N_t^{hs})$ is the probability that a high educated searcher is matched with a complex occupation, and $M_t^{hc} = M^{hc}(V_t^c, S_t^{hc}U_t^h + O_t N_t^{hs})$ represents the number of complex matches. Similarly, the high educated workers in simple occupations in period $(t+1)$ are composed of those of that type who are neither separated from simple occupations exogenously in period t according to the separation rate χ^{hs}, nor are matched with complex occupations as a result of on-the-job search, in addition to the new matches from the searchers pool of the high educated unemployed,

$$N_{t+1}^{hs} = (1-\chi^{hs})\left(1 - O_t P_t^{hc}\right) N_t^{hs} + P_t^{hs}\left(S_t^{hs} U_t^h\right), \tag{6}$$

where $P_t^{hs} = M_t^{hs}/S_t^{hs}U_t^h$ is the probability that a high educated searcher is matched with a simple occupation, and $M_t^{hs} = M^{hs}(Z_t V_t^s, S_t^{hs}U_t^h)$ represents the number of simple matches with the high educated. Z_t is the proportion of simple vacancies directed to the high educated. Finally, the low educated workers in simple occupations in period $(t+1)$ are composed of those of that type who are not exogenously separated in period t according to the separation rate χ^{ls}, in addition to the new matches from the searchers pool of the low educated unemployed,

$$N_{t+1}^{ls} = (1-\chi^{ls})N_t^{ls} + P_t^{ls}\left(S_t^{ls} U_t^l\right), \tag{7}$$

where $P_t^{ls} = M_t^{ls}/S_t^{ls}U_t^l$ is the probability that a low educated searcher is matched with a simple occupation, and $M_t^{ls} = M^{ls}[(1-Z_t)V_t^s, S_t^{ls}U_t^l]$ represents the number of simple matches with the low educated. The constant separation rates are justified by Hall (2005), who concludes that over the past fifty years job separation rates have remained almost constant in the United States, and by Shimer (2005), who demonstrates that separation rates exhibit acyclicality. The matching functions are constant–returns to scale homogeneous functions of degree one of the number of corresponding vacancies, V_t^c and V_t^s, and effective searchers. The representative household chooses consumption such that the marginal utility of consumption equals the Lagrange multiplier λ_t,

$$\frac{\partial \mho(C_t)}{\partial C_t} = \lambda_t. \tag{8}$$

The household chooses the optimal proportion of time the high educated unemployed allot to searching for a complex occupation S_t^{hc}, such that the disutility from increasing search by one unit is offset by the discounted expected value of an additional high educated worker in a complex occupation,

$$\frac{\partial \Omega^h}{\partial S_t^{hc}} + \beta P_t^{hc} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hc}}\right] = 0. \tag{9}$$

The household chooses the optimal proportion of time the high educated unemployed allot to searching for simple occupations S_t^{hs}, such that the disutility from increasing search by one unit is offset by the discounted expected value of an additional high educated worker in a simple occupation,

$$\frac{\partial \Omega^h}{\partial S_t^{hs}} + \beta P_t^{hs} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hs}}\right] = 0. \tag{10}$$

The household chooses the optimal proportion of time the low educated unemployed allot to searching for a simple occupation S_t^{ls}, such that the disutility from increasing search by one unit is offset by the discounted expected value of an additional low educated worker in a simple occupation,

$$\frac{\partial \Omega^{l}}{\partial S_t^{ls}} + \beta P_t^{ls} E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{ls}} \right] = 0. \quad \textbf{(11)}$$

The household chooses on-the-job search intensity O_t, such that the disutility from increasing search by one unit is offset by the difference between the discounted expected value to the household from an additional high educated worker in a complex occupation and that of an additional high educated worker in a simple occupation,

$$\frac{\partial \Omega^{hs}}{\partial O_t} + P_t^{hc} \beta E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hc}} \right] - P_t^{hc} \beta E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hs}} \right] (1 - \chi^{hs}) = 0. \quad \textbf{(12)}$$

From the envelope theorem, an additional high educated worker matched with a complex occupation accrues a value to the household that is given by

$$\begin{aligned} \frac{\partial \Gamma_t^{H}}{\partial N_t^{hc}} &= \Omega^{hc} \left(1 - H_t^{hc}\right) - \Omega^{h} \left(1 - S_t^{hc} - S_t^{hs}\right) + \lambda_t W_t^{hc} H_t^{hc} \\ &\quad + \beta \left(1 - \chi^{hc} - P_t^{hc} S_t^{hc}\right) E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hc}} \right] - \beta P_t^{hs} S_t^{hs} E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hs}} \right]. \end{aligned} \quad \textbf{(13)}$$

Similarly, an additional high educated worker matched with a simple occupation accrues a value to the household that is given by

$$\begin{aligned} \frac{\partial \Gamma_t^{H}}{\partial N_t^{hs}} &= \Omega^{hs} \left(1 - H_t^{hs} - O_t\right) - \Omega^{h} \left(1 - S_t^{hc} - S_t^{hs}\right) + \lambda_t W_t^{hs} H_t^{hs} \\ &\quad + \beta \left[(1 - \chi^{hs}) \left(1 - O_t P_t^{hc}\right) - P_t^{hs} S_t^{hs}\right] E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hs}} \right] \\ &\quad + \beta \left(P_t^{hc} O_t - P_t^{hc} S_t^{hc}\right) E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{hc}} \right]. \end{aligned} \quad \textbf{(14)}$$

Finally, an additional low educated worker matched with a simple occupation accrues a value to the household that is given by

$$\begin{aligned} \frac{\partial \Gamma_t^{H}}{\partial N_t^{ls}} &= \Omega^{ls} \left(1 - H_t^{ls}\right) - \Omega^{l} \left(1 - S_t^{ls}\right) + \lambda_t W_t^{ls} H_t^{ls} \\ &\quad + \left(1 - \chi^{ls} - P_t^{ls} S_t^{ls}\right) E_t \left[\frac{\partial \Gamma_{t+1}^{H}}{\partial N_{t+1}^{ls}} \right]. \end{aligned} \quad \textbf{(15)}$$

Substituting the envelope conditions into the first order conditions yields the following representative household's optimal conditions:

$$\frac{\tau^h}{\beta P_t^{hc}} = -\tau^h E_t\left(1 - S_{t+1}^{hc} - S_{t+1}^{hs}\right) + E_t\left[\Omega^{hc}\left(1 - H_{t+1}^{hc}\right)\right] + E_t\left[\frac{H_{t+1}^{hc}W_{t+1}^{hc}}{C_{t+1}}\right] + E_t\left[\left(1 - \chi^{hc} - P_{t+1}^{hc}S_{t+1}^{hc}\right)\left(\frac{\tau^h}{P_{t+1}^{hc}}\right)\right] - E_t\left[\tau^h S_{t+1}^{hs}\right], \quad (16)$$

$$\frac{\tau^h}{\beta P_t^{hs}} = -\tau^h E_t\left(1 - S_{t+1}^{hc} - S_{t+1}^{hs}\right) + E_t\left[\Omega^{hs}\left(1 - H_{t+1}^{hs} - O_{t+1}\right)\right] + E_t\left[\frac{H_{t+1}^{hs}W_{t+1}^{hs}}{C_{t+1}}\right] + E_t\left[\tau^h\left(O_{t+1} - S_{t+1}^{hc}\right)\right] + E_t\left[\left((1 - \chi^{hs})\left(1 - O_{t+1}P_{t+1}^{hc}\right) - P_{t+1}^{hs}S_{t+1}^{hs}\right)\left(\frac{\tau^h}{P_{t+1}^{hs}}\right)\right], \quad (17)$$

$$\frac{\tau^l}{\beta P_t^{ls}} = -\tau^l E_t\left(1 - S_{t+1}^{ls}\right) + E_t\left[\Omega^{ls}\left(1 - H_{t+1}^{ls}\right)\right] + E_t\left[\frac{H_{t+1}^{ls}W_{t+1}^{ls}}{C_{t+1}}\right] + E_t\left[\left(1 - \chi^{ls} - P_{t+1}^{ls}S_{t+1}^{ls}\right)\left(\frac{\tau^l}{P_{t+1}^{ls}}\right)\right], \quad (18)$$

where τ^h and τ^l are the marginal utilities of leisure of the high and the low educated unemployed, respectively.

