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What Can a New Keynesian Labor Matching Model Match?

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Abstract:

A labor matching model with nominal rigidities can match short-run movements in labor's share with some success. However, it cannot explain much of the behavior of employment, vacancies, and job flows in postwar US data without resorting to additional shocks beyond monetary policy and productivity shocks. In particular, the model suggests that monetary policy shocks can account for only a small portion of postwar fluctuations, except for the Volcker and late-1940s episodes. Productivity shocks can account for some of the pattern in labor's share and in employment between the late 1960s and the early 1980s. Based on the timing of observed fluctuations in interest rates, inflation, and productivity, it appears that the vast majority of observed fluctuations in the real economy remain unexplained by standard real and nominal shocks.

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1. Introduction

The RBC and New Keynesian revolutions have reached a point where scholars and policymakers have begun to use DSGE models to make forecasts and set policy. Analysis has typically centered on a canonical New Keynesian model, in which an RBC model is modified to include a number of nominal and real rigidities. Smets and Wouters (2004, 2007); Christiano, Eichenbaum, and Evans (2005); Del Negro, Schorfheide, Smets, and Wouters (2005); Dib, Gammoudi, and Moran (2008); and others give examples of highly parameterized DSGE models which fit aspects of the data as well as or better than unrestricted VARs. One unattractive feature of many of these models consists of their limited treatment of labor markets. For the most part they do not differentiate between the extensive and intensive margins and they do not feature involuntary unemployment. As a result, when confronted with the data, they assign a large importance to wedges between labor supply and demand.[1]

Cooley and Quadrini (1999), Walsh (2002, 2005), Blanchard and Galí (2008), and Trigari (2009) address this by showing how labor search frictions and wage bargaining can amplify and propagate both real and nominal shocks. Particularly when combined with nominal rigidities and inertial monetary policy rules, these models can produce fluctuations that look much like monetary-driven business cycles with a more appealing theoretical structure and fewer additional assumptions about real rigidities. Yashiv (2006); Christoffel, Küster, and Linzert (2007); Beauchemin and Tasci (2008); Krause, Lopez-Salido, and Lubik (2008); and Gertler, Sala, and Trigari (2008) have investigated the aspects of these models using real-world data. The latter two papers, in particular, use Bayesian methods to estimate a very large-scale DSGE labor matching model with many rigidities and shocks for the US. These papers disagree about the sources and consequences of economic fluctuations (especially the importance of productivity shocks), but

[1] Chari, Kehoe, and McGrattan (2007) discuss the behavior of a series of wedges as deviations from an RBC model.

they do point out that exogenous monetary policy shocks might not be as important as many had thought.

This paper falls within the latter literature but takes a different approach. It presents estimates for a series of structural shocks in the context of a smaller-scale New Keynesian labor matching model during the postwar period. This makes it possible to trace out the effects of these shocks and see how they contribute to specific episodes. The allowance for additional measurement error also makes it possible to evaluate the model's fit with the data, without forcing it to be exactly identified. There are shocks to a long-run inflation target and to shocks to a Taylor rule (the latter being a typical New Keynesian monetary shock). There are shocks which affect long-run productivity and short-run productivity (the latter being a typical RBC-style productivity shock). There are residual shocks to labor's outside option and to the bargaining process, which correspond with the neoclassical "labor wedge".

As it turns out, the model delivers similar performance to the other New Keynesian models with respect to the observed empirical effects of monetary policy. In this model, shocks to monetary policy play a predominant role during the Volcker episode and some role during the deflationary late-1940s recession but much smaller roles during other episodes. The model furthermore produces a believable story about the Fed's evolving long-run inflation target. Productivity shocks, depending on the detrending method, can explain the late 1960s boom and some of the economic weakness of the 1970s and early 1980s. Neither set of shocks can explain any of the movements in employment since the early 1980s. Most fluctuations in employment are unexplained in the model and are assigned to the two labor shocks. Even in a search and matching model, it seems that there is a large unexplained role for a "labor wedge" as a source of fluctuations.

Perhaps more surprisingly, the labor matching model with Nash bargaining and endogenous separation but otherwise flexible real wages goes a long way toward matching the behavior of labor's share of income over the business cycle.[2] It does not do quite so well at matching the behavior of job flows, both in the long run and at business-cycle frequencies. The model can at least produce a positive correlation between predicted job separation and accession rates and the data, but it does not match the timing, and the fit becomes particularly bad during the latter half of the postwar period. The most important failure of the New Keynesian labor matching model, however, comes from the fact that it simply lacks a credible source of impulses. These findings suggest that labor matching models might say something useful about the relationship between labor market frictions and wage-setting, but they have some of the same serious limitations as other New Keynesian and RBC models.

2. The data

This paper makes use of detrended quarterly observations on nine variables related to real activity, job flows, and nominal variables from the second quarter of 1947 through the first quarter of 2007. The sample period thus misses the episode which began near the middle of that year. Quarterly statistics on real GDP, GDP prices, and labor's share of corporate gross income come from the National Income and Product Accounts. Raw data on employment levels and unemployment rates (used to detrend employment) come from the CES and CPS, respectively. Secondary market rates on three-month treasury bills come from the St. Louis Fed's FRED database. The Conference Board's Help Wanted Index is used as a proxy for vacancies from 1957 through 2007, with corrections applied to the post-1993 data to account for online vacancy postings. For the period before 1957, the Met Life Help Wanted Index is ratio-spliced to the Conference Board's index.[3] Finally, quarterly data on job flows from manufacturing come from

[2] Gomme and Rupert (2004) Hansen and Prescott (2005), Choi and Ríos-Rull (2008), and Ríos-Rull and Santaeulàlia-Llopis (2008), along with others, discuss the cyclical behavior of the labor share. Merz (1995), Andolfatto (1996), and Cheron and Langot (2004), mention that the labor share might not be constant in matching models due to the bargaining process.

[3] Valletta (2005) describes how to adjust the post-1993 data using the Job Openings and Labor Turnover Survey (JOLTS). Zagorsky (1998) discusses the long-run stability and accuracy of this composite series.

Faberman (2006), updated to reflect revisions to the BED data released in 2006 and 2007. The post-1992 revised data are spliced onto the earlier data using the average ratio between the revised and original data from 1992 to 2007. The series is then led a period to reflect the fact that the data reflect lagged job flows while the model uses leads.

Detrended employment is based on unemployment rates, based on a postwar average of 5.3 percent. Employment is at two percent above trend at the beginning of 1947 and at trend in the second quarter of 1964, the third quarter of 1979, the fourth quarter of 1996, and the fourth quarter of 2005. A piecewise log-linear trend is drawn through these points, and vacancies share the same underlying trend. Log output per worker is linearly detrended, and detrended log output equals detrended log employment plus detrended log output per worker. As a result these series retain their possible unit roots and show large swings over time, particularly before 1970.

Figure 1 depicts the resulting series on detrended real GDP, vacancies (divided by ten for the sake of comparability) and employment. Figure 2 shows detrended output per worker. Detrended employment follows the CBO's employment and output gaps (not shown) very closely and shows considerable low-frequency variation. Figure 3 shows the behavior of the manufacturing separation and accession rates throughout the sample. In manufacturing, most of the volatility during recessions is with separations, while a smaller wave of accessions typically accompanies the early stages of an expansion. This has become less noticeable in recent years. Figure 4 shows the behavior of labor's share of corporate gross income. It shows an inverted U-shape at low frequencies, with a particularly high labor share during the 1970s. It tends to negatively lead employment and positively lag it, with no contemporaneous correlation. Figure 5 shows the familiar behavior of price inflation along with the return to three-month treasury bills. Inflation and interest rates are positively correlated with output and employment at high frequencies, while at low frequencies, the relationship is negative. Finally, data on the money supply (demand deposits plus currency, not shown) come from the St. Louis Fed for the period after 1959 and Friedman and Schwartz (1970) for the period before 1959.

