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LABOR MISMATCH, SKILL OBSOLESCENCE AND UNEMPLOYMENT PERSISTENCE

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Abstract

This paper attempts to assess the impact of skill loss by both the unemployed and the mismatched workers on the persistence of unemployment. The observations show that the total unemployment rate is highly persistent, and that the persistence of the unemployment rate of the unskilled workers is higher than that of the skilled workers. A framework that features search frictions is developed, where workers are either high educated or low educated. Firms post complex and simple vacancies that can be matched with both the high and the low educated. The high educated lose their skills if unemployed, and if employed 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, and the subsequent skill mismatch and obsolescence, allow the model to capture the observed unemployment persistence.

Keywords: unemployment, skill loss, business cycle, search and matching.

JEL Classification: E24, E32, J64.

1. Introduction

This paper attempts to assess the impact of skill loss and obsolescence on the persistence of unemployment over the business cycle. The paper argues that in a cyclical downturn, as the probability of unemployment increases, skilled workers compete with unskilled workers for unskilled occupations. As the skilled occupy unskilled jobs, they crowd out the unskilled into unemployment. Accordingly, there is a mismatch between the educational qualifications of the skilled workers, and the educational requirements of the unskilled jobs they occupy. Skilled workers lose their skills not only while unemployed for an extended period of time, but also when employed in occupations that do not require their specific skills. The unemployed skilled workers lose their skills because they are not applying their skills in the working place. The

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skilled workers, mismatched with unskilled occupations, lose their skills because the jobs they are occupying do not require the application of their skills in the working place. As the mismatched skilled workers lose their skills, and become unskilled, they are more likely to be crowded out of unskilled jobs due to their higher separation rates. These mismatched workers, who lose their skills and flow into unemployment as unskilled unemployed, in addition to the unemployed skilled workers who lose their skills are less attractive to potential employers. This lowers the probability of employment, and causes unemployment to exhibit persistence. Even though few studies considered the aspect of skill loss of the skilled unemployed, this paper extends the analysis to consider the skill obsolescence of the mismatched labor as well. The extension allows the paper to succeed in capturing the observed unemployment persistence.

To this purpose, the paper derives a set of stylized facts that captures not only the high persistence of the total unemployment rate, but also the higher persistence of the unemployment rate of the unskilled workers compared to that of the skilled workers. In addition, the observations capture the cyclical allocation of labor input in a labor market with heterogeneous agents across educational levels. 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 dataset is compiled including measures of employment of the high educated in complex and in simple occupations, employment of the low educated in complex and in simple occupations, besides the total unemployment rate, and the unemployment rates of the high educated 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 all those employed in complex occupations and a decrease in the unemployment of all types of labor, and the crowding out effect. These observations reflect a possible lagged downgrading of jobs and a consequent crowding out of the low educated into unemployment after an adverse shock. The labor mismatch, besides the skill loss of the high educated unemployed and the high educated in simple occupations, provide a possible explanation for the persistence of unemployment.

The paper develops a model to identify the factors 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. The labor force is divided into high educated and low educated workers. Firms post two types of vacancies: the complex and the simple that can be matched with the high and the low educated. The high educated in simple occupations are allowed to search on-the-job for a complex occupation. The high educated lose their skills if unemployed, and if employed in simple occupations. The low educated in complex occupations acquire training to become high educated. 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, and the subsequent skill loss, allow the model to capture the observed unemployment persistence.

This paper adopts a different approach compared to previous studies that attempted to explain the persistence of unemployment. For instance, Esteban-Pretel (2003) and Esteban-Pretel and Faraglia (2005) include the aspect of skill loss by the high educated if unemployed for an extended period of time. 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. 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 an 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, since the perceived productivity of an unemployed worker may be lower than that of an employed worker. 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 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. Khalifa (2012) shows that in a cyclical downturn, the skilled workers compete with unskilled workers over unskilled jobs, and thus crowd out the unskilled into unemployment. Accordingly, there is a mismatch between the educational qualifications of the skilled workers, and the educational requirements of the unskilled jobs they occupy. The job competition across skills and the crowding out of the unskilled into unemployment provide an explanation for the unemployment persistence.

This paper, however, argues that unemployment persistence can be reproduced in a model without the aspects of recurring job loss, or ranking of job applicants. The paper is the first attempt in the literature to consider the two aspects of labor mismatch and skill loss to explain unemployment persistence. The paper also improves upon the studies that focused only on the skill loss of the unemployed by considering the additional aspect of skill obsolescence of mismatched labor as well. 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. This downgrading of jobs, and the subsequent labor mismatch and skill obsolescence, 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, section 6 concludes, section 7 includes the data and derivations appendices. References, tables and figures are included thereafter.

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.[2] 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. Levels of employment are calculated for all the employed types. Using the weighted average weekly hours of work of each group and the level of employment, the total hours of each group is 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 high educated amongst all those employed in simple occupations, such that its increase reflects an increase in the crowding out process 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 total hours of the high educated employed in complex occupations, (2) the total hours of the low educated employed in complex occupations, (3) the total hours of the high educated employed in simple occupations, (4) the total hours of the low educated employed in simple occupations, (5) the proportion of the high educated unemployed, (6) the proportion of the low educated unemployed, and (7) the crowding out effect. This monthly time series is transformed into quarterly data by taking three months averages.

The cross correlation coefficients between real gross domestic product in period t and these variables in lag and lead periods are displayed in table 5. These patterns demonstrate that the total hours of the high educated in complex occupations is procyclical and lags the cycle by 3 quarters, as the cross correlation coefficient with output reaches 0.4742 which is statistically significant. The total hours of the low educated in complex occupations is procyclical and lags the cycle by 4 quarters, as the cross correlation coefficient with output reaches 0.2570 which is statistically significant. The total hours of the high and the low educated in simple occupations are positively correlated with contemporaneous output with statistically significant cross correlation coefficients of 0.5483 and 0.7105, respectively. The proportion of the high educated unemployed is countercyclical and lags the cycle where the cross correlation coefficient with output reaches -0.6275 and is statistically significant, while the proportion of the low educated unemployed is countercyclical where the cross correlation coefficient with output of

[2] Detailed data description is included in appendix 7.1.

-0.8877 is also statistically significant. The total unemployment rate is countercyclical where the cross correlation coefficient of -0.8877 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 total hours of the high educated in complex occupations is procyclical with a lag. (2) The total hours of the low educated in complex occupations is procyclical with a lag. (3) The total hours of the high educated in simple occupations is procyclical. (4) The total hours of the low educated in simple occupations is procyclical. (5) The unemployment rate of the high educated is countercyclical with a lag. (6) The unemployment rate of the low educated is countercyclical. (7) The total unemployment rate is countercyclical. (8) The crowding out effect is countercyclical with a lag.

Table 6 shows the countercyclical pattern of the aggregate unemployment rate extracted from the Bureau of Labor Statistics BLS. This observation is consistent with those on the disaggregated data extracted from the Current Population Survey CPS. Table 7 displays the serial correlations of the total unemployment rate, and that 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.

This paper uses of the 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. For instance, the lagged increase in the total hours of the high educated in complex occupations reveals a possible lagged procyclical upgrading of jobs. Evidence on the cyclical upgrading of jobs is provided by Devereux (2000, 2004) who 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. The skill loss of the mismatched workers 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 representative firm posts complex and simple vacancies. The complex and simple vacancies are matched with both the high educated and the low educated. The firm also chooses the proportion of complex and simple vacancies directed towards the high educated and the low educated. An explanation can be that there are different newspapers for the high educated and for the low educated, where 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 by their creation costs, and these costs generate rents which give rise to equilibrium wage differentials between occupation types. The setup also features skill loss by the high educated unemployed, and by the high educated in simple occupations. Finally, the low educated in complex occupations acquire training to become high educated. Figure 1 shows the model flows into and out of employment and unemployment.