3.2. Firms

The representative firm chooses the number of complex and simple vacancies to post, besides the proportion of the simple vacancies directed to the high educated, in order to maximize the discounted expected infinite sum of its future profit streams. The profit function is given by the difference between the value of its production, where the price of one unit of output is normalized to one, and the total cost incurred for creating the two types of vacancies, as well as the wages of the three labor types. Assuming the firm has the value function $\Gamma_t^F = \Gamma^F(H_t^{hc}N_t^{hc}, H_t^{hs}N_t^{hs}, H_t^{ls}N_t^{ls})$, the optimization problem can be written in the recursive form

$$\Gamma_t^F = \underset{\{V_t^s, V_t^c, Z_t\}}{\text{Max}}\left\{Y_t - \omega^s V_t^s - \omega^c V_t^c - N_t^{hc}H_t^{hc}W_t^{hc} - N_t^{hs}H_t^{hs}W_t^{hs} - N_t^{ls}H_t^{ls}W_t^{ls} + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\Gamma_{t+1}^F\right]\right\}, \quad (19)$$

where ω^c is the cost of creating a complex vacancy, and ω^s is the cost of creating a simple vacancy. The discount factor of firms is such that it effectively evaluates profits in terms of the values attached to them by households, who ultimately own the firms. Thus, the utility-based and time-varying discount factor used by firms is given by $(\beta\lambda_{t+1}/\lambda_t)$. The maximization is subject to the production function, which is a composite of the complex occupation output $(H_t^{hc}N_t^{hc})$ and the simple occupation output $(H_t^{ls}N_t^{ls} + H_t^{hs}N_t^{hs})$,

$$Y_t = Y\left[A_t, \left(H_t^{hc}N_t^{hc}\right), \left(H_t^{ls}N_t^{ls} + H_t^{hs}N_t^{hs}\right)\right], \tag{20}$$

where A_t is the aggregate technology. The maximization problem of the firm is also subject to the employment dynamics:

$$N_{t+1}^{hc} = (1-\chi^{hc})N_t^{hc} + q_t^{hc}V_t^c, \tag{21}$$

$$N_{t+1}^{hs} = (1-\chi^{hs})\left(1 - O_t P_t^{hc}\right)N_t^{hs} + q_t^{hs}Z_t V_t^s, \tag{22}$$

$$N_{t+1}^{ls} = (1-\chi^{ls})N_t^{ls} + q_t^{ls}(1-Z_t)V_t^s, \tag{23}$$

where $q_t^{hc} = M_t^{hc}/V_t^c$ is the probability of filling a complex vacancy, $q_t^{hs} = M_t^{hs}/Z_t V_t^s$ is the probability that a simple vacancy is filled by a high educated worker, and $q_t^{ls} = M_t^{ls}/(1-Z_t)V_t^s$ is the probability that a simple vacancy is filled by a low educated worker. The firm chooses the optimal level of complex vacancies to post, V_t^c, such that the expected marginal cost of posting this type of vacancy is equal to the discounted expected value for the firm of an additional high educated worker in a complex occupation,

$$\frac{\omega^c}{q_t^{hc}} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{hc}}\right]. \tag{24}$$

The firm chooses the optimal level of simple vacancies to post, V_t^s, such that the cost of posting a simple vacancy is equal to the discounted expected value of creating an occupation from this vacancy, whether it is filled by a high or a low educated worker,

$$\omega^s = q_t^{hs}Z_t\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{hs}}\right] + q_t^{ls}(1-Z_t)\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{ls}}\right]. \tag{25}$$

The firm chooses the optimal proportion of simple vacancies directed to the high educated, Z_t, so that the discounted expected value of an additional high educated worker in a simple occupation is equal to the discounted expected value of an additional low educated worker in a simple occupation:

$$q_t^{hs}E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{hs}}\right] = q_t^{ls}E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{ls}}\right]. \tag{26}$$

From the envelope theorem, the value for the firm of an additional high educated worker in a complex occupation is given by the difference between its marginal productivity and the wage, in addition to the discounted expected value of the match in case the worker is not exogenously separated,

$$\frac{\partial \Gamma_t^F}{\partial N_t^{hc}} = \frac{\partial Y_t}{\partial N_t^{hc}} - H_t^{hc} W_t^{hc} + (1-\chi^{hc})\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{hc}} \right]. \tag{27}$$

Similarly, the value for the firm of an additional high educated worker in a simple occupation is given by the difference between its marginal productivity and the wage, in addition to the discounted expected value of the match in case the worker is neither exogenously separated nor matched with a complex occupation as a result of on-the-job search,

$$\frac{\partial \Gamma_t^F}{\partial N_t^{hs}} = \frac{\partial Y_t}{\partial N_t^{hs}} - H_t^{hs} W_t^{hs} + (1-\chi^{hs})\left(1 - O_t P_t^{hc}\right)\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{hs}} \right]. \tag{28}$$

Finally, the value for the firm of an additional low educated worker in a simple occupation is given by the difference between its marginal productivity and the wage, in addition to the discounted expected value of the match in case the worker is not exogenously separated,

$$\frac{\partial \Gamma_t^F}{\partial N_t^{ls}} = \frac{\partial Y_t}{\partial N_t^{ls}} - H_t^{ls} W_t^{ls} + (1-\chi^{ls})\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{ls}} \right]. \tag{29}$$

Substituting the envelope conditions into the first-order conditions yields the representative firm's optimal conditions,

$$\frac{\omega^c}{q_t^{hc}} = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{\partial Y_{t+1}}{\partial N_{t+1}^{hc}} - H_{t+1}^{hc} W_{t+1}^{hc} + (1-\chi^{hc}) \frac{\omega^c}{q_{t+1}^{hc}} \right] \right\}, \tag{30}$$

$$\frac{\omega^s}{q_t^{hs}} = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{\partial Y_{t+1}}{\partial N_{t+1}^{hs}} - H_{t+1}^{hs} W_{t+1}^{hs} + (1-\chi^{hs})\left(1 - O_{t+1} P_{t+1}^{hc}\right) \frac{\omega^s}{q_{t+1}^{hs}} \right] \right\}, \tag{31}$$

$$\frac{\omega^s}{q_t^{ls}} = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{\partial Y_{t+1}}{\partial N_{t+1}^{ls}} - H_{t+1}^{ls} W_{t+1}^{ls} + (1-\chi^{ls}) \frac{\omega^s}{q_{t+1}^{ls}} \right] \right\}. \tag{32}$$

3.3. Wages and Hours

We follow the literature in assuming that a realized match share the surplus through a bargaining problem. Therefore, the wage of a high educated worker in a complex occupation is given by[2]

$$H_t^{hc}W_t^{hc} = (1-\xi^{hc})\left[\frac{\partial Y_t}{\partial N_t^{hc}} + P_t^{hc}S_t^{hc}\frac{\omega^c}{q_t^{hc}}\right] + \xi^{hc}C_t\left[\Omega^h\left(1 - S_t^{hc} - S_t^{hs}\right)\right.$$
$$\left. - \Omega^{hc}\left(1 - H_t^{hc}\right) + S_t^{hs}\tau^h\right], \tag{33}$$

where ξ^{hc} is the firm's share of the surplus. The wage is a weighted average of two terms: the first indicates that the worker is rewarded by a fraction $(1-\xi^{hc})$ of both the firm's revenues from the worker's productivity and the discounted expected value of the match to the firm. The second term indicates that the worker is compensated by a fraction ξ^{hc} for the foregone benefit from the worker's outside option or the difference between the leisure of a high educated unemployed person and that of a high educated worker in a complex occupation, in addition to the forgone benefit from being matched with a simple vacancy. Similarly, the wage of the high educated worker in a simple occupation is given by[3]