3. The model

This paper adapts the basic model of Walsh (2002) to allow for disturbances to labor's market power, to the disutility from work, and to the demand for money. On the household side, it consists of infinitely lived consumers who face a monetary friction. Production and hiring take place in a firm-worker match, as in Mortensen and Pissarides (1994). A retail sector aggregates output from the wholesale sector and resets retail prices in a staggered manner. This allows for a straightforward treatment of sticky prices. The monetary authority adjusts interest rates according to a Taylor rule with one important qualification—sometimes it adjusts its long-run inflation target without immediately changing interest rates. Implicitly this paper takes a stand that long-run fluctuations to the inflation rate are driven purely by these long-run monetary policy shocks.

3.1. The household sector

Individual households supply labor; they either work for a set number of hours per week or do not work at all. They also have the choice between consuming in a given period and investing in nominal bonds in order to consume later. They each seek to maximize the objective function

$$E_t \sum_{i=0}^{\infty} \beta^i \left[\frac{C_{t+i}^{1-\sigma}}{1-\sigma} - \chi_{t+i} A_{t+i} \bar{z}_{t+i} \right], \tag{1}$$

where C_{t+i} equals the household's period-by-period real consumption and χ_{t+i} is an indicator variable equal to one if the household worked in a given period. Put this way, $A_{t+i}\bar{z}_{t+i}$ is the net disutility from having to go to work instead of staying home to produce and consume a home production good. The long-run productivity shifter $\bar{z}_{t+i}$ appears for balanced-growth reasons; it applies symmetrically to market output, home production, and vacancy posting costs.[4]

Markets operate in three stages per period. In the first stage, after shocks are realized and known to those concerned, financial markets open. People trade bonds and withdraw money in order to make their consumption purchases. In the second stage, the goods market opens. Production and consumption occur. In the third stage, workers and shareholders take home their paychecks which clear by the beginning of the following period. Households cannot consume out of current income and must spend money in an exogenous proportion to their consumption purchases, and this gives rise to a cost channel. Households are large and members participate in an informal insurance scheme.

Households face a transactions constraint and a budget constraint. Households cannot spend their current income on current consumption because they have not yet received their factor payments. The transaction friction, which contains an exogenous time-varying transactions technology shifter V_t, states that intermediate cash holdings must go toward a proportion of consumption expenditures:

$$P_t C_t = V_t M_{t+1}. \qquad (2)$$

After consumption purchases are made, money spent on consumption flows back to the households at the end of the period in the form of factor payments, thus completing the circular flow. Most models similar to this one omit the money demand shifter with no loss of generality, but including the shifter allows data on the money supply to be used in the estimation procedure as it contains useful information about nominal output.

The household's budget constraint relates household money holdings, total income, bond purchases, money transfers, and consumption. B_t equals the household's purchases, at the beginning of the period, of one-period nominal bonds that mature at the beginning of the next

[4] It appears for much the same reasons that one might place restrictions on preferences in a Hansen (1985)-Rogerson (1988) model, that is, to keep employment from wandering off with productivity in the long run.

period. They earn the gross nominal interest rate R_t. T_t equals the level of net cash transfers received by the household from monetary authorities.

$$M_{t+1} + B_{t+1} + P_t C_t = P_t Y_t + R_{t-1} B_t + M_t + T_t \,. \tag{3}$$

The household's first-order conditions end up looking familiar. Optimization in bonds generates the usual intertemporal asset pricing relationship

$$\lambda_t = E_t \beta R_t \frac{P_t}{P_{t+1}} \lambda_{t+1} \,, \tag{4}$$

where the household's marginal utilities of consumption and wealth are equal:

$$C_t^{-\sigma} - \lambda_t = 0 \,. \tag{5}$$

Because of market clearing, output equals consumption:

$$Y_t = C_t \,, \tag{6}$$

and the quantity equation therefore holds:

$$P_t Y_t = V_t M_{t+1} \,. \tag{7}$$

Equations (4) through (7) characterize the behavior of the household sector.

3.2. The retail sector and sticky prices

Monopolistically competitive retailers buy output competitively from the wholesale sector and resell it to households at a markup. Households aggregate it according to a Dixit-Stiglitz aggregator. Retailers buy their products y_{jt} competitively from wholesale producers who produce homogeneous intermediate goods. The aggregate level of output is given by

$$Y_t = \left[\int_0^1 y_{jt}^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \,, \tag{8}$$

for some substitutability parameter θ greater than one. From this expression, each individual retail firm faces a demand curve

$$y_{jt} = \left(\frac{p_{jt}}{P_t} \right)^{-\theta} Y_t, \tag{9}$$

where the aggregate price level P_t equals the CES price index:

$$P_t = \left[\int_0^1 p_{jt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}}. \tag{10}$$

The retailers buy unfinished output from the wholesalers at a price P_t^W and sell it at an aggregate markup $\mu_t \equiv P_t / P_t^W$. Each retailer, in the spirit of Calvo (1983), can only change its price with a probability $1\text{-}\omega$. Based on these random intervals between price changes, prices will tend to show persistence and this introduces one possible channel for nominal shocks to have real effects.

Those firms that change their price in a given period do so symmetrically and reset their prices to p_t^*. They maximize expected discounted profits. Letting $D_{i,t+1}$ equal the discount factor $\beta^i(\lambda_{t+i}/\lambda_{t+1})$, the objective function for the price-changers equals

$$E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+1} \left[\left(\frac{p_t^*}{P_{t+i}} \right)^{1-\theta} - \mu_{t+i}^{-1} \left(\frac{p_t^*}{P_{t+i}} \right)^{-\theta} \right] Y_{t+i}. \tag{11}$$

Long-run profit maximization results in the first order condition

$$\left(\frac{p_t^*}{P_t} \right) = \left(\frac{\theta}{\theta - 1} \right) \frac{E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+1} \mu_{t+i}^{-1} \left(\frac{P_{t+i}}{P_t} \right)^{\theta} Y_{t+i}}{E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+1} \left(\frac{P_{t+i}}{P_t} \right)^{\theta-1} Y_{t+i}}, \tag{12}$$

with the aggregate retail price index given by

$$P_t^{1-\theta} = (1-\omega)(p_t^*)^{1-\theta} + \omega P_{t-1}^{1-\theta}. \tag{13}$$

Current prices are a weighted function of lagged prices and the prices set by those firms that could adjust. Conditions (12) and (13) generate a New Keynesian Phillips Curve relationship which relates current retail markups to current and expected future inflation.

3.3. The wholesale sector and labor matching

The wholesale sector distinguishes this model from most typical sticky-price models. The labor market in this model is a special case of that of den Haan, Ramey, and Watson (2000), without fixed capital. Workers and firms may only produce when in a match. They may separate for both exogenous and endogenous reasons, and firms search for workers based on expectations of future profitability. Walsh goes through the model in much more detail, but the components of it are discussed here.

The unemployment pool, $U_t = 1 - N_t$ equals the number of workers searching for a job at the beginning of the period, with the population normalized to one. There is a constant probability ρ^x that a match will end exogenously. The remaining $(1 - \rho^x)N_t$ matches experience an iid, idiosyncratic productivity shock a_{it} (with a distribution function F), a systematic temporary productivity shock z_t, and a systematic permanent productivity shock $\bar{z}_t$, all of which the worker and firm observe at the beginning of the period. Based on their realizations, the worker and firm decide whether to continue the relationship or to separate. If the relationship continues, the match produces $y_{it} = a_{it}\bar{z}_t z_t$ which is sold at the wholesale price P_t^w to the retailers. If the relationship separates, production equals zero; the job is destroyed; and the worker becomes unemployed. All three sets of shocks have an unconditional mean of one and are independent from each other.