3.1 Households

Let N_t^{ij} denote 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. Let U_t^i denote the number of the unemployed of type i. Assume that the high educated unemployed lose their skills with probability σ, and that the high educated in simple occupations lose their skills with probability θ. Therefore, the high educated unemployed, excluding those who lost their skills, are denoted $U_t^h = (1-\sigma)\left(U_t^h\right)^*$. The low educated unemployed, including the high educated unemployed who lost their skills, are denoted $U_t^l = \sigma\left(U_t^h\right)^* + \left(U_t^l\right)^*$. The high educated in simple occupations, excluding those who lost their skills, are denoted $N_t^{hs} = (1-\theta)\left(N_t^{hs}\right)^*$. The low educated employed in simple occupations, including the high educated in simple occupations who lost their skills, are denoted $N_t^{ls} = \left(N_t^{ls}\right)^* + \theta\left(N_t^{hs}\right)^*$. The high educated in complex occupations, including the low educated who completed their training in complex occupations, are denoted $N_t^{hc} = \left(N_t^{hc}\right)^* + \delta\left(N_t^{lc}\right)^*$. The low educated in complex occupations, excluding those who completed their training, are denoted $N_t^{lc} = (1-\delta)\left(N_t^{lc}\right)^*$. The variables with the stars denote employment and unemployment before skill loss and acquisition. The labor force is normalized to one. In this context, the high and the low educated household members are divided into those employed and those unemployed as follows

$$N_t^{hc} + N_t^{hs} + N_t^{lc} + N_t^{ls} + U_t^h + U_t^l = 1 \quad \text{… (1)}$$

Time for all types is normalized to one. A high educated unemployed, excluding those who lost their skills, 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 $\left(1 - S_t^{hc} - S_t^{hs}\right)$ for leisure. A low educated unemployed, including the high educated unemployed who lost their skills, uses a portion S_t^{lc} of its time to search for a complex occupation, a portion S_t^{ls} of its time to search for a simple occupation, and $\left(1 - S_t^{lc} - S_t^{ls}\right)$ for leisure. A high educated worker in a complex occupation, including the low educated who completed their training, spends a portion H_t^{hc} hours at work and $\left(1 - H_t^{hc}\right)$ for leisure. A high educated worker in a simple occupation, excluding those who lost their skills, spends a portion H_t^{hs} hours at work, a portion O_t to search on-the-job for a complex occupation, and $\left(1 - H_t^{hs} - O_t\right)$ for leisure. The low educated in complex occupations, excluding those who completed their training, spends a portion H_t^{lc} hours at work and $\left(1 - H_t^{lc}\right)$ for leisure. The low educated in a simple occupation, including the high educated in a simple occupation who lost their skills, spends a portion H_t^{ls} hours at work and $\left(1 - H_t^{ls}\right)$ for leisure.

As different employment histories amongst 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, who 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 following value function $\Gamma_t^H = \Gamma^H\left(H_t^{hc}N_t^{hc}, H_t^{hs}N_t^{hs}, H_t^{lc}N_t^{lc}, H_t^{ls}N_t^{ls}\right)$, the optimization problem of the household can be written in the following recursive form

$$\Gamma_t^H = \underset{\{C_t, S_t^{hc}, S_t^{hs}, O_t, S_t^{ls}, S_t^{lc}\}}{\mathrm{Max}} \left\{\mho\left(C_t\right) + U_t^h\Omega_t^h + U_t^l\Omega_t^l + N_t^{hc}\Omega_t^{hc} + N_t^{hs}\Omega_t^{hs} + N_t^{lc}\Omega_t^{lc} + N_t^{ls}\Omega_t^{ls} + \beta E_t\left[\Gamma_{t+1}^H\right]\right\} \qquad \ldots (2)$$

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

$$C_t = N_t^{hc}H_t^{hc}W_t^{hc} + N_t^{hs}H_t^{hs}W_t^{hs} + N_t^{lc}H_t^{lc}W_t^{lc} + N_t^{ls}H_t^{ls}W_t^{ls} + D_t - \varphi\delta N_t^{lc} \qquad \ldots (3)$$

where W_t^{ij} is the period t wage for labor type ij, D_t is the dividends distributed by firms, and φ is the cost of training. 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 comprised 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, who did not lose their skills

$$N_{t+1}^{hc} = \left(1 - \chi^{hc}\right)N_t^{hc} + P_t^{hc}\left(S_t^{hc}U_t^h + O_tN_t^{hs}\right) \qquad \ldots (4)$$

where $P_t^{hc} = \frac{M_t^{hc}}{S_t^{hc}U_t^h + O_tN_t^{hs}}$ is the probability that a high educated searcher is matched with a complex occupation, and $M_t^{hc} = M^{hc}\left(Z_t^cV_t^c, S_t^{hc}U_t^h + O_tN_t^{hs}\right)$ represents the number of complex matches. Z_t^c is the proportion of complex vacancies directed to the high educated. Similarly, the high educated workers in simple occupations in period $t+1$ are comprised of those of that type, who did not lose their skills, and 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, who did not lose their skills

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

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

$$N_{t+1}^{lc} = \left(1 - \chi^{lc}\right) N_t^{lc} + P_t^{lc} S_t^{lc} U_t^l \quad \dots (6)$$

where $P_t^{lc} = \frac{M_t^{lc}}{S_t^{lc} U_t^l}$ is the probability that a low educated searcher is matched with a complex occupation, and $M_t^{lc} = M^{lc}\left(\left(1 - Z_t^c\right) V_t^c, S_t^{lc} U_t^l\right)$ represents the number of complex matches with the low educated. Similarly, the low educated workers in simple occupations in period $t+1$ are comprised of those of that type, including the high educated in simple occupations who lost their skills, 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 including the high educated unemployed who lost their skills

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

where $P_t^{ls} = \frac{M_t^{ls}}{S_t^{ls} U_t^l}$ is the probability that a low educated searcher is matched with a simple occupation, and $M_t^{ls} = M^{ls}\left(\left(1 - Z_t^s\right) V_t^s, S_t^{ls} U_t^l\right)$ represents the number of simple matches with the low educated. Finally, the high educated unemployed in period $t+1$ are comprised of those of that type who did not match with a complex or a simple occupation in period t, in addition to the high educated separated from complex or simple vacancies

$$U_{t+1}^h = \left(1 - P_t^{hc} S_t^{hc} - P_t^{hs} S_t^{hs}\right) U_t^h + \chi^{hc} N_t^{hc} + \chi^{hs} N_t^{hs} \quad \dots (8)$$

The constant separation rates are justified by Hall (2005), who concludes that over the past fifty years job separation rates 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 of degree one functions of the number of corresponding vacancies, V_t^c and V_t^s, and effective searchers. The dynamic equation for U_{t+1}^l is given by (1).

The representative household chooses consumption such that the marginal utility of consumption equals the Lagrange multiplier λ_t, such that $\frac{\partial \mho(C_t)}{\partial C_t} = \lambda_t$. The household chooses the optimal proportion of time the high educated unemployed, who did not lose their skills, allot to search for an occupation type $j \in (c,s)$, S_t^{hj}, such that the disutility from increasing search by one unit is offset by the discounted expected value of an additional high educated in an occupation type j

$$\frac{\partial \Omega^h}{\partial S_t^{hj}} + \beta P_t^{hj} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hj}}\right] - \beta P_t^{hj} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial U_{t+1}^{h}}\right] = 0 \quad \text{… (9)}$$

The household chooses the optimal proportion of time the low educated unemployed, including the high educated unemployed who lost their skills, allot to search for an occupation type $j \in (c,s)$, S_t^{lj}, such that the disutility from increasing search by one unit is offset by the discounted expected value of an additional low educated in an occupation type j

$$\frac{\partial \Omega^l}{\partial S_t^{lj}} + \beta P_t^{lj} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{lj}}\right] = 0 \quad \text{… (10)}$$

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

$$\frac{\partial \Omega^{hs}}{\partial O_t} + P_t^{hc} \beta E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hc}}\right] - P_t^{hc} \beta E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hs}}\right] = 0 \quad \text{… (11)}$$

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

$$\begin{aligned} \frac{\partial \Gamma_t^H}{\partial N_t^{hc}} = {} & \Omega^{hc}\left(1 - H_t^{hc}\right) - \Omega^l\left(1 - S_t^{lc} - S_t^{ls}\right) + \lambda_t W_t^{hc} H_t^{hc} + \beta\left(1 - \chi^{hc}\right) E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{hc}}\right] \\ & + \beta \chi^{hc} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial U_{t+1}^{h}}\right] - \beta P_t^{lc} S_t^{lc} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{lc}}\right] - \beta P_t^{ls} S_t^{ls} E_t\left[\frac{\partial \Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right] \end{aligned} \quad \text{… (12)}$$

An additional high educated matched with a simple occupation accrues a value to the household of

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

An additional low educated matched with a complex occupation accrues a value to the household of

$$\frac{\partial\Gamma_t^H}{\partial N_t^{lc}} = \Omega^{lc}\left(1-H_t^{lc}\right) - \Omega^{l}\left(1-S_t^{lc}-S_t^{ls}\right) + \lambda_t W_t^{lc} H_t^{lc} - \lambda_t \varphi\delta$$
$$+\beta\left(1-\chi^{lc}\right)E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{lc}}\right] - \beta P_t^{lc} S_t^{lc} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{lc}}\right] - \beta P_t^{ls} S_t^{ls} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right] \quad \ldots (14)$$