$$H_t^{hs}W_t^{hs} = (1-\xi^{hs})\left[\frac{\partial Y_t}{\partial N_t^{hs}} + P_t^{hs}S_t^{hs}\frac{\omega^s}{q_t^{hs}}\right] + \xi^{hs}C_t\left[\Omega^h\left(1 - S_t^{hc} - S_t^{hs}\right)\right.$$
$$\left. - \Omega^{hs}\left(1 - H_t^{hs} - O_t\right) - \left(O_t - S_t^{hc}\right)\tau^h\right], \tag{34}$$

where ξ^{hs} is the firm's share of the surplus. The wage is a weighted average of two terms: the first indicates that the worker is rewarded by a fraction $(1-\xi^{hs})$ of both the firm's revenues from the worker's productivity and the discounted expected value of the match for the firm. The second term indicates that the worker is compensated by a fraction ξ^{hs} for the outside options or the difference between the leisure of a high educated unemployed person and that of a high educated worker in a simple occupation, in addition to the forgone benefit from being matched with a complex vacancy. Finally, the bargained wage of the low educated worker in a simple occupation is given by[4]

$$H_t^{ls}W_t^{ls} = (1-\xi^{ls})\left[\frac{\partial Y_t}{\partial N_t^{ls}} + P_t^{ls}S_t^{ls}\frac{\omega^s}{q_t^{ls}}\right] + \xi^{ls}C_t\left[\Omega^l\left(1 - S_t^{ls}\right)\right.$$
$$\left. - \Omega^{ls}\left(1 - H_t^{ls}\right)\right], \tag{35}$$

where ξ^{ls} is the firm's share of the surplus. The wage is a weighted average of two terms: the first indicates that the worker is rewarded by a fraction $(1-\xi^{ls})$ of the firm's revenues from the worker's productivity and the discounted expected value of the match for the firm. The second term indicates that the worker is compensated by a fraction ξ^{ls} for the outside options or the difference between the leisure of a low educated unemployed person and that of a low educated worker in a simple occupation.

The hours of the high educated in complex occupations are chosen so that the disutility of leisure from increasing the hours of work by one unit is offset by the increase in marginal productivity due to an increase in hours by one unit,[5]

$$\frac{\partial\left(\partial Y_t/\partial N_t^{hc}\right)}{\partial H_t^{hc}} + \left(\frac{1}{\lambda_t}\right)\frac{\partial \Omega_t^{hc}}{\partial H_t^{hc}} = 0. \quad (36)$$

The hours of the high educated in simple occupations are chosen so that the disutility of leisure from increasing the hours of work by one unit is offset by the increase in marginal productivity due to an increase in hours by one unit,[6]

$$\frac{\partial\left(\partial Y_t/\partial N_t^{hs}\right)}{\partial H_t^{hs}} + \left(\frac{1}{\lambda_t}\right)\frac{\partial \Omega_t^{hs}}{\partial H_t^{hs}} = 0. \quad (37)$$

The hours of the low educated in simple occupations are chosen so that the disutility of leisure from increasing the hours of work by one unit is offset by the increase in marginal productivity due to an increase in hours by one unit,[7]

$$\frac{\partial\left(\partial Y_t/\partial N_t^{ls}\right)}{\partial H_t^{ls}} + \left(\frac{1}{\lambda_t}\right)\frac{\partial \Omega_t^{ls}}{\partial H_t^{ls}} = 0. \quad (38)$$

Finally, the crowding-out effect is defined as

$$\text{Crowding}_t = \frac{N_t^{hs} H_t^{hs}}{N_t^{hs} H_t^{hs} + N_t^{ls} H_t^{ls}}. \quad (39)$$

Total unemployment is defined as $U_t = U_t^h + U_t^l$. To close the model, we have

$$Y_t = C_t + \omega^c V_t^c + \omega^s V_t^s. \quad (40)$$

4. CALIBRATION

The functional forms are determined and the parameters are calibrated in order to solve the model numerically. In this context, numerical values are assigned to the structural parameters in order to conduct a quantitative analysis. Table 4 shows the values chosen for the parameters of the model. In this context, some of the parameters are set as is standard in the literature. Because information may not be available for the other parameters, their values are computed in the steady state system of equations after values are set for variables quantifiable from the data. It is worth mentioning that the time period in the model is a quarter.

The steady state values for certain variables are calculated from the averages in the data set during the period under study. For instance, the proportion of the high educated in the population, δ, is set at 0.5, which equals the data average. Similarly, the proportions of the employed types are set at $N^{hc} = 0.23$, $N^{hs} = 0.25$, $N^{ls} = 0.46$ and the unemployed types at $U^h = \delta - N^{hc} - N^{hs} = 0.02$, $U^l = 1 - \delta - N^{ls} = 0.04$, and $U = 0.06$, which are equal to the data averages during the period under study as well.

TABLE 4. Calibration of model parameters

Exogenous	Value	Description
δ	0.5	Proportion of the high educated in the population
β	0.98	Household discount factor
η	4	Parameter in the utility of leisure
χ^{hc}	0.01	Separation rate from complex occupations
χ^{hs}	0.02	Separation rate of high educated from simple occupations
χ^{ls}	0.02	Separation rate of low educated from simple occupations
γ	0.5	Elasticity of matches with respect to vacancies
μ	0.5	Elasticity of output to complex occupation output
ξ^{hc}	0.5	Firm share from bargaining with a high educated worker in a complex occupation
ξ^{hs}	0.5	Firm share from bargaining with a high educated worker in a simple occupation
ξ^{ls}	0.5	Firm share from bargaining with a low educated worker in a simple occupation
ρ^A	0.9	Autoregressive coefficient of aggregate technology
$\sigma_{\epsilon A}$	0.0049	Standard deviation of the aggregate technology shock
Calibrated	**Value**	**Description**
ω^c	2.28	Cost of posting a complex vacancy
ω^s	0.12	Cost of posting a simple vacancy
T^{hc}	0.1	Efficiency in the complex-occupation matching function
T^{hs}	0.1	Efficiency in the simple-occupation matching function with the high educated
T^{ls}	0.1	Efficiency in the simple occupation matching function with the low educated
τ^h	1.7	Parameter in the utility of leisure of the high educated unemployed
τ^l	0.7	Parameter in the utility of leisure of the low educated unemployed
τ^{hc}	2.5	Parameter in the utility of leisure of the high educated in complex occupations
τ^{hs}	0.7	Parameter in the utility of leisure of the high educated in simple occupations
τ^{ls}	0.6	Parameter in the utility of leisure of the low educated in simple occupations

Given the proportion of employment of all types, the three wages, W^{hc}, W^{hs}, and W^{ls}, are set equal to the data average, such that the steady state skill premium

$$\frac{\left(\dfrac{N^{hc}W^{hc}+N^{hs}W^{hs}}{N^{hc}+N^{hs}}\right)}{W^{ls}}$$

is 1.52, which is also equal to the data average in the period under study. In addition, given the proportion of employment of every type, the hours of work of every type is chosen equal to the data average, such that Crowding $= N^{hs}H^{hs}/(N^{hs}H^{hs} + N^{ls}H^{ls}) = 0.39$ is also set equal to the data average.

The household's discount factor β is given by 0.98, which is standard in the literature. The instantaneous utility function of consumption is represented by the logarithm of consumption expenditures, $\mho(C_t) = \ln(C_t)$. A nonlinear utility function of leisure is introduced to examine the case when workers are risk-averse to fluctuations in hours worked. In this context, if workers dislike high volatility in hours, firms find it more appealing to adjust the level of employment rather than the level of hours. Therefore, the instantaneous utility function of leisure is given by $\Omega_t^h = \tau^h(1 - S_t^{hc} - S_t^{hs})^{1-\eta}/(1-\eta)$, $\Omega_t^l = \tau^l(1 - S_t^{ls})^{1-\eta}/(1-\eta)$, $\Omega_t^{hc} = \tau^{hc}(1 - H_t^{hc})^{1-\eta}/(1-\eta)$, $\Omega_t^{hs} = \tau^{hs}(1 - H_t^{hs} - O_t)^{1-\eta}/(1-\eta)$, $\Omega^{ls} = \tau^{ls}(1 - H_t^{ls})^{1-\eta}/(1-\eta)$, such that $\eta = 4$, which implies that the average individual labor supply elasticity is $\frac{1}{2}$, which is consistent with the bulk of empirical estimates. The parameter in the utility of leisure for the high educated unemployed, τ^h, is given by 1.7; for the low educated unemployed, τ^l is given by 0.7. The parameter in the utility of leisure for the high educated in complex occupations, τ^{hc}, is given by 2.5; for the high educated in simple occupations, τ^{hs} is given by 0.7; and for the low educated in simple occupations, τ^{ls} is given by 0.6. These parameters are solved for in the steady state equations for the optimal hours of work, given the proportion of employment and hours of work of every type.