Firms seeking workers post vacancies at a fixed cost. As a result of these matching frictions, matches earn an economic surplus, and in a well-functioning bargaining environment, workers and firms will want to remain matched so long as that surplus exceeds zero. Because of the transactions friction and the slight delay in making factor payments, this period's money income only becomes available the following period to consume. As a result, sales (and factor payments) are discounted at the rate R_t. This serves to introduce a simple cost channel into the model.

Noting that the retailer's gross markup μ_t equals P_t / P_t^w, the surplus of a match at period t equals the real value of the match's product in time t, less the instantaneous disutility of work, plus the expected discounted continuation value of the match (denoted by q_{it}), all in product terms:

$$s_{it} = \frac{a_{it} z_t \bar{z}_t}{\mu_t R_t} - A_t \bar{z}_t + q_{it} . \qquad (14)$$

Since only matches with a nonnegative surplus will continue, for a match to do so, it will require that a_{it} exceed a certain cutoff value $\tilde{a}_t$. Since the shock a_{it} is iid, the continuation value of the surplus q_{it} will equal the same value q_t across matches. Setting (14) to zero gives the value of this cutoff:

$$\tilde{a}_t = \frac{\mu_t R_t (A_t \bar{z}_t - q_t)}{z_t \bar{z}_t} . \qquad (15)$$

If a_{it} has the distribution F, then the endogenous separation probability ρ_t^n equals $F(\tilde{a}_t)$ and the aggregate separation rate ρ_t and the match survival rate φ_t are given by:

$$\rho_t = \rho^x + (1 - \rho^x) F(\tilde{a}_t) , \qquad (16)$$

and

$$\varphi_t = (1 - \rho^x)[1 - F(\tilde{a}_t)] = (1 - \rho_t) . \qquad (17)$$

In a match, workers and firms engage in Nash bargaining. The worker receives a time-varying exogenous share of the surplus η_t; the firm receives the share (1 - η_t). The probability of the worker actually finding a match equals k_t^w, based on a matching function. These conditions give the continuation value of the surplus:

$$q_t = (1-\rho^x)\beta E_t \frac{\lambda_{t+1}}{\lambda_t}(1-\eta_{t+1}k_t^w)\int_{\tilde{a}_{t+1}}^{\infty} s_{it+1}dF(a_{it+1}). \tag{18}$$

Firms can post vacancies at a fixed cost $\gamma\bar{z}_t$ but face no other barriers to entry. Vacancies get filled at a gross rate k_t^f. This results in a free-entry condition equating the present value of a firm's vacancy posting with the cost of posting that vacancy:

$$\gamma\bar{z}_t = (1-\rho^x)k_t^f \beta E_t \frac{\lambda_{t+1}}{\lambda_t}(1-\eta_{t+1})\int_{\tilde{a}_{t+1}}^{\infty} s_{it+1}dF(a_{it+1}). \tag{19}$$

To a first-order approximation, (18) and (19) yield the continuation value:

$$q_t \approx E_t \frac{\gamma\bar{z}_t(1-\eta_{t+1}k_t^w)}{(1-\eta_{t+1})k_t^f}. \tag{20}$$

Aggregating these things is rather simple. The total number of job searchers in a period equals the starting stock of unemployed plus those who separate at the beginning of the period. Abstracting from labor force entry and exit, this comes out to

$$u_t \equiv U_t + \rho_t N_t = 1-(1-\rho_t)N_t. \tag{21}$$

The number of vacancies posted in a given period equals v_t. Given a constant-returns Cobb-Douglas matching function $m(u_t,v_t) = \varsigma u_t^a v_t^{1-a}$, the vacancy-filling rate is given by

$$k_t^f = \frac{m(u_t,v_t)}{v_t}, \tag{22}$$

and the worker's job-finding rate is given by

$$k_t^w = \frac{m(u_t,v_t)}{u_t}. \tag{23}$$

Abstracting from exit and entry into the labor force, the number of matches evolves according to the accounting identity

$$N_{t+1} = (1-\rho_t)N_t + m(u_t, v_t)\,, \tag{24}$$

and the gross output of the matched firms and workers is given by

$$Q_t = \frac{(1-\rho_t)N_t z_t \bar{z}_t \left[\int_{\tilde{a}_t}^{\infty} a_{it}\, dF(a_{it})\right]}{1-F(\tilde{a}_t)}. \tag{25}$$

Output (in value-added terms) equals gross output minus vacancy posting costs:

$$Y_t = Q_t - \gamma \bar{z}_t v_t \qquad , \tag{26}$$

and total labor compensation is determined from the Nash bargaining arrangement, after solving for the value of a filled vacancy from (19):

$$W_t = \frac{Q_t}{\mu_t} - R_t \varphi_t N_t \left((1-\eta_t)s_t - \frac{\gamma \bar{z}_t}{k_t^f} \right). \tag{27}$$

Taken together, these conditions describe an equilibrium in the labor market. The main effects of using a model with hiring frictions and bargaining to move away from perfectly competitive labor markets are twofold. First of all, the economy responds much more slowly to shocks since it is difficult to adjust labor inputs. Secondly, the bargaining mechanism ensures that productivity shocks result in a less than one-for-one change in wages (that is, a fall in the labor share when temporary productivity rises) since workers are not paid their marginal product. As it turns out, this allows the labor matching model to go a long way toward matching the behavior of labor's share.

3.4. The monetary authority

It has become common practice to model monetary policymakers as adjusting interest rates in response to inflation and output, an approach popularized by Taylor (1993) and Woodford (2003). This paper continues in that tradition, with a few modifications. First of all, Walsh (2005) shows how sluggish interest rate adjustment feeds back into inflation and output dynamics, and in practice the Fed seems to adjust interest rates incrementally. Additionally, Bordo, Erceg, Levin, and Michaels (2007) investigate the behavior of interest rates and output in the presence of a changing inflation target, with an application to the Volcker disinflation. They modify their Taylor rule to include changes in a long-run inflation target, in addition to adding lagged interest rate terms. The basic form of the Taylor rule used in this paper closely resembles their specification.

Expressed as deviations from the steady state, the Taylor rule follows the form

$$\begin{aligned} \hat{r}_t - \hat{\pi}_t^* &= \rho_r(\hat{r}_{t-1} - \hat{\pi}_t^*) + \rho_\pi(\hat{\pi}_t - \hat{\pi}_t^*) \\ &+ \rho_{EMPL}(\hat{n}_t - \hat{n}_{t-1}) + \varepsilon_t^r . \end{aligned} \tag{28}$$

An increase in the inflation target $\hat{\pi}_t^*$ eventually results in a one-for-one increase in nominal interest rates, after a period of slow adjustment. As a result, a rising inflation target results in a period of unusually low real interest rates. Such behavior of interest rates matches the experience of the US relatively well, with low real interest rates during the 1960s and 1970s and high real interest rates during the disinflationary 1980s and 1990s. This specification of the Taylor rule allows for monetary policymakers to adjust interest rates in response to *changes* in macroeconomic conditions, as captured in the coefficient ρ_{EMPL}.

The inflation target itself evolves according to a persistent AR(1) process:

$$\hat{\pi}_t^* = \rho_{\pi^*}\hat{\pi}_t^* + \varepsilon_t^{\pi^*} . \tag{29}$$

It seems reasonable to treat the money demand shifter V_t as a highly persistent AR(1) process:

$$\ln(V_t) = (1-\rho_V)\ln(V) + \rho_V \ln(V_{t-1}) + \varepsilon_t^V . \tag{30}$$

Fluctuations in the money demand shifter have no real effects because the Fed follows an interest rate rule, and most monetized RBC models without loss of generality drop this set of shocks or they ignore money entirely. Including this shock allows for monetary data to be used as an additional observable variable in the estimation procedure.