An additional low educated matched with a simple occupation accrues a value to the household of

$$\frac{\partial\Gamma_t^H}{\partial N_t^{ls}} = \Omega^{ls}\left(1-H_t^{ls}\right) - \Omega^{l}\left(1-S_t^{lc}-S_t^{ls}\right) + \lambda_t W_t^{ls} H_t^{ls} + \left(1-\chi^{ls}\right)E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right]$$
$$-\beta P_t^{lc} S_t^{lc} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{lc}}\right] - \beta P_t^{ls} S_t^{ls} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right] \quad \ldots (15)$$

Finally, an additional high educated unemployed accrues a value to the household that is given by

$$\frac{\partial\Gamma_t^H}{\partial U_t^h} = \Omega^{h}\left(1-S_t^{hc}-S_t^{hs}\right) - \Omega^{l}\left(1-S_t^{lc}-S_t^{ls}\right) + \beta P_t^{hc} S_t^{hc} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{hc}}\right] + \beta P_t^{hs} S_t^{hs} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{hs}}\right]$$
$$+\beta E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial U_{t+1}^h}\right]\left(1-P_t^{hc}S_t^{hc}-P_t^{hs}S_t^{hs}\right) - \beta P_t^{lc} S_t^{lc} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{lc}}\right] - \beta P_t^{ls} S_t^{ls} E_t\left[\frac{\partial\Gamma_{t+1}^H}{\partial N_{t+1}^{ls}}\right] \quad \ldots (16)$$

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

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

$$\frac{\tau^h}{\beta P_t^{hs}} = \tau^{hs} E_t\left(1-H_{t+1}^{hs}\right) + E_t\left[\frac{H_{t+1}^{hs} W_{t+1}^{hs}}{C_{t+1}}\right] + \tau^h E_t\left[\frac{1-\chi^{hs}}{P_{t+1}^{hs}} - 1\right] \quad \ldots (18)$$

$$\frac{\tau^l}{\beta P_t^{lc}} = \tau^{lc} E_t\left(1-H_{t+1}^{lc}\right) + E_t\left[\frac{H_{t+1}^{lc} W_{t+1}^{lc}}{C_{t+1}}\right] + \tau^l E_t\left[\frac{1-\chi^{lc}}{P_{t+1}^{lc}} - 1\right] - E_t\left(\frac{\varphi\delta}{C_{t+1}}\right) \quad \ldots (19)$$

$$\frac{\tau^l}{\beta P_t^{ls}} = \tau^{ls} E_t\left(1-H_{t+1}^{ls}\right) + E_t\left[\frac{H_{t+1}^{ls} W_{t+1}^{ls}}{C_{t+1}}\right] + \tau^l E_t\left[\frac{1-\chi^{ls}}{P_{t+1}^{ls}} - 1\right] \quad \ldots (20)$$

$$\tau^{hs} = \tau^h\left[1-\frac{P_t^{hc}}{P_t^{hs}}\right] \quad \ldots (21)$$

where τ^{ij} is the marginal utility of leisure of labor type i in occupation j.

3.2 Firms

The representative firm chooses the number of complex and simple vacancies to post, besides the proportion of the complex and 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 all labor types. Assuming the firm has the following value function $\Gamma_t^F = \Gamma^F\left(H_t^{hc}N_t^{hc}, H_t^{hs}N_t^{hs}, H_t^{lc}N_t^{lc}, H_t^{ls}N_t^{ls}\right)$, the optimization problem can be written in the following recursive form

$$\Gamma_t^F = \underset{\{V_t^s, V_t^c, Z_t^c, Z_t^s\}}{\text{Max}} \left\{ Y_t - \omega^s V_t^s - \omega^c V_t^c - N_t^{hc}H_t^{hc}W_t^{hc} - N_t^{hs}H_t^{hs}W_t^{hs} - N_t^{lc}H_t^{lc}W_t^{lc} - N_t^{ls}H_t^{ls}W_t^{ls} + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\Gamma_{t+1}^F\right]\right\} \quad \text{… (22)}$$

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 given 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 $\left(\beta\frac{\lambda_{t+1}}{\lambda_t}\right)$. The maximization is subject to the production function

$$Y_t = Y\left[A_t, \left(H_t^{hc}N_t^{hc} + H_t^{lc}N_t^{lc}\right), \left(H_t^{ls}N_t^{ls} + H_t^{hs}N_t^{hs}\right)\right] \quad \text{… (23)}$$

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

$$N_{t+1}^{hc} = \left(1 - \chi^{hc}\right)N_t^{hc} + q_t^{hc}Z_t^cV_t^c \quad \text{… (24)}$$

$$N_{t+1}^{hs} = \left(1 - \chi^{hs} - O_tP_t^{hc}\right)N_t^{hs} + q_t^{hs}Z_t^sV_t^s \quad \text{… (25)}$$

$$N_{t+1}^{lc} = \left(1 - \chi^{lc}\right)N_t^{lc} + q_t^{lc}\left(1 - Z_t^c\right)V_t^c$$

$$N_{t+1}^{ls} = \left(1 - \chi^{ls}\right)N_t^{ls} + q_t^{ls}\left(1 - Z_t^s\right)V_t^s \quad \text{… (26)}$$

where $q_t^{hc} = \frac{M_t^{hc}}{Z_t^cV_t^c}$ is the probability that a complex vacancy is filled by a high educated, $q_t^{hs} = \frac{M_t^{hs}}{Z_t^sV_t^s}$ is the probability that a simple vacancy is filled by a high educated, $q_t^{lc} = \frac{M_t^{lc}}{\left(1-Z_t^c\right)V_t^c}$ is the probability that a complex vacancy is filled by a low educated, and $q_t^{ls} = \frac{M_t^{ls}}{\left(1-Z_t^s\right)V_t^s}$ is the probability that a simple vacancy is filled by a low educated. The firm chooses the optimal level of complex vacancies to post V_t^c , such that the expected marginal cost of posting a complex 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

$$\omega^{c} = q_t^{hc} Z_t^{c} \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hc}} \right] + q_t^{lc} \left(1 - Z_t^{c}\right) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{lc}} \right] \quad \ldots (27)$$

The firm chooses the optimal level of simple vacancies to post V_t^{s}, such 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

$$\omega^{s} = q_t^{hs} Z_t^{s} \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hs}} \right] + q_t^{ls} \left(1 - Z_t^{s}\right) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{ls}} \right] \quad \ldots (28)$$

The firm chooses the optimal proportion of complex vacancies directed to the high educated Z_t^{c}, such that the discounted expected value of an additional high educated worker in a complex occupation is equal to the discounted expected value of an additional low educated worker in a complex occupation

$$q_t^{hc} V_t^{c} E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hc}} \right] = q_t^{ls} V_t^{c} E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{lc}} \right] \quad \ldots (29)$$

The firm chooses the optimal proportion of simple vacancies directed to the high educated Z_t^{s}, such 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

$$q_t^{hs} V_t^{s} E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hs}} \right] = q_t^{ls} V_t^{s} E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{ls}} \right] \quad \ldots (30)$$

From the envelope theorem, the value of an additional high educated worker in a complex occupation for the firm 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

$$\frac{\partial \Gamma_t^{F}}{\partial N_t^{hc}} = \frac{\partial Y_t}{\partial N_t^{hc}} - H_t^{hc} W_t^{hc} + \left(1 - \chi^{hc}\right) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hc}} \right] \quad \ldots (31)$$

Similarly, the value of an additional high educated worker in a simple occupation, who did not lose skills, for the firm 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

$$\frac{\partial \Gamma_t^{F}}{\partial N_t^{hs}} = \frac{\partial Y_t}{\partial N_t^{hs}} - H_t^{hs} W_t^{hs} + \left(1 - \chi^{hs} - O_t P_t^{hc}\right) \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \Gamma_{t+1}^{F}}{\partial N_{t+1}^{hs}} \right] \quad \ldots (32)$$

Similarly, the value of an additional low educated worker in a complex occupation for the firm 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

$$\frac{\partial \Gamma_t^F}{\partial N_t^{lc}} = \frac{\partial Y_t}{\partial N_t^{lc}} - H_t^{lc} W_t^{lc} + \left(1-\chi^{lc}\right)\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{lc}}\right] \quad \ldots (33)$$

The value of an additional low educated worker in a simple occupation, or a high educated in a simple occupation who lost skills, for the firm 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

$$\frac{\partial \Gamma_t^F}{\partial N_t^{ls}} = \frac{\partial Y_t}{\partial N_t^{ls}} - H_t^{ls} W_t^{ls} + \left(1-\chi^{ls}\right)\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\partial \Gamma_{t+1}^F}{\partial N_{t+1}^{ls}}\right] \quad \ldots (34)$$