The matching functions for the complex and simple occupations are represented as a Cobb–Douglas specification with constant returns to scale, and are given by $M_t^{hc} = T^{hc}(V_t^c)^\gamma(S_t^{hc}U_t^h + O_tN_t^{hs})^{1-\gamma}$, $M_t^{hs} = T^{hs}(Z_tV_t^s)^\gamma(S_t^{hs}U_t^h)^{1-\gamma}$, and $M_t^{ls} = T^{ls}((1-Z_t)V_t^s)^\gamma(S_t^{ls}U_t^l)^{1-\gamma}$, where $\gamma \in (0, 1)$ is the elasticity of matching with respect to vacancies. T^{hc}, T^{hs}, and T^{ls} are the level parameters of the matching functions, which capture all factors that influence the efficiency of matching. The elasticity of matches with respect to vacancies γ is set at 0.5, as is standard in the literature. The level parameters in the matching functions T^{hc}, T^{hs}, and T^{ls} are given by 0.1. The choice of the level parameters is determined to target the separation rates. In steady state, the flows out of employment equal the flows out of unemployment. This ensures that the employment level of every type stays constant. Thus, we have $\chi^{hc}N^{hc} = M^{hc}$, $(\chi^{hs} + OP^{hc} - \chi^{hs}OP^{hc})N^{hs} = M^{hs}$, and $\chi^{ls}N^{ls} = M^{ls}$ in steady state. Therefore, the choice of T^{hc}, T^{hs}, and T^{ls} determines the matches, and accordingly targets the separation rates.

The separation rates χ^{hc}, χ^{hs}, and χ^{ls} from the complex and simple occupations are given by 0.01, 0.02, and 0.02, respectively. These are selected so that the separation rate from simple vacancies is higher than that in complex ones, and so their average is close to the weighted average separation rate calculated by Hall (2005) and Shimer (2005).

The costs of creating the complex vacancy ω^c and the simple vacancy ω^s are 2.28 and 0.12, respectively. These values are determined through the steady state equations for the optimal number of vacancies. The firm's shares of the surplus,

ξ^{hc}, ξ^{hs}, and ξ^{ls}, are set at 0.5, 0.5, and 0.5, respectively, as is standard in the literature. The bargaining power of the households is set equal to the elasticity of matching with respect to vacancies, which, as shown in Hosios (1990), implies that the bargaining process yields a Pareto-optimal allocation of resources.

The technological constraints faced by the firm is also represented by a constant–returns to scale Cobb–Douglas function, $Y_t = A_t(H_t^{hc}N_t^{hc})^{\mu}(H_t^{hs}N_t^{hs} + H_t^{ls}N_t^{ls})^{1-\mu}$, where $\mu \in (0, 1)$ is the elasticity of output with respect to the complex occupation output. The logarithm of the aggregate technology A_t is assumed to follow an AR(1) process as follows,

$$\log A_{t+1} = \rho^A \log A_t + \epsilon_{t+1}^A, \qquad (41)$$

where ϵ_{t+1}^A is an independently and identically distributed random variable drawn from a normal distribution with mean zero and standard deviation denoted by $\sigma_{\epsilon A}$. The elasticity parameter in the production function μ is given by 0.5, as in Krause and Lubik (2004). The autoregressive coefficient in the technological law of motion, ρ^A, is given by 0.9. As is common in the literature, an innovation variance is chosen such that the baseline model's predictions match the standard deviation of the U.S. GDP, which is 1.62%. Consequently, the standard deviation of technology is set to $\sigma_{\epsilon A} = 0.0049$.

5. ANALYSIS

5.1. Impulse Responses

The model is solved by computing the nonstochastic steady state around which the equation system is linearized. The resulting model is solved by the methods developed in Sims (2002). The success of the model can be primarily assessed by comparing the serial correlations of the total unemployment rate, and the unemployment rates of the high and the low educated produced by the model, referred to as the benchmark model, and those observed in the data. Table 3 shows that the model succeeds in reproducing the high persistence observed in the data. For instance, the first lagged serial correlation of total unemployment is 0.870 in the data and 0.922 in the model. The first lagged autocorrelation of the unemployment of the high educated is 0.796 in the data and 0.908 in the model, whereas that of the unemployment of the low educated is 0.855 in the data and 0.871 in the model. For the remaining lagged serial correlations of the unemployment variables, the persistence is higher in the model than in the data.

The impulse responses in Figures 1 and 2 show the dynamic evolution of the variables of interest, along with a deviation of output from its long-run trend as a consequence of a negative aggregate technological shock. The adverse shock decreases the productivity of all types of workers. This reduces the discounted expected value to the firm of an additional worker of any type. The firm posts complex vacancies so that the expected marginal cost of posting a complex vacancy

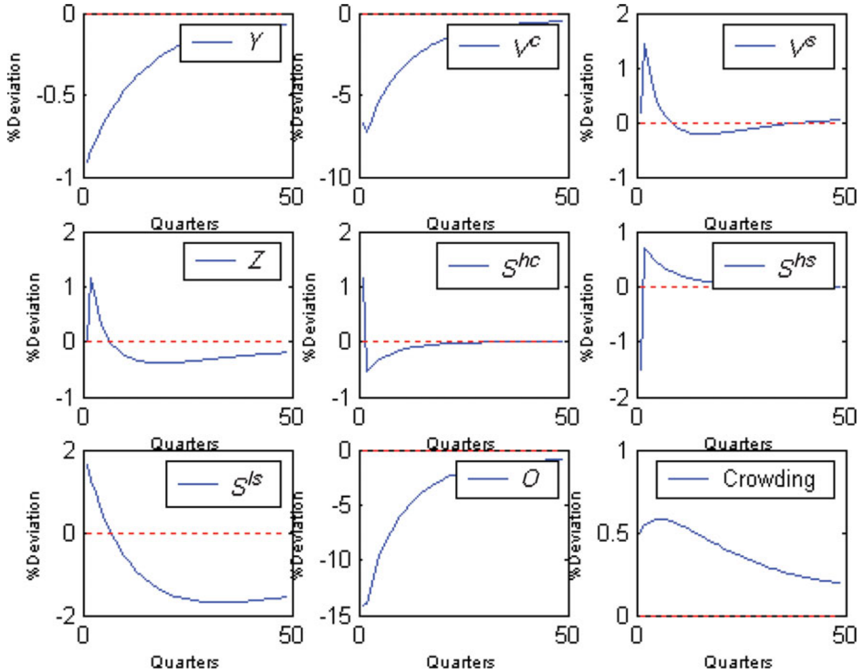

FIGURE 1. Benchmark model impulse response functions to a negative 1% aggregate technological shock.

is equal to the discounted expected value for the firm of an additional high educated worker. Accordingly, the decrease in the marginal productivity of workers induces firms to decrease their posting of complex vacancies. On the other hand, firms post simple vacancies so that the expected marginal cost of posting a simple vacancy is equal to the discounted expected value of creating an occupation from this vacancy, whether it is filled by a high or a low educated worker. Even though the productivity of both types of workers declined, the probability that a simple vacancy is filled by a high educated worker increases. This causes an increase in the posting of simple vacancies directed to the high educated.