3.5. Productivity and real factors

Letting $\overline{\Gamma}$ equal the long-run growth rate of the permanent level of productivity, it is convenient to assume that it follows a highly persistent AR(1) process on top of a time trend:

$$\ln(\bar{z}_t) - \overline{\Gamma}t = \rho_{\bar{z}}\left[\ln(\bar{z}_{t-1}) - \overline{\Gamma}(t-1)\right] + \varepsilon_t^{\bar{z}}. \tag{31}$$

The temporary productivity shifter z_t follows an exogenous stationary AR(1) process:

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \varepsilon_t^z. \tag{32}$$

This way, it is possible to model the effects of both temporary and permanent productivity shocks with unemployment acting in a well-behaved manner in the long run. The shocks will exhibit very different impulse responses from each other; a positive permanent productivity shock results in a proportionate increase in each of the terms in the surplus equation. It will therefore have no direct effect on separations or vacancy creation. By contrast, a positive temporary productivity shock boosts labor demand and has its usual effects. The allocation of movements in productivity between these shocks is particularly important in evaluating their effects.

The bargaining weight η_t also follows an AR(1) process as does the labor disutility A_t:

$$\ln(\eta_t) = (1-\rho_\eta)\ln(\eta) + \rho_\eta \ln(\eta_{t-1}) + \varepsilon_t^\eta, \tag{33}$$

and

$$\ln(A_t) = (1-\rho_A)\ln(A) + \rho_A \ln(A_{t-1}) + \varepsilon_t^A. \tag{34}$$

Positive shocks to either process would somewhat increase labor's share of total income, but they would have different effects on job turnover and vacancies. Shocks to bargaining power result in dramatic falls in both vacancy creation and turnover as surpluses rise but it becomes unprofitable to post vacancies. Shocks to labor supply result in negligible changes in vacancies, but turnover rates rise as surpluses shrink.

3.6. Equilibrium and solution method

The aggregate household conditions (4) through (7), the New Keynesian retail conditions (12) and (13), the aggregated versions of (14) through (27) from the wholesale sector, and the shock processes (28) through (34) constitute a rational expectations equilibrium for this economy, should one exist. The method used to estimate the shocks hitting this economy involves taking a log-linear approximation around a steady state. An appendix derives the system of equations describing the steady state and the linearization of the model around that steady state. In this particular situation, a nonexplosive equilibrium exists and is locally unique.

4. Estimation strategy and calibration

4.1. State space approach

The linearized model conveniently lends itself to a state space representation. Given a set of feedback rules and quarterly data on nine variables, it is fairly simple to use the Kalman Filter to estimate the underlying unobservable states.[5] The filter also delivers the Gaussian likelihood of the model and makes it possible to compute the maximum likelihood estimates for those parameters such as the shock variances for which it is not possible to impose a sensible external calibration.

The first half of the state space approach consists of the reduced-rank VAR representation of the linearized model. The transition equation follows the form

$$x_t = A_1 x_{t-1} + B_1 \varepsilon_t , \tag{35}$$

where the values of the coefficients come directly from the solution to the linearized model. The second half of the state space approach consists of the observation equation relating the variables in the model to the nine observed data series (denoted by x_t^*). Based on the linearized model, one can represent the data as some linear combination of the true underlying economic variables. Algebraically, this idea can be represented by the observation equation:

[5] Hamilton (1994, 2005) shows how to straightforwardly implement the Kalman Filter in such a setting.

$$x_t^* = D_1 x_t + \varepsilon_t^* . \qquad (36)$$

The iid (across time and variables) observation shocks ε_t^* consist of a combination of model misspecification and true observation errors, especially in the case of the vacancy and job flow data. In this exercise the variances of the observation errors are calibrated manually based on the likelihood function; they do not force the model to explain every fluctuation in the data.

4.2. Calibrated parameter values

Most of the parameter values follow the calibrations used in Walsh (2002), and they are used in order to set up the transition equation (34) based on the linearized model. Households have a coefficient of relative risk aversion σ of 2, implying greater risk aversion than log preferences but less risk aversion than equity prices might imply. The nominal interest rate R is based on net 4.5 percent real return on assets per year, implying a value of β of 0.9974. Output and consumption per capita grow at 1.7 percent per year. The model is linearized around a zero-inflation steady state.

Also taken from Walsh's calibration, the gross retail markup μ equals 1.1, for a value of θ of 11. The likelihood function encourages a massive amount of nominal stickiness—retail firms change their prices on average once every two years for a value of ω of 0.875. This is much higher than Bils and Klenow's (2004) estimates of about 0.5 but is in line with the higher values typically used in the macro literature.[6] As it happens, nominal shocks do not appear to drive most of the postwar business cycles no matter what one is willing to assume about nominal rigidities.

The exogenous job separation rate ρ^x equals 0.068 and the total job separation rate ρ equals 0.10 per quarter. These values imply a value of $\rho^n = F(\tilde{a})$ equal to 0.0343 per quarter. The idiosyncratic process a_{it} is lognormal with an arithmetic mean of 1 and a dispersion

[6] Christiano, Eichenbaum, and Evans (2005) find that, in the absence of explicit nominal wage rigidity, their model favors an extreme degree of price rigidity.

parameter σ_a of 0.13, for a central location parameter μ_a of -0.0085. This delivers a value for $\widetilde{a}$ of 0.7826. Hairault (2002) and Walsh calibrate vacancy posting costs to one percent of value added. According to Andolfatto (1996), the share of output taken by vacancy costs does not greatly affect the results of the model, and others have followed him out of custom. However, the estimated effects of different shocks do appear sensitive to this. The likelihood function of the model in the baseline setup in fact does favor a share for vacancy posting costs of about one percent of output.

The unemployment share a of the matching function, in the baseline calibration, equals 0.4. Walsh cites Blanchard and Diamond (1989, 1991) who use postwar CPS data to derive such an estimate. A sensitivity analysis reveals that the likelihood function encourages a somewhat higher unemployment share.[7] The steady-state unemployment rate U equals 0.05. The worker-finding rate k^f equals 0.7 and the job-finding rate k^w equals 0.6, both from Walsh's calibration. These imply that there are 0.145 job searchers u and 0.124 vacancies v in the steady state. Based on the steady state of the contracting model, the baseline calibration implies initial values of 0.461 for labor's bargaining power η, 0.835 for the disutility of work A, and 0.132 for the continuation value q.

To capture the persistence of the driving processes while keeping the estimation process simple, the autoregressive parameters for the shocks to target inflation, to money demand, long-run productivity, labor's bargaining power, and labor supply all equal 0.999. The resulting endogenous variables become nearly cointegrated. The autoregressive parameter on z_t equals 0.9 based on information provided by the likelihood function. The results are not particularly sensitive to this parameter.

Based on the likelihood, it is also possible to calibrate the variances of the shock processes. The standard deviations of the nine observation error processes in the baseline case are set to 0.45% for quarterly inflation, 0.16% for the level of output, 0.13% for employment,

[7] The likelihood of the model encourages an unemployment share on the order of 0.5.

zero for quarterly money growth, 0.04% for the quarterly nominal interest rate, 0.3% for labor's share of output, zero for vacancies, 21.2% for the log separation rate, and 23.1% for the log accession rate. The baseline model can match everything except the job flows rather well, with some high-frequency mismeasurement of inflation.

The baseline model features shocks to long-run productivity which have no other effects, in addition to standard RBC-style shocks to short-run productivity. As it turns out, the series on labor's share identifies the different types of productivity shocks. An alternative calibration, the "RBC calibration", relaxes this identification. In this calibration, the standard deviation of the observation error on labor's share is set to 1.3% and of the errors on separations and accessions to 15% and 11%, respectively. All long-run productivity shocks are set to zero; and the persistence of short-run productivity rises to 0.98. To reflect these changes, all of the data are HP-detrended using a smoothing parameter of 100,000. This allows for the fact that traditional business cycle models are not necessarily constructed to match the low-frequency components of the data. This calibration shows what happens when one gives the RBC theory its best chance at explaining business cycles. It also provides an independent test for the model's ability to match the business-cycle components of productivity with labor's share of income—as it turns out, these things match each other (but still not the data on job flows) surprisingly well. Results for both calibrations are reported below.