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

$$\frac{\omega^c}{q_t^{hc}} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\partial Y_{t+1}}{\partial N_{t+1}^{hc}} - H_{t+1}^{hc}W_{t+1}^{hc} + \left(1-\chi^{hc}\right)\frac{\omega^c}{q_{t+1}^{hc}}\right)\right] \quad \ldots (35)$$

$$\frac{\omega^s}{q_t^{hs}} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\partial Y_{t+1}}{\partial N_{t+1}^{hs}} - H_{t+1}^{hs}W_{t+1}^{hs} + \left(1-\chi^{hs} - O_{t+1}P_{t+1}^{hc}\right)\frac{\omega^s}{q_{t+1}^{hs}}\right)\right] \quad \ldots (36)$$

$$\frac{\omega^c}{q_t^{lc}} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\partial Y_{t+1}}{\partial N_{t+1}^{lc}} - H_{t+1}^{lc}W_{t+1}^{lc} + \left(1-\chi^{lc}\right)\frac{\omega^c}{q_{t+1}^{lc}}\right)\right] \quad \ldots (37)$$

$$\frac{\omega^s}{q_t^{ls}} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\partial Y_{t+1}}{\partial N_{t+1}^{ls}} - H_{t+1}^{ls}W_{t+1}^{ls} + \left(1-\chi^{ls}\right)\frac{\omega^s}{q_{t+1}^{ls}}\right)\right] \quad \ldots (38)$$

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[3]

$$H_t^{hc}W_t^{hc} = \left(1-\xi^{hc}\right)\left[\frac{\partial Y_t}{\partial N_t^{hc}}\right] + \xi^{hc}C_t\left[\tau^h - \Omega^{hc}\left(1-H_t^{hc}\right)\right] \quad \ldots (39)$$

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 $\left(1-\xi^{hc}\right)$ of both the firm's revenues from the worker's productivity. 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 and that of a high educated in a complex occupation, in

3 Detailed derivations of the wages of all labor types are included in appendix 7.2.1.

addition to the forgone benefit from being matched with a simple vacancy. Similarly, the wage of the high educated in a simple occupation, who did not lose their skills, is given by

$$H_t^{hs}W_t^{hs} = \left(1-\xi^{hs}\right)\left[\frac{\partial Y_t}{\partial N_t^{hs}} - O_t P_t^{hs}\frac{\omega^s}{q_t^{hs}}\right] + \xi^{hs}C_t\left[\tau^h - \Omega^{hs}\left(1-H_t^{hs}-O_t\right)\right] \quad \ldots (40)$$

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 $\left(1-\xi^{hs}\right)$ 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 and that of a high educated in a simple occupation, in addition to the forgone benefit from being matched with a complex vacancy. Similarly, the wage of the low educated in a complex occupation is given by

$$H_t^{lc}W_t^{lc} = \left(1-\xi^{lc}\right)\left[\frac{\partial Y_t}{\partial N_t^{lc}}\right] + \xi^{lc}C_t\left[\tau^l - \Omega^{lc}\left(1-H_t^{lc}\right) + \frac{\varphi\delta}{C_t}\right] \quad \ldots (41)$$

where ξ^{lc} 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 $\left(1-\xi^{lc}\right)$ of both the firm's revenues from the worker's productivity. The second term indicates that the worker is compensated by a fraction ξ^{lc} for the outside options or the difference between the leisure of a high educated unemployed and that of a low educated in a complex occupation, in addition to the forgone benefit from being matched with a simple vacancy. Finally, the bargained wage of the low educated in a simple occupation, including the high educated in simple occupations who lost their skills, is given by

$$H_t^{ls}W_t^{ls} = \left(1-\xi^{ls}\right)\left[\frac{\partial Y_t}{\partial N_t^{ls}}\right] + \xi^{ls}C_t\left[\tau^l - \Omega^{ls}\left(1-H_t^{ls}\right)\right] \quad \ldots (42)$$

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 $\left(1-\xi^{ls}\right)$ for the firm's revenues from the worker's productivity. 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 and that of a low educated in a simple occupation, in addition to the forgone benefit from being matched with a complex vacancy.

The hours of the worker of education type i in occupation j are chosen such 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[4]

[4] Detailed derivations are included in appendix 7.2.2.

$$\frac{\partial\left(\frac{\partial Y_t}{\partial N_t^{ij}}\right)}{\partial H_t^{ij}} + \left(\frac{1}{\lambda_t}\right)\frac{\partial \Omega_t^{ij}}{\partial H_t^{ij}} = 0,\ (ij) \in (hc, hs, lc, ls) \qquad \dots (43)$$

Finally, the crowding out effect is defined as $Crowding_t = \frac{N_t^{hs}}{N_t^{hs}+N_t^{ls}}$. Total unemployment is defined as $U_t = U_t^h + U_t^l$. To close the model, we have $Y_t = C_t + \omega^c V_t^c + \omega^s V_t^s$.

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. Since information may not be available for the other parameters, their values are computed in the steady state system of equations after setting values for variables quantifiable from the data.

The steady state values for certain variables are calculated from the averages in the dataset during the period under study. For instance, the proportions of the employed types are set at $N^{hc} = 0.23$, $N^{hs} = 0.25$, $N^{lc} = 0.01$, $N^{ls} = 0.45$ and the unemployed types at $U^h = 0.02$, $U^l = 0.04$, and $U = 0.06$, which are equal to the data averages during the period under study as well. Given the proportion of employment of all types, the wages, W^{hc}, W^{hs}, W^{lc} and W^{ls} are set equal to the data average, such that the steady state skill premium is 1.52 , which is also equal to the data average of 1.51389439 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 $Crowding = 0.35$ is also set equal to the data average of 0.357143 .

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 $\mho(C_t) = \ln(C_t)$. The instantaneous utility functions of leisure are given by $\Omega_t^h = \tau^h\left(1 - S_t^{hc} - S_t^{hs}\right)$, $\Omega_t^l = \tau^l\left(1 - S_t^{lc} - S_t^{ls}\right)$, $\Omega_t^{hc} = \tau^{hc}\left(1 - H_t^{hc}\right)$, $\Omega_t^{hs} = \tau^{hs}\left(1 - H_t^{hs} - O_t\right)$, $\Omega_t^{lc} = \tau^{lc}\left(1 - H_t^{lc}\right)$, $\Omega^{ls} = \tau^{ls}\left(1 - H_t^{ls}\right)$. The parameters 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 parameters 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 , for the low educated in complex occupations τ^{lc} is given by 1.5 , 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 $M_t^{hc} = T^{hc}\left(Z_t^c V_t^c\right)^{\gamma}\left(S_t^{hc} U_t^h + O_t N_t^{hs}\right)^{1-\gamma}$, $M_t^{hs} = T^{hs}\left(Z_t^s V_t^s\right)^{\gamma}\left(S_t^{hs} U_t^h\right)^{1-\gamma}$, $M_t^{lc} = T^{lc}\left(\left(1 - Z_t^c\right) V_t^c\right)^{\gamma}\left(S_t^{lc} U_t^l\right)^{1-\gamma}$

and $M_t^{ls} = T^{ls}\left(\left(1-Z_t^s\right)V_t^s\right)^{\gamma}\left(S_t^{ls}U_t^l\right)^{1-\gamma}$, where $\gamma \in (0,1)$ is the elasticity of matching with respect to vacancies. T^{hc}, T^{hs}, T^{lc} 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}, T^{lc} and T^{ls} are given by 0.1. The choice of the level parameters is determined to target the separation rates. In the steady state, the flows out of employment equals the flows out of unemployment. This ensures that the employment level of every type stays constant. Thus, we have $\chi^{hc}N^{hc} = M^{hc}$, $\left(\chi^{hs}+OP^{hc}\right)N^{hs} = M^{hs}$, $\chi^{lc}N^{lc} = M^{lc}$ and $\chi^{ls}N^{ls} = M^{ls}$ in the steady state. Therefore, the choice of T^{hc}, T^{hs}, T^{lc} and T^{ls} determines the matches, and accordingly targets the separation rates.