Accordingly, the intensity of search for simple vacancies by the high educated increases, and that of search for complex vacancies decreases. This causes a decline in the employment of the high educated in complex occupations, and an increase in the employment of the high educated in simple occupations. As the decline in the former is smaller than the increase in the latter, the unemployment of the high educated increases slightly and then decreases with a lag, contrary to the observations.

On the other hand, the low educated unemployed reduce their search intensity for simple occupations because of the decline in the proportion of simple vacancies directed to this type. This causes a decrease in the employment of the low educated

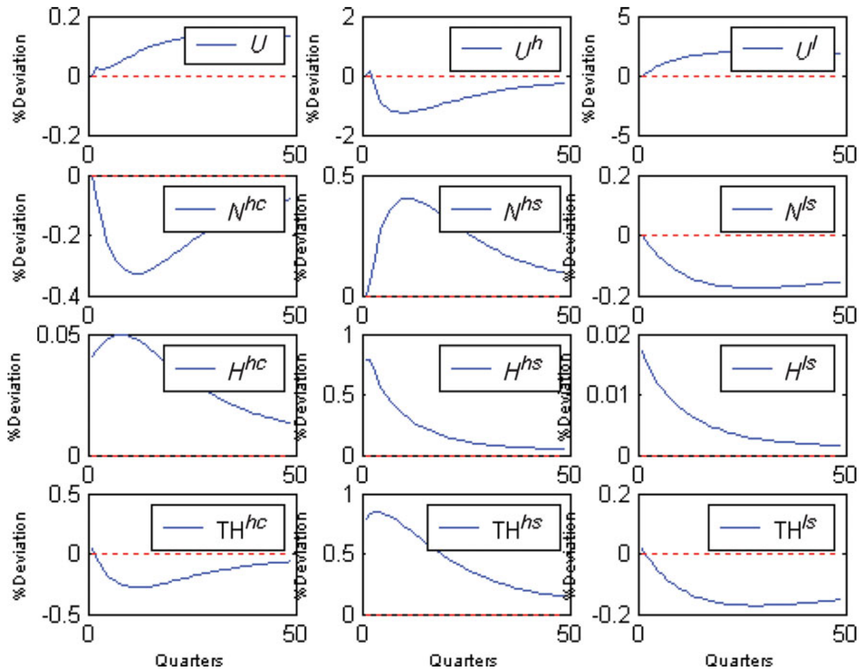

FIGURE 2. Benchmark model impulse response functions to a negative 1% aggregate technological shock.

in simple occupations and an increase in the unemployment of the low educated. The impulse responses show a high persistence of total unemployment, and that the persistence of unemployment of the low educated is higher than that of the high educated, consistent with the observations.

The hours of work of any type are chosen so that the disutility of leisure from increasing the hours of work by one unit is offset by the increase in marginal productivity due to an increase in hours by one unit. Figure 2 shows that the hours of work of all types in this model increase. This reflects the risk aversion of workers to fluctuations in hours worked. In this context, the firms respond to the adverse shock by adjusting the level of employment and not the hours of work. Due to the increase in the employment and the hours of the high educated in simple occupations, the total hours of this type increase. Therefore, the crowding-out variable increases. This crowding out of the low educated by the high educated contributes to the persistence of unemployment.

Comparing the moments of the model in Table 5 to the data, the model succeeds in several respects. The model replicates the lagged procyclicality of the employment of the high educated in complex occupations, and the lagged procyclicality of the total hours of the high educated in complex occupations. The model does not succeed in reproducing the procyclicality of the employment and total hours of

TABLE 5. Benchmark model moments: standard errors in () calculated by bootstrapping

	Cross correlations of output(t) and $x(t+i)$								
x	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$
N^{hc}	0.6462	0.6850	0.7259	0.7645	0.8058	0.8550	0.8924	0.9154	0.9292
	(0.0558)	(0.0498)	(0.0428)	(0.0353)	(0.0287)	(0.0218)	(0.0157)	(0.0115)	(0.0093)
H^{hc}	−0.7406	−0.7841	−0.8241	−0.8691	−0.9256	−0.9238	−0.9264	−0.9285	−0.9200
	(0.0371)	(0.0325)	(0.0262)	(0.0192)	(0.0114)	(0.0103)	(0.0096)	(0.0088)	(0.0101)
TH^{hc}	0.6244	0.6622	0.7031	0.7403	0.7786	0.8367	0.8803	0.9070	0.9247
	(0.0558)	(0.0503)	(0.0448)	(0.0395)	(0.0332)	(0.0246)	(0.0177)	(0.0140)	(0.0096)
N^{hs}	−0.6467	−0.6852	−0.7260	−0.7650	−0.8057	−0.8536	−0.8967	−0.9206	−0.9332
	(0.0550)	(0.0486)	(0.0406)	(0.0341)	(0.0285)	(0.0223)	(0.0147)	(0.0110)	(0.0089)
H^{hs}	−0.8170	−0.8593	−0.8882	−0.9284	−0.9934	−0.9168	−0.8527	−0.8098	−0.7589
	(0.0218)	(0.0199)	(0.0160)	(0.0111)	(0.0009)	(0.0125)	(0.0210)	(0.0270)	(0.0281)
TH^{hs}	−0.7867	−0.8299	−0.8674	−0.9116	−0.9699	−0.9514	−0.9372	−0.9256	−0.9037
	(0.0317)	(0.0252)	(0.0198)	(0.0134)	(0.0045)	(0.0064)	(0.0089)	(0.0099)	(0.0118)
N^{ls}	0.2416	0.2943	0.3509	0.4013	0.4542	0.5178	0.5769	0.6255	0.6663
	(0.0906)	(0.0823)	(0.0747)	(0.0758)	(0.0703)	(0.0638)	(0.0584)	(0.0515)	(0.0461)
H^{ls}	−0.8129	−0.8568	−0.8882	−0.9322	−0.9990	−0.9258	−0.8772	−0.8438	−0.7989
	(0.0230)	(0.0206)	(0.0158)	(0.0107)	(0.0002)	(0.0116)	(0.0174)	(0.0213)	(0.0245)
TH^{ls}	0.1934	0.2457	0.3028	0.3526	0.4034	0.4735	0.5374	0.5894	0.6342
	(0.0910)	(0.0911)	(0.0788)	(0.0803)	(0.0726)	(0.0670)	(0.0624)	(0.0594)	(0.0500)

TABLE 5. Continued.

	Cross correlations of output(t) and $x(t+i)$								
x	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$
U^h	0.6462	0.6840	0.7240	0.7645	0.8034	0.8470	0.9075	0.9341	0.9432
	(0.0508)	(0.0482)	(0.0423)	(0.0334)	(0.0303)	(0.0242)	(0.0138)	(0.0092)	(0.0075)
U^l	−0.2416	−0.2943	−0.3509	−0.4013	−0.4542	−0.5178	−0.5769	−0.6255	−0.6663
	(0.0885)	(0.0833)	(0.0799)	(0.0784)	(0.0697)	(0.0626)	(0.0568)	(0.0529)	(0.0460)
U	−0.0190	−0.0748	−0.1353	−0.1876	−0.2440	−0.3088	−0.3600	−0.4127	−0.4633
	(0.0952)	(0.0892)	(0.0875)	(0.0865)	(0.0843)	(0.0835)	(0.0802)	(0.0741)	(0.0722)
Crowding	−0.7365	−0.7822	−0.8241	−0.8712	−0.9312	−0.9267	−0.9246	−0.9233	−0.9114
	(0.0391)	(0.0332)	(0.0274)	(0.0193)	(0.0104)	(0.0093)	(0.0103)	(0.0099)	(0.0113)

Notes: TH^{hc}: total hours of the high educated in complex occupations; TH^{hs}: total hours of the high educated in simple occupations; TH^{ls}: total hours of the low educated in simple occupations.