5. Estimation results

5.1. The driving processes

The standard deviations of the six driving processes must be estimated by maximum likelihood. Under the baseline calibration they equal 0.0017 for the interest rate shocks, 0.0010 for shocks to trend inflation, 0.0070 for the temporary productivity shocks, 0.0083 for the long-run productivity shocks, 0.0114 for the money demand shocks, 0.0574 for the labor bargaining power shocks, and 0.0040 for the labor supply shocks. The estimated standard deviations under the RBC calibration equal 0.0017 for the interest rate shocks, 0.0013 for shocks to trend inflation, 0.0077 for the temporary productivity shocks, 0.0105 for the money demand shocks, 0.0553 for the labor bargaining power shocks, and 0.0058 for the labor supply shocks.

5.2. Monetary policy and its effects

Under the baseline calibration, monetary policy shows a clear split between those portions of inflation which the Fed accommodates and those portions of inflation which it acts to reverse, in addition to a noise component. The coefficients ρ_r, ρ_π, and ρ_{EMPL} have reasonable values after taking trend shifts into account (0.85, 0.42, and 0.29, respectively). Interest rates, even conditional on trend inflation, show a strong degree of persistence—the Fed appears reluctant to adjust interest rates too quickly, and this in fact helps to ensure determinacy in the presence of a cost channel. Interest rates respond strongly to above-trend inflation (with a long-run response of 0.42/0.15, or 2.8 times), while the Fed only slowly adjusts interest rates one-for-one to match changes in inflation which it wishes to accommodate. This results in low real interest rates during periods of rising trend inflation and explains the low real interest rates of the 1970s and the high real interest rates of the1980s.

Figure 6 depicts the behavior of the nominal variables. The upper left hand panel compares the filtered inflation rate with the unfiltered data. The model manages to capture most of the variation in inflation over the postwar period, the notable exceptions being the Korean War period and much of the very short-run variation in measured inflation. The upper right-hand panel of Figure 6 shows the filtered inflation series (solid blue line) and the estimated trend π* (dashed green dashed line). Interestingly, it shows a number of local peaks. These peaks occur in the third quarter of 1947, the first quarter of 1951, the fourth quarter of 1955 or the third quarter of 1956, the second quarter of 1968, the fourth quarter of 1974, the first quarters of 1980 and 1981, and the first quarter of 1989, with rising trend inflation near the end of the sample. All but the 1951 peak fall within one to two quarters of dates identified by Romer and Romer (1989, 1994) as representing the beginnings of intentional disinflationary actions by the Fed. The narrative evidence seems to support the contention that this is an economically meaningful trend inflation series.

Figure 8 depicts the cumulative effects of shocks to monetary policy on employment since 1947 under the baseline calibration. The green dashed line depicts the effects of changes in the inflation target. The rising inflation target provided a slight stimulus during the 1960s. By the late 1970s, interest rates had gradually risen to reflect the rise in trend inflation, and this exerted a minor but noticeable drag on employment. This supports Berentsen, Menzio, and Wright's (2008) findings.[8] The black dotted line depicts the effects of interest rate shocks on employment. For the most part, exogenous monetary policy shocks appear not to have generated postwar recessions. The exceptions consist of the fall in employment surrounding the Volcker disinflation and, debatably, a portion of the recession at the end of the 1940s. Even in a model with a very large degree of nominal rigidity, it is very difficult to attribute business cycles to real-world fluctuations in monetary policy.

Under the RBC calibration, the coefficients ρ_r, ρ_π, and ρ_{EMPL} are similar to those under the baseline calibration, with a lower response to inflation. These coefficients equal 0.85, 0.195, and 0.29, respectively, for a long-run response of interest rates to above-trend inflation of 1.3. Looking at the simulation results in Figure 9, the RBC calibration shows similar employment responses to monetary shocks as under the baseline calibration. Monetary policy now accounts for larger portions of the late-1940s and Volcker recessions as well as a small portion of other cycles during the 1950s and 1970s. In general, though, both calibrations imply that exogenous shocks to monetary policy have not played that large a role in most postwar recessions, with no role at all for monetary policy shocks since the mid-1980s. Smets and Wouters (2007) and

[8] Owyang and Ramey (2004) estimate an inflation target using a simple regime-switching model, and in their "dove" (high-inflation) episodes, which lead the Romer dates, interest rates rise as well.

Gertler et al. (2008) find a similarly small role for monetary policy shocks in postwar fluctuations, again with the exception of the Volcker episode. This appears to be a robust feature of New Keynesian models when confronted with the data. An additional finding of this exercise is that shocks to trend inflation, because of the cost channel, can account for much of the long-run *positive* relationship between inflation and unemployment when estimated carefully using a structural approach.

5.3. The role of productivity shocks

Figure 7 depicts the behavior of the short-run and long-run productivity shifters under the baseline calibration. These two productivity shifters show very different behavior from each other. The short-run productivity shifter does not fluctuate that much, showing some weakness during the 1970s. The long-run productivity shifter shows a large, persistent rise up until about 1973. After that period, it falls gradually, picking up again beginning in the mid to late 1990s. Figure 10 shows the cumulative effects of productivity shocks. Under the baseline calibration, the data do not favor the RBC hypothesis as a plausible explanation for short-run fluctuations. Productivity shocks can explain some of the economic weaknesses of the 1970s but they do not appear to generate recessions at business-cycle frequencies.

To further investigate this issue, Figure 11 shows the results from the RBC calibration. Here, productivity shocks can do a somewhat better job of explaining the behavior of employment at business-cycle frequencies. Shocks to productivity can explain some of the behavior of employment from the early 1960s through the early 1970s, and they can also contribute somewhat to the poor economic performance of the early 1980s. Apart from these few episodes, observed productivity fluctuations simply cannot match the real-world behavior of employment. It appears that Shimer (2005), Hall (2005), and others might be correct—based on the timing of real-world shocks, it appears that productivity does not drive most postwar business cycles in a labor matching model. If one wishes to match the timing of these variables (and not just their second moments), it is unrealistic to expect productivity shocks to account for much.

5.4. The role of labor market disturbances

The top two panels in Figure 7 shows the estimated bargaining power and labor supply shifters under the baseline parameterization, expressed as percent deviations from steady state. The data seem to indicate that from the perspective of the model, large increases in labor's bargaining power η_t occurred during each of the NBER recessions in the sample. The bargaining power shifter does not seem to track the gradual fall in union membership since the 1960s; instead, the estimation procedure treats it more as a generic shock which results in a fall in vacancy creation and somewhat higher wages. The labor supply shifter (the disutility from work A_t) shows far fewer systematic cyclical movements, with most of its movements happening at lower frequencies.

Figure 12 shows the effects of these shocks under the baseline calibration and Figure 13 under the RBC calibration. From the perspective of the labor matching model, most of the fluctuations in vacancies and employment appear to come from the labor market shocks. This reflects the fact that exogenous shocks to productivity and monetary policy, when confronted with actual data on employment and output, simply cannot account for most of the employment fluctuations in the postwar period. Even in a labor matching model, the labor wedge, as a residual, seems to matter for most flucutations.

5.5. How does the model fit the data on job flows and labor's share?

Figures 14 and 15 depict the performance of the model at matching job flows and labor's share under the baseline and RBC calibrations, respectively. The model matches the other variables, except for inflation, almost exactly, and under the baseline parameterization the labor share is used to identify short-run productivity. The baseline parameterization cannot match the behavior of job flows at all. It gets the low-frequency components of job creation and destruction rates completely wrong. At higher frequencies, fitted separation rates have a correlation of +0.24 with the data, and fitted accession rates have a +0.08 correlation with the data. Under the RBC calibration which ignores lower-frequency movements, these correlations rise to +0.35 and +0.22. In particular, the fitted separation rate is not volatile enough, and it does not track the data well after the early 1980s. The fitted accession rate completely misses the behavior of employment during the 1980s, but it shows a more reasonable amount of volatility.