The separation rates χ^{hc}, χ^{hs}, χ^{lc} and χ^{ls} from the complex and simple occupations are given by 0.01, 0.02, 0.01, and 0.03, respectively. These are selected such that the separation rate from simple vacancies is higher than that from complex ones, the separation rate of the low educated is higher than those of the high educated, and that 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 given by 2.28 and 0.12, respectively. These values are determined through the steady state equations of the optimal number of vacancies. The firm's share of the surplus ξ^{hc}, ξ^{hs}, ξ^{lc} and ξ^{ls} are all set at 0.5, as is standard in the literature. The bargaining power of the households are 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 probability of skill loss of the high educated unemployed σ is determined by multiplying the proportion of long term unemployment out of total unemployment, by the proportion of the high educated unemployed out of total unemployment. The longer the duration of the spell of unemployment, the higher the deterioration of skills. Thus, the unemployed for a long time are more likely to lose their skills. According to a Congressional Budget Office paper (2007), the highest proportion of long term unemployment out of total unemployment in the period 1950-2000 is around 20%. Assuming that the probability of the high educated unemployed for a long period is similar to the proportion of the high educated unemployed out of total unemployment $\frac{0.02}{0.06} = \frac{1}{3}$, then the portion of those who lose skills during the spell of unemployment are equal to the portion of the high educated in long term unemployment $\sigma = \left(\frac{1}{3}\right)(0.2) = 0.066666667$. Similarly, the probability of skill loss of the high educated in simple occupations θ is determined by multiplying the proportion of long term mismatch by the proportion of the high educated employed in simple occupations out of all those employed in simple occupations= $\frac{0.25}{0.25+0.46} = 0.352112676$. There is no information available on long term mismatch. Assume the long term mismatch out of total mismatched labor is similar to long term unemployment=20%, then $\theta = (0.352112676)(0.2) = 0.070422535$. The training parameter δ is set at 0.5, which is close to the value in Esteban-Pretel and Faraglia (2005).

The technological constraints faced by the firm is also represented by a constant returns to scale Cobb-Douglas function $Y_t = A_t \left(H_t^{hc}N_t^{hc} + H_t^{lc}N_t^{lc}\right)^{\mu} \left(H_t^{hs}N_t^{hs} + H_t^{ls}N_t^{ls}\right)^{1-\mu}$, 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 $\log A_{t+1} = \rho^A \log A_t + \varepsilon_{t+1}^A$ 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 $\sigma_{\varepsilon A}$. 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 $\sigma_{\varepsilon A} = 0.0049$.

5. Analysis

5.1 Impulse Responses

The model with the features of labor mismatch and skill loss, referred to as the "Mismatch/Loss1" model hereinafter, 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 impulse responses in figures 2 and 3 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 of an additional worker of any type to the firm. The firm posts complex and simple vacancies such that the expected marginal cost of posting a 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. Accordingly, the decrease in the marginal productivity of workers induces firms to decrease their posting of complex and simple vacancies.

Firms also reduce the portion of the simple and complex vacancies directed at the high educated. The decline in the former is larger than the decline in the latter. Accordingly, the high educated decrease their search intensity for complex occupations. This causes a decline in the employment of the high educated in complex occupations. As the high educated unemployed reduce their search intensity for complex occupations, the high educated in simple occupations increase their on-the-job search. This is due to the diminished competition from the unemployed searchers. This also causes an increase in the search intensity for simple occupations, which causes a lagged increase in the employment of the high educated in simple occupations. The decline in the employment in complex occupations causes an increase in the unemployment of the high educated.

On the other hand, the low educated unemployed reduce their search intensity for simple occupations due to the increased competition from the high educated searchers. The low educated unemployed reduce their search intensity for complex occupations due to increased competition from the high educated on-the-job searchers. This causes a decrease in the employment of the low educated in simple and in complex occupations besides 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, consistently with the observations. The lagged increase in the high educated in simple occupations, and the decrease in the low educated in simple occupations cause the crowding out variable to increase, consistently with the observations.

The hours of work of any type are chosen such that the disutility of leisure from increasing the hours of work by one unit is offset by the increase in the marginal productivity due to an increase in hours by one unit. Figure 3 shows that the hours of all types decline due to the reduction in marginal productivity. Accordingly, total hours decline as well.

Comparing the moments of the model in table 8 to the data observations, the model succeeds in several aspects. The model succeeds in replicating the lagged countercyclicality of the unemployment of the high educated, the first lag correlation coefficient of the model is -0.9930, and is statistically significant. The model, however, produces a lagged countercyclical unemployment of the low educated, and a lagged countercyclical total unemployment where the first lag correlation coefficient of -0.9823 is statistically significant. Finally, the model produces a countercyclical crowding out effect, without the lag that is observed in the data.

The success of the model can be also assessed by comparing the serial correlations of the unemployment rates produced by the model, and those observed in the data. Table 7 shows that the model succeeds in reproducing the high persistence observed in the data. For instance, the first lag serial correlation of total unemployment is 0.870 in the data and 0.820 in the model. The first lag autocorrelation of the unemployment of the high educated is 0.796 in the data and 0.835 in the model, while that of the unemployment of the low educated is 0.855 in the data and 0.841 in the model. For the remaining lagged serial correlations of the unemployment variables, the persistence is higher in the model than 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 are sensitive to the features of a specific framework. The model with the features of labor mismatch and skill loss is considered a benchmark and is referred to as the "Mismatch/Loss1" model hereinafter. The "Mismatch/Loss1" model is compared to a similar model with the same features, but without the aspect of skill loss of mismatched labor where $\theta = 0$. In this context, only the high educated unemployed lose their skills. This model is referred to as the "Mismatch/Loss2" model hereinafter.[5] The "Mismatch/Loss1" is also compared to a similar one with the same features, but without the aspect of skill loss where $\sigma = \theta = 0$. In this context, neither the unemployed nor the mismatched workers lose their skills. This model is referred to as the "Mismatch/No Loss" model hereinafter.[6] Table 7 shows that the serial correlations are lower in the "Mismatch/No Loss" model than in the two models with the aspect of skill loss. This confirms that introducing the aspect of skill obsolescence increases the

[5] Figures 4 shows the impulse responses of the "Mismatch/Loss2" model.

[6] Figure 5 shows the impulse responses of the "Mismatch/No Loss" model.

persistence of unemployment. In addition, the serial correlations of the "Mismatch/Loss2" model is higher than those in the "Mismatch/Loss1" model. This is because in the former, the high educated unemployed lose their skills, and become low educated unemployed whose probability of finding a job is low. This causes the persistence of unemployment to be high. In the latter, the loss of skills of mismatched workers, cause the high educated in simple occupations to become low educated. The low educated in simple occupations have a higher separation rate into unemployment. As they become unemployed, this allows an opportunity to the high educated unemployed to escape unemployment into simple occupations. This reduces the unemployment persistence compared to the model without the skill loss of the mismatched labor. Therefore, the "Mismatch/Loss1" performs better than the "Mismatch/Loss2" in capturing the observed persistence of unemployment.

In addition, we compare the above mentioned models that feature labor mismatch to one where there is no labor mismatch. In this context, there are two types of workers and two types of vacancies, but the aspect of job competition and crowding out are assumed away. In this context, the complex vacancies are filled by the high educated only, while the simple vacancies are filled by the low educated only. There is no on-the-job search in this case. This model, with the aspect of skill loss, is referred to as the "No Mismatch/Loss" model hereinafter,[7] while the one without the aspect of skill loss is referred to as the "No Mismatch/No Loss" model hereinafter.[8] It is obvious from the serial correlations that the models without the aspect of labor mismatch exhibits higher persistence compared to the models with mismatched labor. This can be attributed to the observation that after the initial shock, the recovery of the economy is captured in a 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 the hours of work, to exhibit higher persistence. The models with labor mismatch are 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. This allows the simple occupations to absorb a portion of the high educated, who would have been unemployed otherwise, and accordingly 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 an 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

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7 The details of the "No Mismatch/Loss" model are available from the author upon request. Figure 6 shows the impulse responses of the "No Mismatch/Loss" model.

8 The details of the "No Mismatch/No Loss" model are available from the author upon request. Figure 7 shows the impulse responses of the "No Mismatch/No Loss" model.

jobs, and the subsequent labor mismatch and skill loss can provide a possible explanation to 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. The high educated unemployed, and the high educated employed in jobs that do not require their level of education, lose their skills. 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, along with the aspect of skill obsolescence generate the persistence of unemployment.