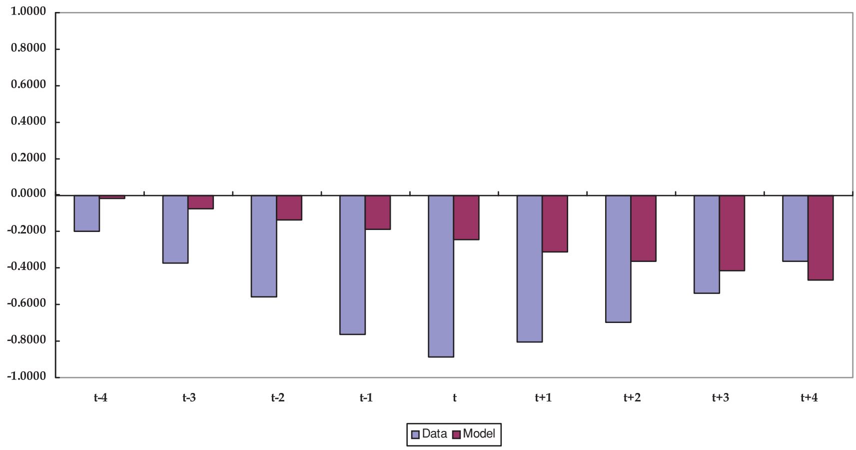

FIGURE 3. Comparison of cross correlations between output and total unemployment in the benchmark model and the data.

the high educated in simple occupations. The model reproduces the procyclicality of the employment and the total hours of the low educated in simple occupations, but the cyclical pattern of these variables exhibits a lag in the model. The model also succeeds in replicating the countercyclicality of the unemployment of the low educated and the total unemployment. The cyclical behavior of these variables shows a lag that is not observed in the data. The countercyclicality of the unemployment of the high educated is not reproduced by the model for the reasons discussed in the analysis of the impulse responses.

The cyclical upgrading of jobs is reflected in the lagged procyclical employment and total hours of the high educated in complex occupations, which is concomitant to lagged countercyclical employment of the high educated in simple occupations. To further assess the success of the model, a comparison between the cross-correlation coefficients of the total unemployment rate of the model and the data is shown in Figure 3. This figure shows how close the correlation coefficients in the model to those observed in the data. Finally, the model produces a countercyclical crowding-out effect, without the lag that is observed in the data.

5.2. Sensitivity Analysis

The robustness of the results of the model is examined to check whether the dynamic evolution of the variables of interest is sensitive to the features of a specific framework. The model with job competition and crowding out is considered a benchmark. This framework is compared to another model where there are two types of workers and two types of vacancies, but the aspects of job competition and crowding out are assumed away. In this context, the complex vacancies are filled by the high educated only, whereas the simple vacancies are filled by the low

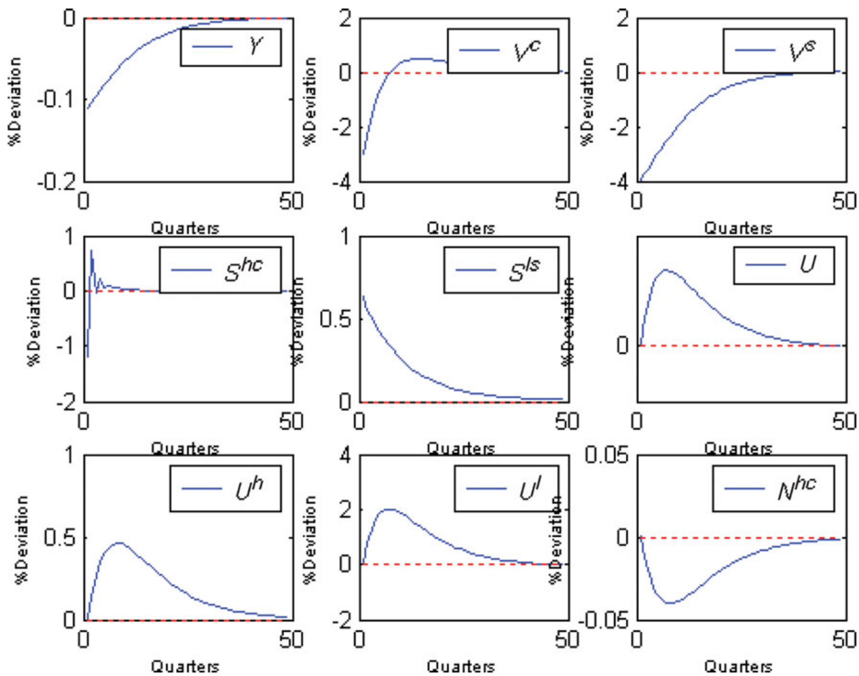

FIGURE 4. No-crowding model impulse response functions to a negative 1% aggregate technological shock.

educated only. There is no on-the-job search in this case. This model is referred to as the "no-crowding" model[8] hereinafter. The impulse responses of this model are shown in Figures 4 and 5. The serial correlations of the total unemployment, and that of the unemployment of the high and the low educated are shown in Table 3. An adverse technological shock reduces the productivity of the high educated and the low educated workers. Firms decrease the creation of complex and simple vacancies, and thus the unemployed reduce their search intensities. This causes a decline in the employment of the two types and an increase in the unemployment rates. The serial correlations of total unemployment and unemployment of the high and the low educated are higher than those observed in the data.

The benchmark model is also compared to another model where there is only one type of worker and one type of vacancy. This model is referred to as the "no-skills" model[9] hereinafter. The impulse responses of this model are shown in Figure 6. The serial correlations of the total unemployment rate are shown in Table 3. An adverse technological shock reduces the creation of vacancies. The unemployed reduce their search intensities, and unemployment increases. The persistence of total unemployment in this case is higher than that observed in the data or in the benchmark model.

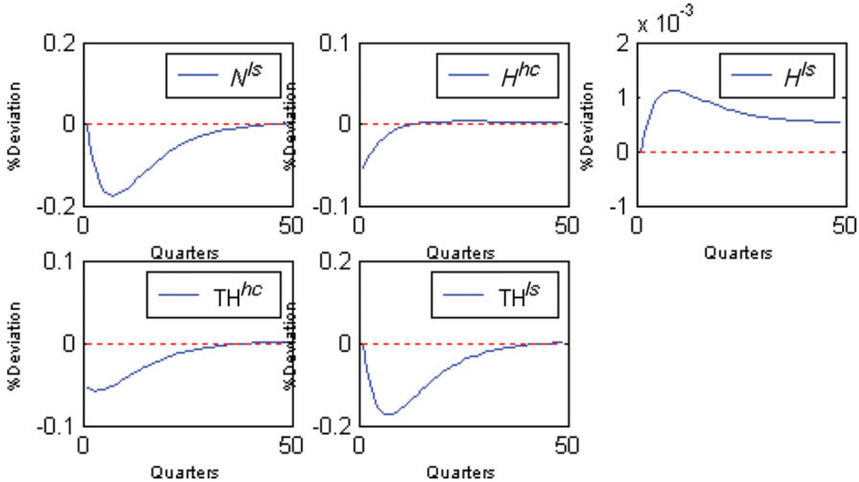

FIGURE 5. No-crowding model impulse response functions to a negative 1% aggregate technological shock.

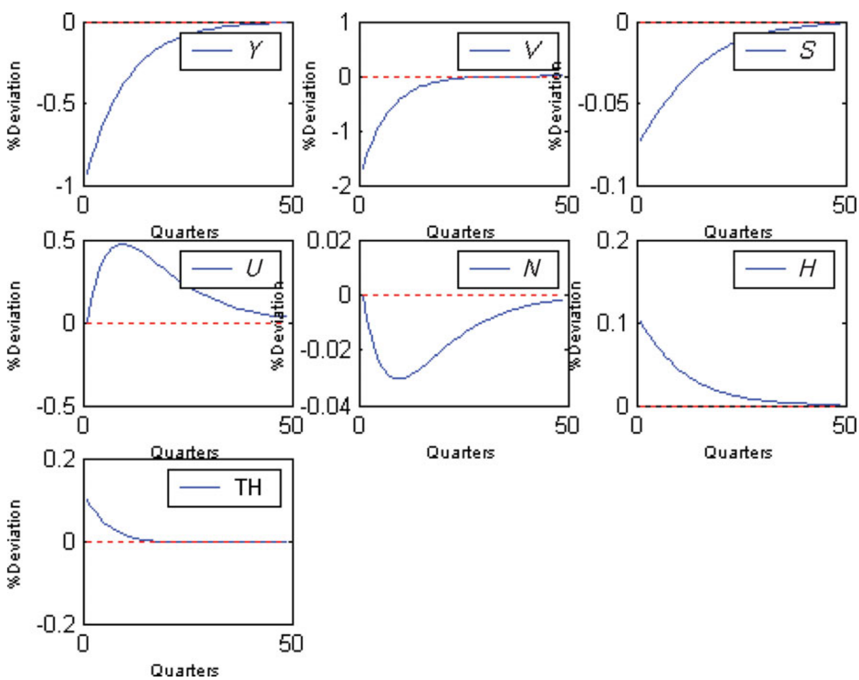

FIGURE 6. No-skills model impulse response functions to a negative 1% aggregate technological shock.