The baseline calibration matches labor's share almost by construction; it ends up using labor's share to identify the short-run versus long-run productivity shocks. The RBC calibration still does a reasonable job at matching labor's share at high frequencies. The correlation between the fitted and actual data is +0.64, with the fitted series *lagging* the actual series by one quarter with a correlation of +0.70. The data have a standard deviation 1.6 times as large as the fitted series, indicating that the model without capital does not quite deliver enough volatility for the log labor share. Still, it does surprisingly well. The data seem to informally support Krause and Lubik's (2007) contention that real wage rigidity is neither necessary nor particularly useful in explaining the behavior of the real economy since unmodeled wage rigidity would result in the fitted series on labor's share *leading* the actual series.

6. Conclusion

A recent literature has sprung up devoted to evaluating New Keynesian models using techniques which involve estimating deep parameters and analyzing the types of shocks that these models imply when confronted with data. A mainstream New Keynesian model which features labor matching frictions shows mixed results when subjected to a detailed model evaluation. As with much of the New Keynesian paradigm, it appears that monetary policy shocks are not an important component of postwar economic fluctuations, except for the Volcker episode and some possible fluctuations early in the postwar period. The Fed's actions which allowed both inflation and interest rates to drift to a high level did seem to contribute to some of the medium-run stagflation of the 1970s, however. Productivity shocks do appear to matter during the boom of the late 1960s and part of the early-1980s bust. Based on the timing of actual fluctuations in inflation, interest rates, and productivity, it seems that neither set of shocks can account for most postwar business cycles. It appears that other shocks to the demand for labor account for the majority of postwar economic fluctuations.

More encouragingly, the model does somewhat well at predicting the behavior of labor's share of output without having to resort to more complicated forms of wage rigidity. The bargaining model seems to tell an economically meaningful story of how productivity changes may feed through into an attenuated change in wages. Those working on dynamic macroeconomic models have made a great deal of progress in explaining some aspects of the data, but the RBC and New Keynesian revolutions have not yet resulted in a theory which can adequately explain the greater portion of postwar economic fluctuations.

Supplementary Appendix: Numerical solution to the model

A.1 Deriving the steady state from calibrated parameters

The state-space approach requires a specification for the state equation (35) which comes from the linearized model. The linearized model in turn contains coefficients which depend on the steady state of the model. Deriving the steady state from the calibrated parameters, taking growth rates into account, is fairly straightforward. Given a nominal interest rate *R*, a balanced growth rate $\overline{\Gamma}$, a gross inflation rate Π, and a risk aversion parameter σ, it is possible to calibrate the rate of time preference β from equation (4) after noting that the costate variable λ grows at rate $\overline{\Gamma}^{-\sigma}$:

$$\beta = \frac{\overline{\Gamma}^{\sigma}\Pi}{R}. \qquad \text{(A1)}$$

In a zero-inflation steady state with a driftless velocity, the money growth rate $\overline{\Theta}$ simply equals the economic growth rate $\overline{\Gamma}$. Given a markup μ, one can solve the equation

$$\mu = \frac{\theta}{\theta - 1},$$

to get θ.

Given a process for a_{it} and total and exogenous separation rates ρ and ρ^x, it is possible to derive the endogenous separation probability and the cutoff value for productivity:

$$F(\tilde{a}) = \rho^n = \frac{\rho - \rho^x}{(1-\rho^x)}. \qquad \text{(A2)}$$

Given an unemployment rate *U* and an employment rate $N = 1 - U$ as well as a total separation rate ρ, and job and worker finding rates k^w and k^f, it is easy to find the number of job searchers, the sum of beginning-of-period unemployed plus separations:

$$u = U + \rho N, \qquad \text{(A3)}$$

the number of vacancies from the homogeneous matching function,

$$k^f v = k^w u\,, \tag{A4}$$

and the retention rate:

$$\varphi = (1-\rho^x)[1-F(\widetilde{a})]\,. \tag{A5}$$

Given the output equation, one can then find a value for gross output Q:

$$Q = \frac{(1-\rho)N\left[\int_{\widetilde{a}_t}^{\infty} a_i dF(a_i)\right]}{1-F(\widetilde{a})}\,. \tag{A6}$$

If vacancy posting costs as a share of output are given as s_v, this gives values for Y and γ based on the equation for value added:

$$Y = \frac{Q}{1+s_v}\,, \tag{A7}$$

and

$$\gamma = \frac{Q-Y}{v}\,. \tag{A8}$$

The vacancy posting and continuation value expressions pin down labor's bargaining power at its initial state, solved from the expression:

$$\gamma = \frac{\Theta(1-\rho^x)k^f(1-\eta)}{\mu R^2}\int_{\widetilde{a}_i}^{\infty}(a_i-\widetilde{a})dF(a_i)\,. \tag{A9}$$

This all yields a closed-form expression for q:

$$q = \frac{\gamma(1-\eta k^w)}{(1-\eta)k^f}\,, \tag{A10}$$

and for A:

$$A = q + \frac{\widetilde{a}}{\mu R}\,. \tag{A11}$$

Finally, the initial value of the costate variable in consumption is determined by the first-order condition of the household's optimization problem:

$$Y^{-\sigma} - \lambda = 0. \qquad \text{(A12)}$$

The initial value of the velocity does not matter for the calibration of this model.

It is also helpful to have expressions for the wage bill *W*. It equals wholesale production marked down, minus the wholesale firms' accounting profits. Those profits in turn equal the firm's share of the surplus minus the discounted value of a filled vacancy, since the value of the firm merely equals the present discounted value of profits. This gives the level of real labor compensation:

$$W_t = \frac{Q_t}{\mu_t} - R_t \varphi_t N_t \left((1-\eta_t) s_t - \frac{\gamma \bar{z}_t}{k_t^f} \right), \qquad \text{(A13)}$$

which in steady state yields

$$W = \frac{Q}{\mu} - \varphi N R \left((1-\eta) s - \frac{\gamma}{k^f} \right). \qquad \text{(A14)}$$

Equations (A1) through (A14) describe the relationships among the different parameters and steady state ratios in this model. The model is then linearized around this steady state using the numerical values obtained from the calibration.

A.2 Linearization around the steady state

Given a calibration and its implied steady state, it is possible to linearize the system around that steady state. This approximates the laws of motion of the system in the region of the initial conditions. In general, because of the driving processes, the system will exhibit a considerable degree of persistence and volatility. The particular model, calibration, and linearization used here rule out transitions between steady states, sunspots, or other forms of indeterminacy. These individual equations are assembled into a matrix of difference equations which yield a reduced-rank stable VAR.

Linearizing the cash-in-advance constraint in first differences obtains the stochastic money demand relation:

$$\hat{\pi}_t + \hat{y}_t - \hat{\Theta}_t - \hat{V}_t = \hat{y}_{t-1} - \hat{V}_{t-1}. \tag{A15}$$

The evolution of the number of matches comes from the accounting condition after substituting the relationship between matches and vacancy filling:

$$\hat{n}_{t+1} = \varphi \hat{n}_t + \varphi \hat{\varphi}_t + \left(\frac{vk^f}{N}\right)\hat{v}_t + \left(\frac{vk^f}{N}\right)\hat{k}_t^f \quad . \tag{A16}$$

The endogenous job destruction margin comes next:

$$\hat{a}_t = \hat{r}_t + \hat{\mu}_t - \hat{z}_t - \left(1 - \frac{A\mu R}{\tilde{a}}\right)\hat{\bar{z}}_t - \left(\frac{\mu R q}{\tilde{a}}\right)\hat{q}_t + \left(\frac{A\mu R}{\tilde{a}}\right)\hat{A}_t, \tag{A17}$$

followed by an expression for the job retention rate:

$$\hat{\varphi}_t = -\left(\frac{\rho^n}{1-\rho^n}\right)e_{Fa}\hat{a}_t, \tag{A18}$$

where e_{Fa} equals the elasticity of F with respect to $\tilde{a}$. The number of job seekers is approximated by the expression

$$\hat{u}_t = -\left(\frac{\varphi N}{u}\right)\hat{\varphi}_t - \left(\frac{\varphi N}{u}\right)\hat{n}_t. \tag{A19}$$