Appendix

Data

The data set used is the Outgoing Rotation Group of the Current Population Survey. The 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. The Outgoing Rotation series is a merged collection of the 4th and 8th month-in-sample groups from all 12 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 is monthly and covers the period from January 1979 until December 2008. At the end of each year, the 12 monthly files from January till December are concatenated into a single annual file. The variables extracted are as follows

Table 1: Extracted variables

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

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 split into high educated and low educated workers, where the former are those who obtained some college education or higher. The following table shows the variables' ranges defining the high and the low educated

Table 2. Ranges for high and low education levels

Period	*High Educated*	*Low Educated*
1979-1988	$14 \leq$ GRDHI ≤ 19	$1 \leq$ GRDHI ≤ 13
1989-1991	$13 \leq$ GRDHI ≤ 18	$1 \leq$ GRDHI ≤ 12
1992-2008	$40 \leq$ GRDATN ≤ 46	$31 \leq$ GRDATN ≤ 39

The high or the low educated are 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. 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 as simple. The results did not change in both cases. The complex and simple occupations are defined by the ranges of the variable OCC specified as follows

Table 3. Ranges for complex and simple occupation types

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

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 such 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 Real Gross Domestic Product data (Chained Dollars, seasonally adjusted at annual rates) is extracted from the National Income and Product Accounts NIPA. As the Gross Domestic Product data is quarterly, these monthly time series are transformed into quarterly ones by taking three months averages. All variables, except the unemployment ratios and the crowding out, are logged. The data is 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 is the monthly seasonally adjusted percentage of unemployment in the labor force of those 16 years and over. The aggregate data is detrended using the Hodrick Prescott filter with a smoothing parameter of 1600.

Derivations

The wage of worker of education type i in occupation j

The wage of the worker of education type i in occupation j is determined by

$$W_t^{ij} = \arg\max \left[\frac{1}{\lambda_t}\frac{\partial \Gamma_t^H}{\partial N_t^{ij}}\right]^{1-\xi^{ij}} \left[\frac{\partial \Gamma_t^F}{\partial N_t^{ij}}\right]^{\xi^{ij}}$$

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

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

Including the first order condition, and solving for the equilibrium wage rule for the worker of education type i in occupation j yields the wage.

The hours of workers of education type i in occupation j

The hours of work of the worker of education type i in occupation j are given by

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

Substituting the envelope conditions for $\frac{\partial\Gamma_t^H}{\partial N_t^{ij}}$ and $\frac{\partial\Gamma_t^F}{\partial N_t^{ij}}$ yields the hours of work.

References

Congressional Budget Office (2007), "Long Term Unemployment", Congress of the United States.

Devereux, Paul (2000), "Task Assignment Over the Business Cycle", *Journal of Labor Economics*, 18(1): 98-124.

Devereux, Paul (2004), "Cyclical Quality Adjustment in the Labor Market", *Southern Economic Journal*, 70(3): 600-615.

Eriksson, Stefan, and Nils Gottfries (2005), "Ranking of Job Applicants, On-the-Job Search, and Persistent Unemployment", *Labour Economics*, 12: 407-428.

Eriksson, Stefan (2006), "Skill Loss, Ranking of Job Applicants and Dynamics of Unemployment", *German Economic Review*, 7(3): 265-296.

Esteban-Pretel, Julen (2005), "The Effects of the Loss of Skill on Unemployment Fluctuations", CIRJE Working Paper F-371.

Esteban-Pretel, Julen and Elisa Faraglia (2010), "Monetary Shocks in a Model with Loss of Skills", *Journal of Money, Credit and Banking*, 42 (7): 1235-1265.

Gautier, Pieter (2002), "Unemployment and Search Externalities in a Model with Heterogeneous Jobs and Workers", *Economica*, 69: 21-40.

Hall, Robert (2005), "Job Loss, Job Finding and Unemployment in the U.S. Economy over the Past Fifty Years", *NBER Macroeconomics Annual*, 101-137.

Hosios, Arthur (1990), "On the Efficiency of Matching and Related Models of Search and Unemployment", *The Review of Economic Studies*, 57(2): 279-298.

Khalifa, Sherif (2012), “Job Competition, Crowding Out, and Unemployment Fluctuations”, *Macroeconomic Dynamics*, 16: 1-34.

Krause, Michael, and Thomas Lubik (2004), “On-the-Job Search and the Cyclical Dynamics of the Labor Market”. European Central Bank Working Paper 779.

Pries, Michael (2004), “Persistence of Employment Fluctuations: A Model of Recurring Job Loss”, *Review of Economic Studies*, 71(1): 193-215.

Shimer, Robert (2005), “The Cyclicality of Hires, Separations and Job to Job Transitions”, *Federal Reserve Bank of St. Louis Review*, 87(4): 493-507.

Sims, Christopher (2002), “Solving Linear Rational Expectations Models”, *Computational Economics*, 20 (1-2): 1-20.

Table 4. Calibration of model parameters

Exogenous	*Value*	*Description*
δ	0.5	training parameter
β	0.98	household discount factor
χ^{hc}	0.01	separation rate of high educated from complex occupations
χ^{hs}	0.02	separation rate of high educated from simple occupations
χ^{lc}	0.01	separation rate of low educated from complex 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 in a complex occupation
ξ^{hs}	0.5	firm share from bargaining with a high educated in a simple occupation
ξ^{lc}	0.5	firm share from bargaining with a low educated in a complex occupation
ξ^{ls}	0.5	firm share from bargaining with a low educated in a simple occupation
σ	0.067	probability that a high educated unemployed lose skills
θ	0.07	probability that a high educated in simple occupations lose skills
ρ^{A}	0.9	autoregressive coefficient of aggregate technology
$\sigma_{\varepsilon A}$	0.0049	standard deviation of the aggregate technology shock
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 with the high educated
T^{hs}	0.1	efficiency in the simple occupation matching function with the high educated
T^{lc}	0.1	efficiency in the complex occupation matching function with the low 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^{lc}	1.5	parameter in the utility of leisure of the low educated in complex occupations
τ^{ls}	0.6	parameter in the utility of leisure of the low educated in simple occupations

Table 5. CPS data moments. standard errors in () calculated by bootstrapping

TH^{ij} : total hours of labor type i in occupation j

	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)
TH^{hc}	-0.0524	0.0044	0.0522	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)
TH^{lc}	-0.1282	-0.1120	-0.521	-0.0414	0.0119	0.0763	0.1804	0.1937	0.2570
	(0.0967)	(0.0956)	(0.1149)	(0.1318)	(0.1532)	(0.1625)	(0.1621)	(0.1420)	(0.153)
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)
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)
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)

Table 6. BLS data moments. standard errors in () calculated by bootstrapping

AggU: aggregate unemployment rate

	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)
AggU	-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)

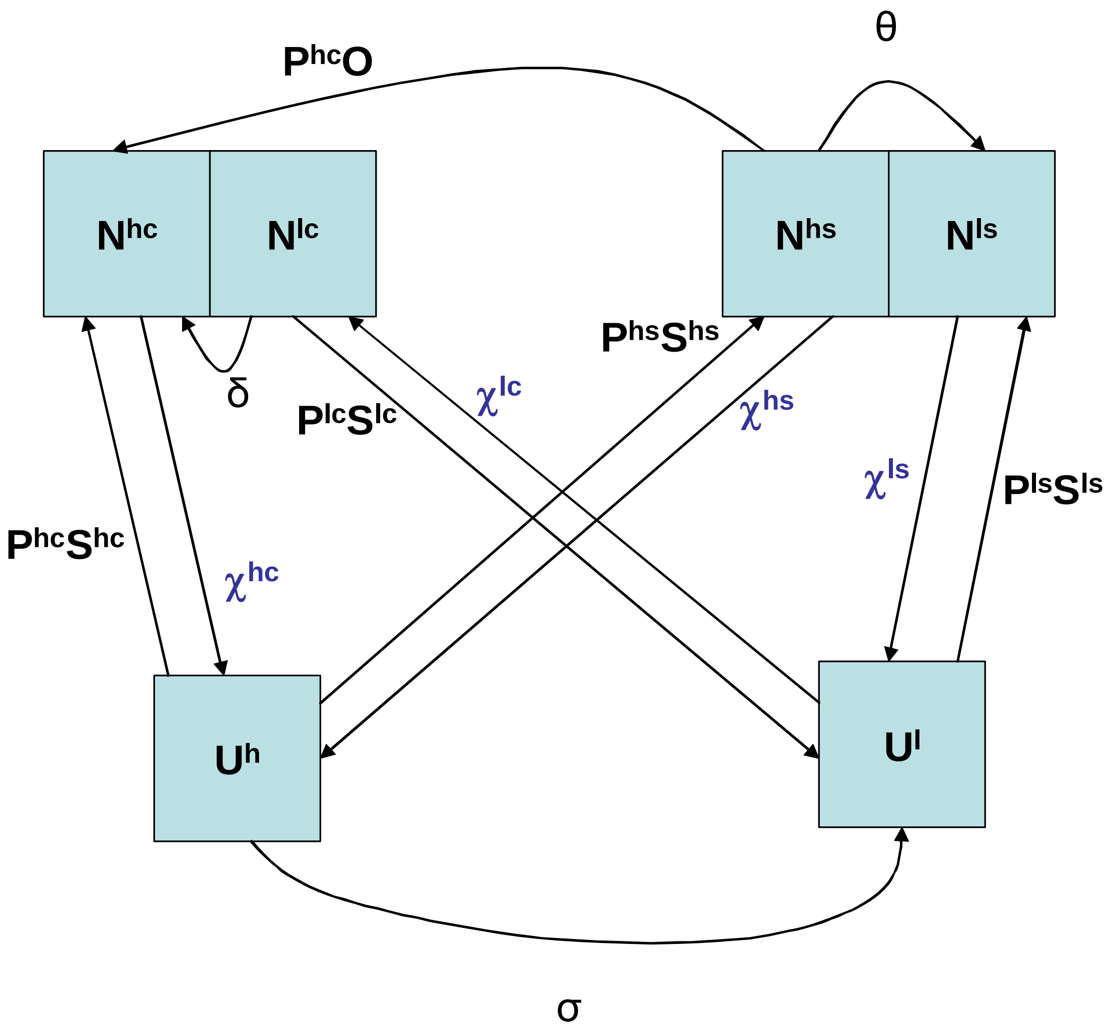
Table 7. Unemployment serial correlations