It is obvious from the serial correlations that the "no-crowding" model exhibits the highest persistence, followed by the "no-skills" model, and then the benchmark model, whose persistence is the closest to that of the data. This can be attributed to the observation that after the initial shock, the recovery of the economy is captured in faster recovery of the hours of work, rather than in the employment levels. This causes the unemployment, in these models with the endogenous choice of hours of work, to exhibit higher persistence. The benchmark model is relatively more successful in reproducing the persistence of unemployment because of the feature of job competition, which allows the employment of the high educated in simple occupations to increase after the adverse shock, and accordingly to reduce the unemployment persistence compared to the other models without that feature.

6. CONCLUSION

This paper attempts to explain the persistence of total unemployment and unemployment across skills over the business cycle. A set of stylized facts imply that economic expansion is accompanied contemporaneously by a rise in the total hours of all labor types in simple occupations and followed with a lag by an increase in the total hours of all those employed in complex occupations and a decrease in the crowding out of the low educated by the high educated in occupying simple jobs. These observations might be intuitively interpreted to reflect a lagged downgrading of jobs by the high educated from a complex to a simple occupation after an adverse shock. Job competition between the high and the low educated to occupy simple jobs, and the subsequent crowding out of the low educated into unemployment by the high educated, can provide a possible explanation for the persistence of unemployment.

To comprehend the factors behind the evolution of these patterns, a model is developed where workers of heterogeneous education levels search for two types of vacancies that are distinguished by their educational requirements. On-the-job search is allowed. A negative aggregate technological shock induces the high educated unemployed to compete with the low educated by increasing their search intensity for simple occupations. As they occupy simple vacancies, they crowd out the low educated into unemployment. This downgrading of jobs, or the increase in the labor input of the high educated in simple occupations, generates the persistence of unemployment.

The success of this model is attributed to the additional dynamics that it introduces, such as competition between those distinguished by their educational levels for a job with a particular educational requirement, the crowding out of the unsuccessful by the successfully matched, and the possibility of a mismatch between the educational level of the successful and the educational requirement of the job they occupy. Possible extensions to the model include the introduction of skill loss when the worker is unemployed for an extended period of time. A comparison between the impact of skill loss and crowding out as two possible explanations of unemployment persistence could enhance our understanding of economic fluctuations in a labor market with heterogeneous agents.

NOTES

1. Detailed data description is included in Appendix A.
2. Detailed derivations are included in Appendix A.2.
3. Detailed derivations are included in Appendix A.2.
4. Detailed derivations are included in Appendix A.2.
5. Detailed derivations are included in Appendix A.2.
6. Detailed derivations are included in Appendix A.2.
7. Detailed derivations are included in Appendix A.2.
8. The details of the "no-crowding" model are available from the author upon request.
9. The details of the "no-skills" model are available from the author upon request.

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APPENDIX

A.1. DATA

The data set used is the Outgoing Rotation Group of the Current Population Survey. The Current Population Survey is a rotating panel. After the fourth month in the survey, the participants take an eight-month hiatus. Afterwards, they are interviewed for another four months, and after the eighth month in sample, they are completely dropped from the survey.

TABLE A.1. Extracted variables

Variable	Definition
MONTH	Month of interview
MLR	Monthly labor force recode
GRDHI	Highest grade attended
GRDATN	Educational attainment
OCC	Occupation of job last week
HOURS	Total hours worked last week
ERNWGT	Earnings weight

The Outgoing Rotation series is a merged collection of the fourth and eighth month-in-sample groups from all twelve months. These two groups play a special role, as they are given additional questions, the answers to which are collected in the Outgoing Rotation Group files. The data are monthly and cover the period from January 1979 until December 2008. At the end of each year, the twelve monthly files from January to December are concatenated into a single annual file. The variables extracted are shown in Table A.1.

Each annual file is divided into monthly files according to the variable MONTH. For each monthly file, participants in the labor force are split into those employed and those unemployed according to MLR. This variable distinguishes between the employed, the unemployed, and those not in the labor force. Both the employed and the unemployed are further split into high educated and low educated workers, where the former are those who obtained some college education or higher. Table A.2 shows the variables' ranges defining the high and the low educated.

Each worker group, the high or the low educated, is further divided into two groups: those employed in complex occupations and those employed in simple occupations, where the former are jobs that require at least some college education. This mapping between occupations and educational requirements is based on judgment. In most cases, it is straightforward to determine whether an occupation requires college education. In the cases where it is not clear, the occupations are considered once as complex and another time as simple. The results did not change. The complex and simple occupations are defined by the ranges of the variable OCC specified in Table A.3.

Therefore, we have four employed and two unemployed types: the high educated employed in a complex occupation, the high educated employed in a simple occupation, the high educated unemployed, the low educated employed in a complex occupation, the low educated employed in a simple occupation, and the low educated unemployed.

The weighted average hours worked last week for each of the working groups are calculated using the proper weights ERNWGT. These weights are created for each month

TABLE A.2. Ranges for high and low education levels

Period	High educated	Low educated
1979–1988	$14 \leqslant \text{GRDHI} \leqslant 19$	$1 \leqslant \text{GRDHI} \leqslant 13$
1989–1991	$13 \leqslant \text{GRDHI} \leqslant 18$	$1 \leqslant \text{GRDHI} \leqslant 12$
1992–2008	$40 \leqslant \text{GRDATN} \leqslant 46$	$31 \leqslant \text{GRDATN} \leqslant 39$

TABLE A.3. Ranges for complex and simple occupation types

Period	Complex occupation	Simple occupation
1979–1982	1–85	86–90
	91–96	100–101
	102–246	260–995
1983–1991	0–173	174–177
	178–242	243–991
1992–2002	0–163	164–165
	166–173	174–177
	178–242	243–999
2003–2008	10–1960	2000–2060
	2100–3650	3700–9830

so that, when applied, the resulting counts are representative of the national counts. Thus, the proper application of weights enables the results to be presented in terms of the population of the United States as a whole, instead of just the participants in the survey. To calculate measures of employment and unemployment, the variable MLR is used to distinguish the two groups. The unemployed are divided into high and low educated as explained earlier. The employed are divided into four types as explained earlier. The total hours are calculated by multiplying the level of employment in every type by the weighted average weekly hours of work for each type. A crowding-out variable is calculated as the proportion of the total hours of the high educated amongst the total hours of all those employed in simple occupations. Finally, the variables compiled and used in the analysis are (1) the employment level and the hours of the high educated in complex occupations, (2) the total hours of the high educated employed in complex occupations, (3) the employment level and the hours of the high educated in simple occupations, (4) the total hours of the high educated employed in simple occupations, (5) the employment level and the hours of the low educated in simple occupations, (6) the total hours of the low educated employed in simple occupations, (7) the proportion of the high educated unemployed, (8) the proportion of the low educated unemployed, and (9) the crowding out. Finally, the real Gross Domestic Product data (chained dollars, seasonally adjusted at annual rates) are extracted from the National Income and Product Accounts. As the Gross Domestic Product data are quarterly, these monthly time series are transformed into quarterly ones by taking three-month averages. All variables, except the unemployment ratios and the crowding out, are logged. The data are seasonally adjusted or deseasonalized using a ratio to moving average multiplicative seasonal filter. All variables are detrended using the Hodrick–Prescott filter with a smoothing parameter of 1600.