The parameterization for the matching function ensures that the vacancy filling probability relates to vacancies and job searchers:

$$\hat{k}_t^f = a\hat{u}_t - a\hat{v}_t, \tag{A20}$$

and the job finding probability relates to the vacancy filling probability such that

$$\hat{k}_t^f + \hat{v}_t = \hat{k}_t^w + \hat{u}_t. \tag{A21}$$

Linearizing the job posting condition yields:

$$\hat{k}_t^f + \hat{q}_t = \hat{\bar{z}}_t - \frac{\eta k^w}{1-\eta k^w}\hat{k}_t^w + \left(\frac{\eta}{1-\eta} - \frac{\eta k^w}{1-\eta k^w}\right)E_t\hat{\eta}_{t+1}. \tag{A22}$$

Linearizing the output equation yields:

$$\hat{y}_t = \left(\frac{Q}{Y}\right)(e_{Ha}\hat{a}_t + \hat{\varphi}_t + \hat{n}_t + \hat{z}_t + \hat{\bar{z}}_t) - \left(\frac{\gamma v}{Y}\right)(\hat{v}_t + \hat{\bar{z}}_t), \tag{A23}$$

where e_{Ha} equals the elasticity of $H(\widetilde{a}) \equiv \frac{1}{1-F(\widetilde{a})}\int_{\widetilde{a}_t}^{\infty} a_i dF(a_i)$ with respect to $\widetilde{a}$.

The asset pricing equation follows its typical form:

$$\hat{\lambda}_t = \hat{r}_t + E_t\hat{\lambda}_{t+1} - E_t\hat{\pi}_{t+1}, \tag{A24}$$

and the first-order condition for consumption yields the usual marginal utility expression:

$$-\sigma Y^{-\sigma}\hat{y}_t - \lambda\hat{\lambda}_t = 0. \tag{A25}$$

The conditions for the retail sector give rise to a New Keynesian Phillips Curve linearized around a zero inflation steady state:

$$\frac{\omega}{R}E_t\hat{\pi}_{t+1} = \omega\hat{\pi}_t + (1-\omega)\left(1-\frac{\omega}{R}\right)\hat{\mu}_t. \tag{A26}$$

The relationship between the continuation value of the surplus and future values of that surplus is approximated by the following:

$$\hat{q}_t = E_t\hat{\varphi}_{t+1} - \hat{r}_t + E_t\hat{\pi}_{t+1} - \frac{\eta k^w}{1-\eta k^w}\left(\hat{k}_t^w + E_t\hat{\eta}_{t+1}\right) + E_t\hat{s}_{t+1}. \tag{A27}$$

To get the factor shares and the continuation value of the match, it is helpful to have a linearized equation for the average surplus:

$$s\hat{s}_t = \frac{Q}{\varphi N\mu R}\left(\frac{Y}{Q}\hat{y}_t + \frac{\gamma v}{Q}\left(\hat{v}_t + \hat{\bar{z}}_t\right) - \hat{\varphi}_t - \hat{n}_t - \hat{\mu}_t - \hat{r}_t\right) - A(\hat{A}_t + \hat{\bar{z}}_t) + q\hat{q}_t,$$

or

$$s\hat{s}_t = -\frac{Q}{\varphi N\mu R}(\hat{\varphi}_t + \hat{n}_t + \hat{\mu}_t + \hat{r}_t) + \frac{Y}{\varphi N\mu R}\hat{y}_t$$
$$+\frac{\gamma v}{\varphi N\mu R}\hat{v}_t + \left(\frac{\gamma v}{\varphi N\mu R} - A\right)\hat{\bar{z}}_t - A\hat{A}_t + q\hat{q}_t \quad , \tag{A28}$$

and of labor's earnings:

$$W\hat{w}_t = \frac{Y}{\mu}\hat{y}_t + \frac{\gamma v}{\mu}\hat{v}_t - \frac{Q}{\mu}\hat{\mu}_t - \varphi NR(1-\eta)s\hat{s}_t$$
$$-\varphi NR\left((1-\eta)s - \frac{\gamma}{k^f}\right)(\hat{\varphi}_t + \hat{n}_t + \hat{r}_t) + \varphi NRs\eta\hat{\eta}_t$$
$$+\left(\frac{\varphi NR\gamma}{k^f} + \frac{\gamma v}{\mu}\right)\hat{\bar{z}}_t - \frac{\varphi NR\gamma}{k^f}\hat{k}_t^f \,. \tag{A29}$$

Finally, it is necessary to include the seven linearized driving processes:

$$\hat{\pi}_t^* = \rho_{\pi^*}\hat{\pi}_t^* + \varepsilon_t^{\pi^*} , \tag{A30}$$

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_t^z , \tag{A31}$$

$$\hat{\bar{z}}_t = \rho_{\bar{z}} \hat{\bar{z}}_{t-1} + \varepsilon_t^{\bar{z}} , \tag{A32}$$

$$\hat{V}_t = \rho_V \hat{V}_{t-1} + \varepsilon_t^V , \tag{A33}$$

$$\hat{\eta}_t = \rho_\eta \hat{\eta}_{t-1} + \varepsilon_t^V , \tag{A34}$$

$$\hat{A}_t = \rho_A \hat{A}_{t-1} + \varepsilon_t^A , \tag{A35}$$

and the Taylor rule:

$$\hat{r}_t - \hat{\pi}_t^* = \rho_r(\hat{r}_{t-1} - \hat{\pi}_t^*) + \rho_\pi(\hat{\pi}_t - \hat{\pi}_t^*)$$
$$+\rho_{EMPL}(\hat{n}_t - \hat{n}_{t-1}) + \varepsilon_t^r \,. \tag{A36}$$

These twenty-two linearized equations in twenty-two unknowns uniquely determine the dynamics of the system in the vicinity of the steady state for the calibrated parameter values chosen. It is possible to solve for the rational expectations equilibrium of this system using the methodology and code provided by Sims (2002). The end result is a reduced-rank VAR representation that provides the laws of motion for the underlying system in the form of equation (35) in the state-observer setup.