	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
Mismatch/No Loss	U_t	0.825	0.730	0.643	0.564	0.492
Mismatch/Loss 1	U_t	0.820	0.740	0.664	0.594	0.527
Mismatch/Loss 2	U_t	0.852	0.787	0.721	0.655	0.589
No Mismatch/ No Loss	U_t	0.885	0.793	0.702	0.616	0.537
No Mismatch/ Loss	U_t	0.822	0.760	0.667	0.589	0.513
CPS Data	U_t^h	0.796	0.643	0.504	0.338	0.118
Mismatch/No Loss	U_t^h	0.832	0.735	0.646	0.566	0.492
Mismatch/Loss 1	U_t^h	0.835	0.750	0.670	0.595	0.526
Mismatch/Loss 2	U_t^h	0.866	0.797	0.727	0.658	0.590
No Mismatch/ No Loss	U_t^h	0.923	0.830	0.737	0.648	0.564
No Mismatch/ Loss	U_t^h	0.929	0.840	0.749	0.660	0.576
CPS Data	U_t^l	0.855	0.649	0.432	0.229	0.038
Mismatch/No Loss	U_t^l	0.842	0.701	0.574	0.461	0.360
Mismatch/Loss 1	U_t^l	0.841	0.699	0.570	0.455	0.352
Mismatch/Loss 2		0.847	0.709	0.583	0.469	0.366
No Mismatch/ No Loss	U_t^l	0.883	0.790	0.699	0.614	0.535
No Mismatch/ Loss	U_t^l	0.816	0.755	0.662	0.584	0.509

Table 8. "Mismatch/Loss1" model moments. standard errors in () calculated by bootstrapping

TH^{ij} : total hours of labor type i in occupation j

	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	– 0.3926	–0.4448	–0.5362	–0.6333	–0.7745	–0.9930	–0.8073	–0.6869	–0.5957
	–(0.0774)	(0.0784)	(0.0738)	(0.0604)	(0.0387)	(0.0014)	(0.0332)	(0.0486)	(0.0645)
U^l	0.1777	0.1415	0.0822	0.0325	–0.0390	–0.1308	–0.2053	–0.2637	–0.3144
	(0.0952)	(0.0961)	(0.0964)	(0.0956)	(0.0925)	(0.0901)	(0.0918)	(0.0857)	(0.0856)
U	–0.3695	–0.4233	–0.5174	–0.6161	–0.7598	–0.9823	–0.8066	–0.6929	–0.6078
	(0.0812)	(0.0783)	(0.0755)	(0.0648)	(0.0386)	(0.0033)	(0.0332)	(0.0466)	(0.0635)
Crowding	–0.4368	–0.5175	–0.6119	–0.7444	–0.9589	–0.6780	–0.5013	–0.3723	–0.2699
	(0.0827)	(0.0704)	(0.0552)	(0.0421)	(0.0073)	(0.0566)	(0.0806)	(0.0960)	(0.0901)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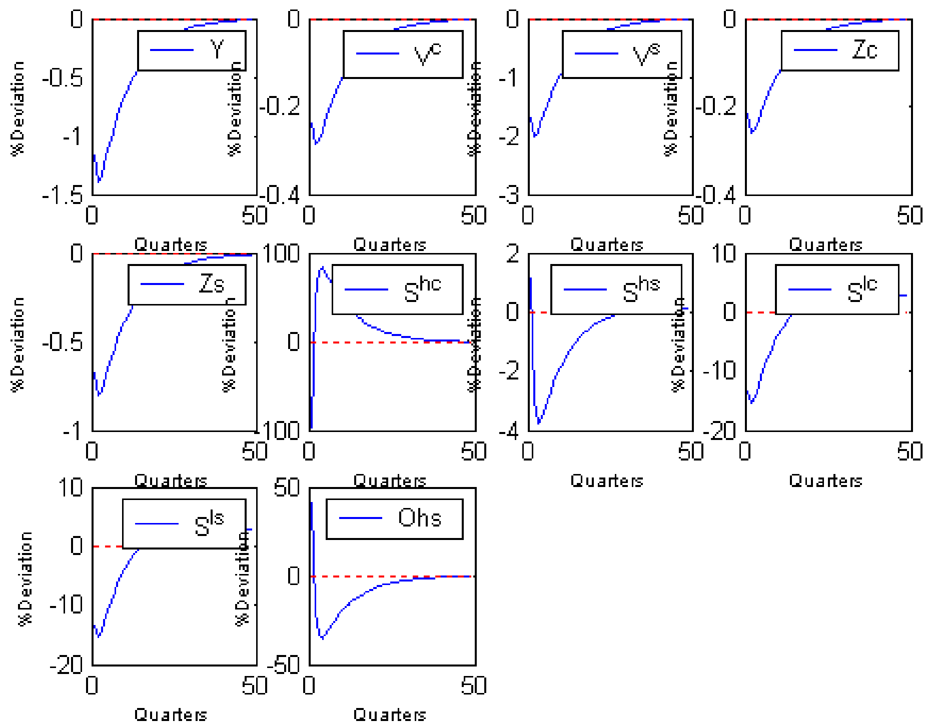
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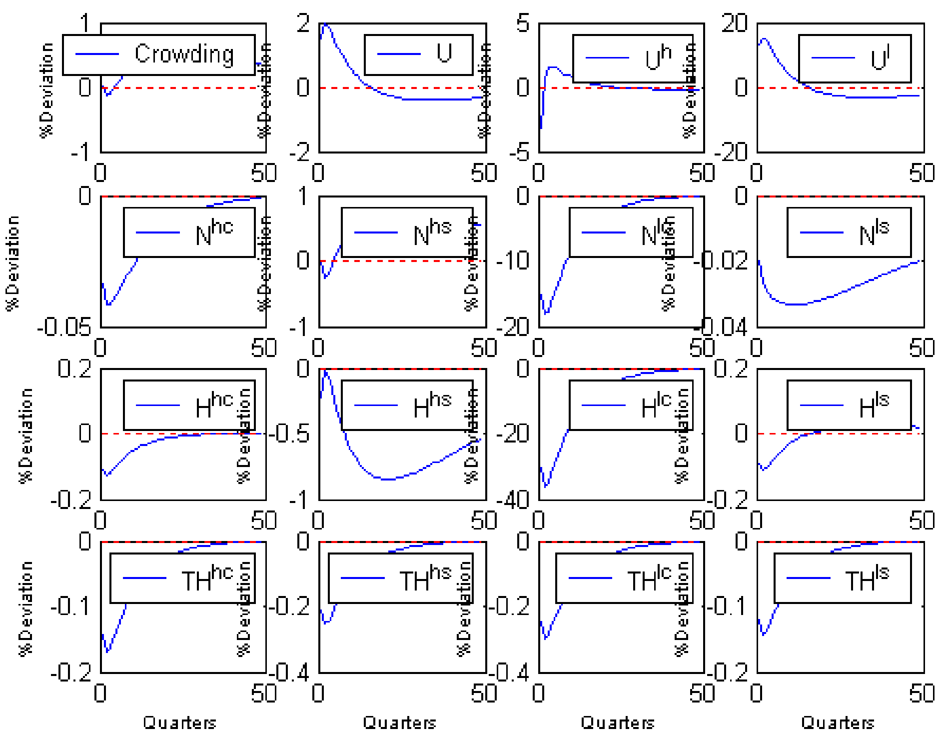
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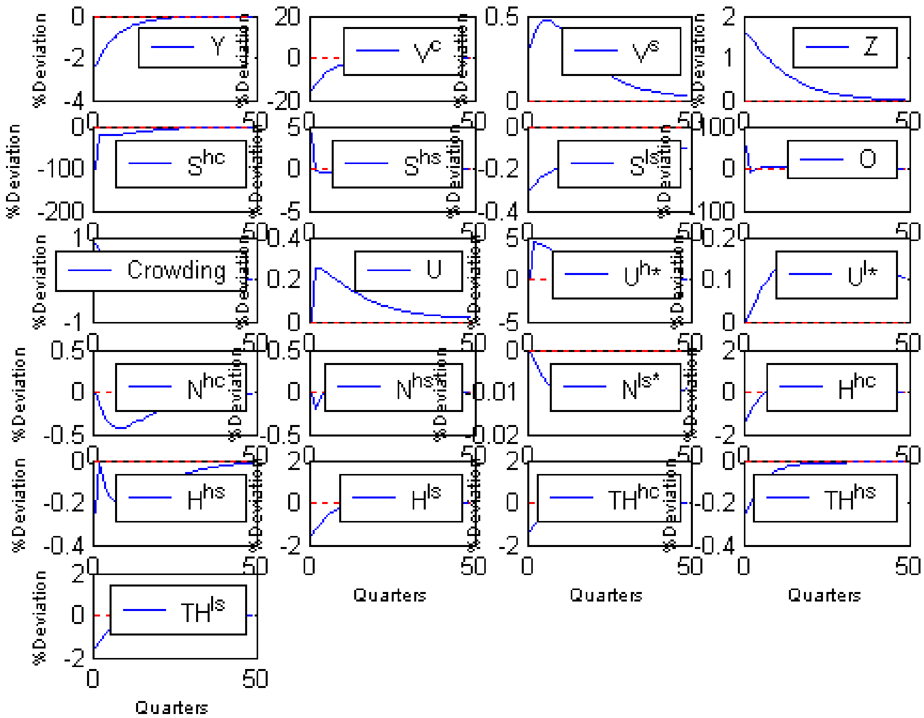