The aggregate unemployment rate is extracted from the Bureau of Labor Statistics. The data are the monthly seasonally adjusted percentages of unemployment in the labor force of those 16 years and over. The total private average weekly hours of production workers are also extracted from the Bureau of Labor Statistics. The data are monthly and seasonally adjusted. The aggregate data are detrended using the Hodrick–Prescott filter with a smoothing parameter of 1600.

A.2. DERIVATIONS

The wage of the high educated in a complex occupation is determined by

$$W_t^{hc} = \text{argmax} \left[\frac{1}{\lambda_t} \frac{\partial \Gamma_t^H}{\partial N_t^{hc}} \right]^{1-\xi^{hc}} \left[\frac{\partial \Gamma_t^F}{\partial N_t^{hc}} \right]^{\xi^{hc}} .$$

Thus the sharing rule implies $\xi^{hc}[\partial \Gamma_t^H / \partial N_t^{hc}] = (1-\xi^{hc})\lambda_t [\partial \Gamma_t^F / \partial N_t^{hc}]$. Substituting the envelope conditions of the household $\partial \Gamma_t^H / \partial N_t^{hc}$ and of the firm $\partial \Gamma_t^F / \partial N_t^{hc}$, in addition to

$$\xi^{hc} \frac{\beta}{\lambda_t} E_t \left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hc}} \right] = (1-\xi^{hc}) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{hc}} \right] = (1-\xi^{hc}) \frac{\omega^c}{q_t^{hc}}$$

from the first-order condition, yields

$$\xi^{hc} \left[-\Omega_t^h + \Omega_t^{hc} + \lambda_t W_t^{hc} H_t^{hc} + \left(1-\chi^{hc} - P_t^{hc} S_t^{hc}\right) \lambda_t \frac{1-\xi^{hc}}{\xi^{hc}} \frac{\omega^c}{q_t^{hc}} - \beta P_t^{hs} S_t^{hs} \frac{\tau^h}{\beta P_t^{hs}} \right]$$
$$= (1-\xi^{hc})\lambda_t \left[\frac{\partial Y_t}{\partial N_t^{hc}} - H_t^{hc} W_t^{hc} + (1-\chi^{hc}) \frac{\omega^c}{q_t^{hc}} \right].$$

Solving for the equilibrium wage rule for the high educated workers in complex occupations yields (33).

The wage of the high educated in a simple occupation is determined by

$$W_t^{hs} = \text{argmax} \left[\frac{1}{\lambda_t} \frac{\partial \Gamma_t^H}{\partial N_t^{hs}} \right]^{1-\xi^{hs}} \left[\frac{\partial \Gamma_t^F}{\partial N_t^{hs}} \right]^{\xi^{hs}} .$$

Thus the sharing rule implies $\xi^{hs}[\partial \Gamma_t^H / \partial N_t^{hs}] = (1-\xi^{hs})\lambda_t [\partial \Gamma_t^F / \partial N_t^{hs}]$. Substituting the envelope conditions of the household $\partial \Gamma_t^H / \partial N_t^{hs}$ and of the firm $\partial \Gamma_t^F / \partial N_t^{hs}$, in addition to

$$\xi^{hs} \frac{\beta}{\lambda_t} E_t \left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hs}} \right] = (1-\xi^{hs}) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{hs}} \right] = (1-\xi^{hs}) \frac{\omega^s}{q_t^{hs}}$$

from the first-order condition, yields

$$\xi^{hs} \left[\begin{array}{c} -\Omega^h \left(1 - S_t^{hc} - S_t^{hs}\right) + \Omega^{hs} \left(1 - H_t^{hs} - O_t\right) + \lambda_t W_t^{hs} H_t^{hs} \\ +\beta \left((1-\chi^{hs}) \left(1 - O_t P_t^{hc}\right) - P_t^{hs} S_t^{hs} \right) \frac{1-\xi^{hs}}{\xi^{hs}} \lambda_t \frac{\omega^s}{q_t^{hs}} \\ +\beta \left(P_t^{hc} O_t - P_t^{hc} S_t^{hc} \right) \frac{\tau^h}{\beta P_t^{hc}} \end{array} \right]$$
$$= (1-\xi^{hs})\lambda_t \left[\frac{\partial Y_t}{\partial N_t^{hs}} - H_t^{hs} W_t^{hs} + (1-\chi^{hs}) \left(1 - O_t P_t^{hc}\right) \frac{\omega^s}{q_t^{hs}} \right].$$

Solving for the equilibrium wage rule for the high educated workers in simple occupations yields (34).

The wage of the low educated in a simple occupation is determined by

$$W_t^{ls} = \text{argmax} \left[\frac{1}{\lambda_t} \frac{\partial \Gamma_t^H}{\partial N_t^{ls}} \right]^{1-\xi^{ls}} \left[\frac{\partial \Gamma_t^F}{\partial N_t^{ls}} \right]^{\xi^{ls}} .$$

Thus the sharing rule implies $\xi^{ls}[\partial\Gamma_t^H/\partial N_t^{ls}] = (1-\xi^{ls})\lambda_t[\partial\Gamma_t^F/\partial N_t^{ls}]$. Substituting the envelope conditions of the household $\partial\Gamma_t^H/\partial N_t^{ls}$ and of the firm $\partial\Gamma_t^F/\partial N_t^{ls}$, in addition to

$$\xi^{ls}\frac{\beta}{\lambda_t}E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right] = (1-\xi^{ls})\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial\Gamma_{t+1}^F}{\partial N_{t+1}^{ls}}\right] = (1-\xi^{ls})\frac{\omega^s}{q_t^{ls}}$$

from the first-order condition, yields

$$\xi^{ls}\left[-\Omega^l\left(1-S_t^{ls}\right)+\Omega^{ls}\left(1-H_t^{ls}\right)+\lambda_t W_t^{ls}+\left(1-\chi^{ls}-P_t^{ls}S_t^{ls}\right)\frac{1-\xi^{ls}}{\xi^{ls}}\lambda_t\frac{\omega^s}{q_t^{ls}}\right]$$
$$=(1-\xi^{ls})\lambda_t\left[\frac{\partial Y_t}{\partial N_t^{ls}}-H_t^{ls}W_t^{ls}+(1-\chi^{ls})\frac{\omega^s}{q_t^{ls}}\right].$$

Solving for the equilibrium wage for low educated workers in simple occupations yields (35).

The hours of work of the high educated workers in complex occupations are given by

$$H_t^{hc} = \text{argmax}\left[\left(\frac{1}{\lambda_t}\frac{\partial\Gamma_t^H}{\partial N_t^{hc}}\right)+\left(\frac{\partial\Gamma_t^F}{\partial N_t^{hc}}\right)\right].$$

Substituting the envelope conditions for $\partial\Gamma_t^H/\partial N_t^{hc}$ and $\partial\Gamma_t^F/\partial N_t^{hc}$, the hours are thus given by (36).

The hours of work of the high educated workers in simple occupations are given by

$$H_t^{hs} = \text{argmax}\left[\left(\frac{1}{\lambda_t}\frac{\partial\Gamma_t^H}{\partial N_t^{hs}}\right)+\left(\frac{\partial\Gamma_t^F}{\partial N_t^{hs}}\right)\right].$$

Substituting the envelope conditions for $\partial\Gamma_t^H/\partial N_t^{hs}$ and $\partial\Gamma_t^F/\partial N_t^{hs}$, the hours are thus given by (37).

The hours of work of the low educated workers in simple occupations are given by

$$H_t^{ls} = \text{argmax}\left[\left(\frac{1}{\lambda_t}\frac{\partial\Gamma_t^H}{\partial N_t^{ls}}\right)+\left(\frac{\partial\Gamma_t^F}{\partial N_t^{ls}}\right)\right].$$

Substituting the envelope conditions for $\partial\Gamma_t^H/\partial N_t^{ls}$ and $\partial\Gamma_t^F/\partial N_t^{ls}$, the hours are thus given by (38).