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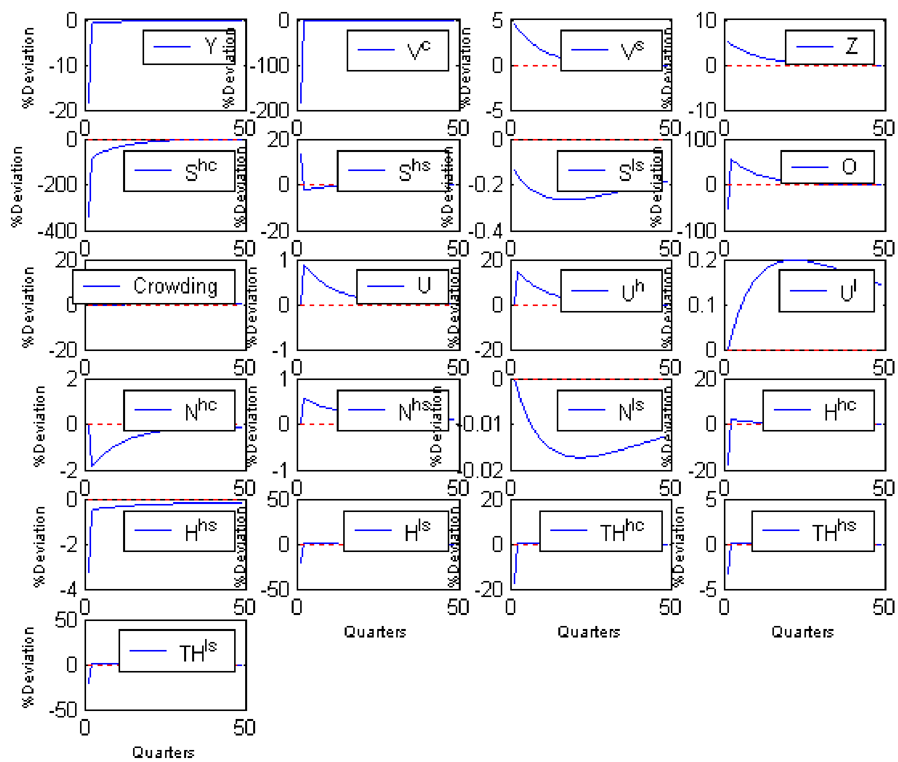

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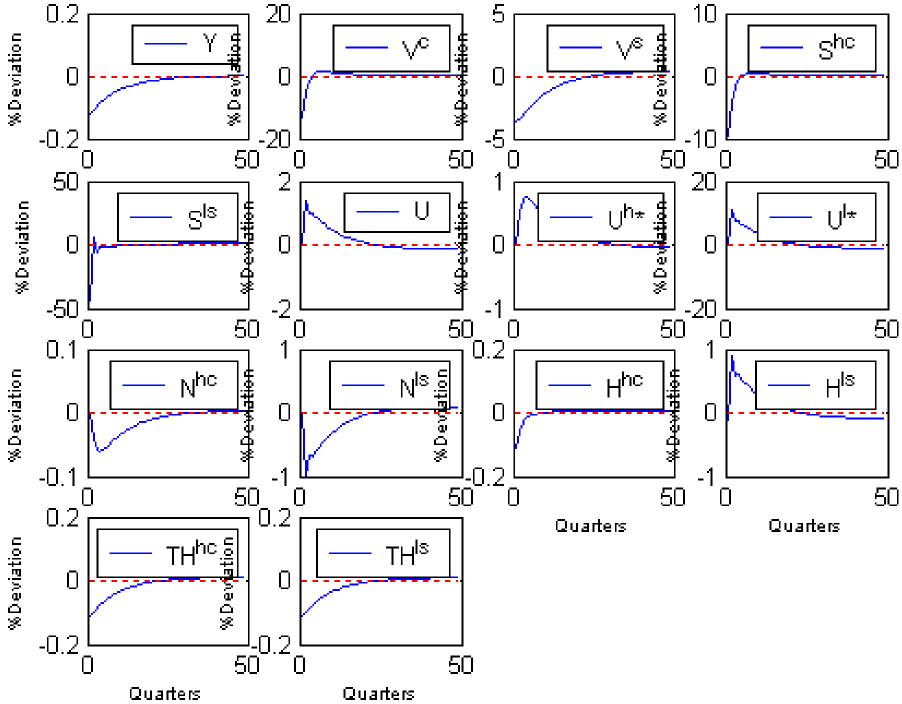
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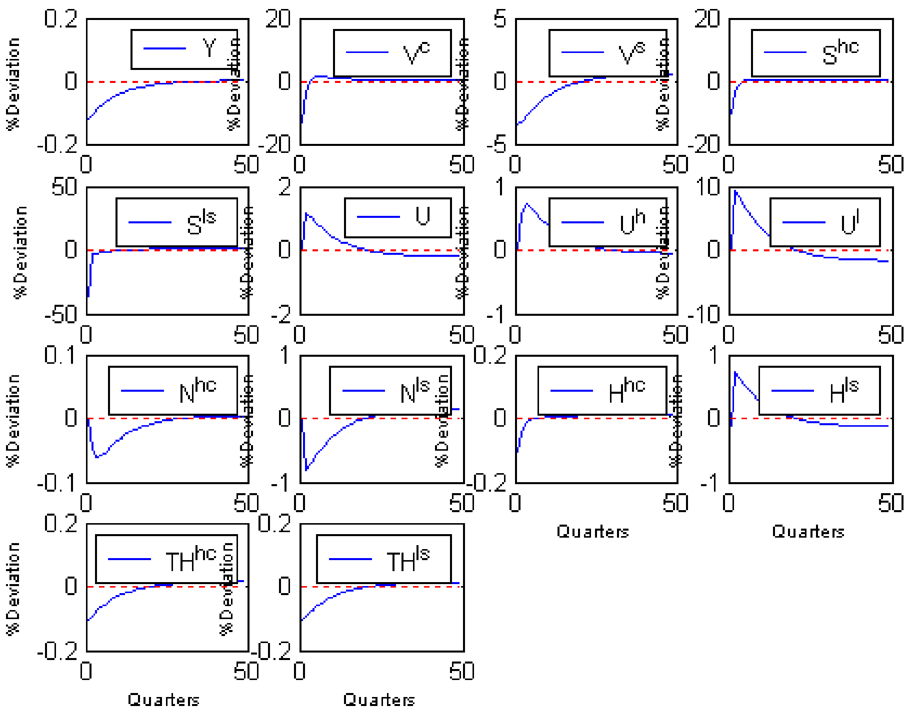
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TH^ls
%Deviation
Quarters