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Tables and figures

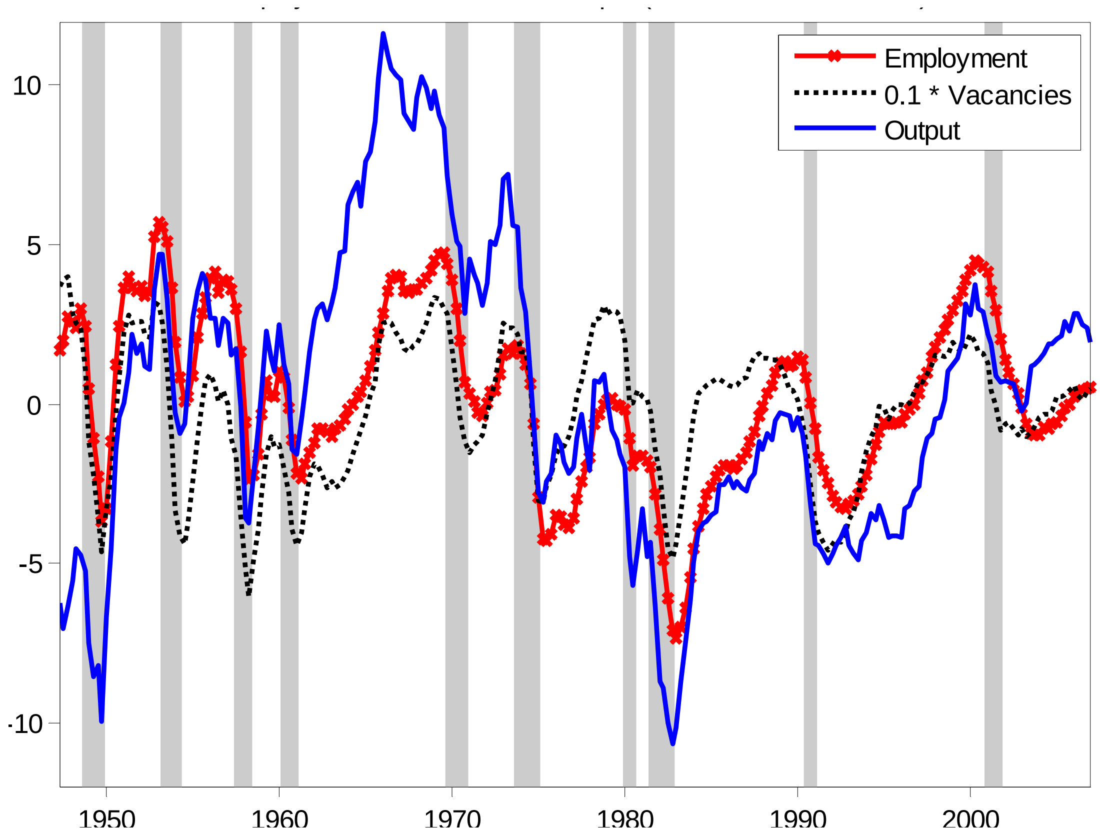

Figure 1: Real GDP, vacancies, and nonfarm employment (% deviation from trend). Source: NIPA, CES, and adjusted Conference Board / Met Life Help Wanted Index.

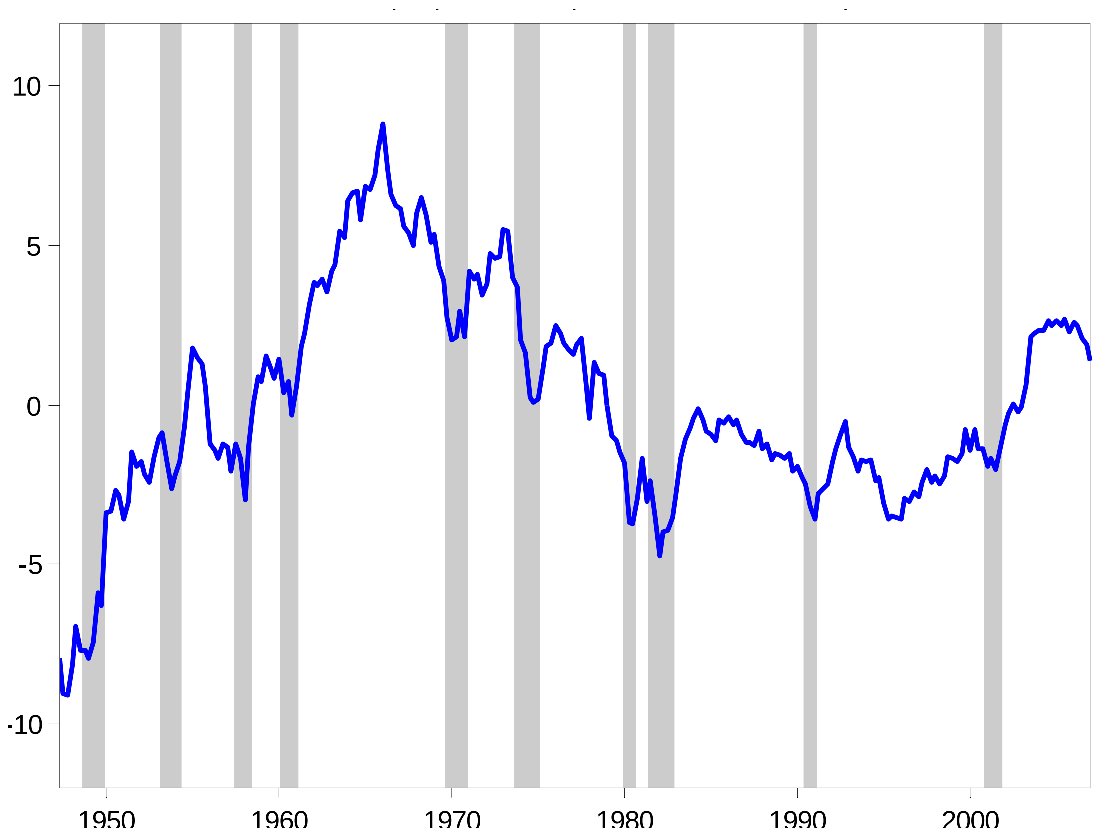

Figure 2: Real GDP per worker (% deviation from trend).
Source: NIPA and CES. This series is the difference of the GDP and employment series in Figure 1.

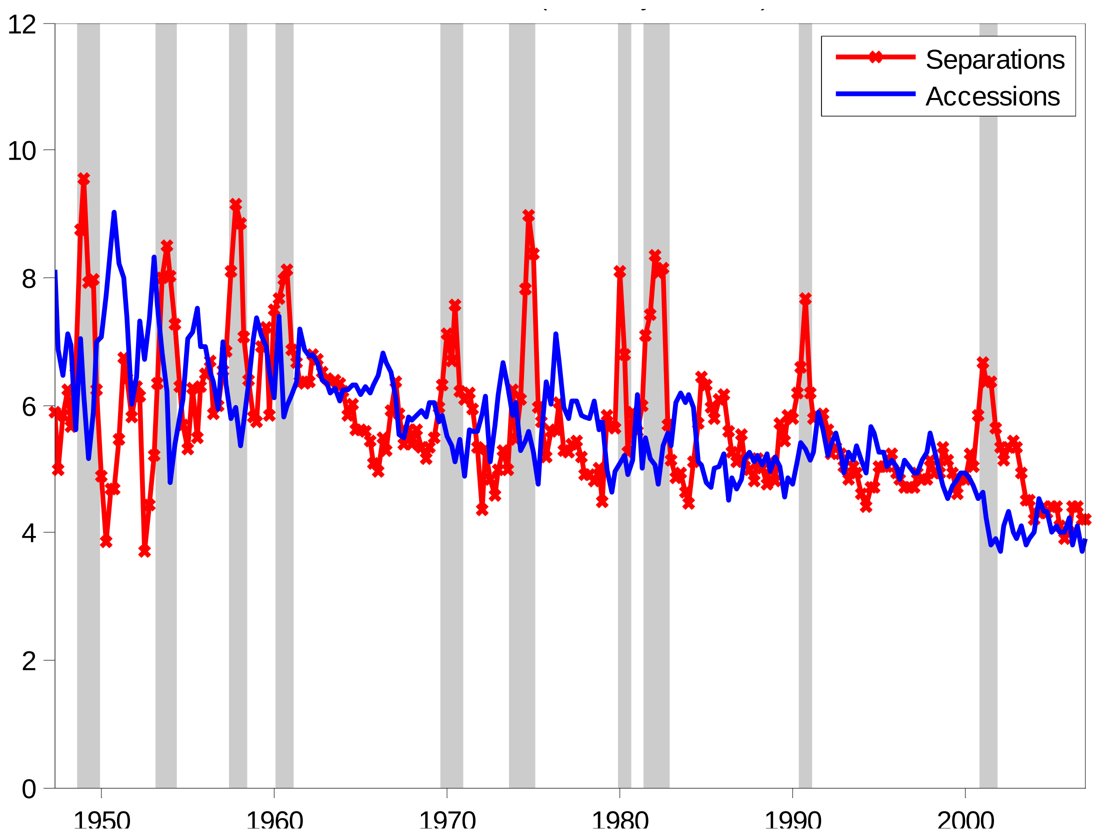

Figure 3: Job flow rates in manufacturing (% quarterly).
Source: Faberman (2006), supplemented with revised BED data.

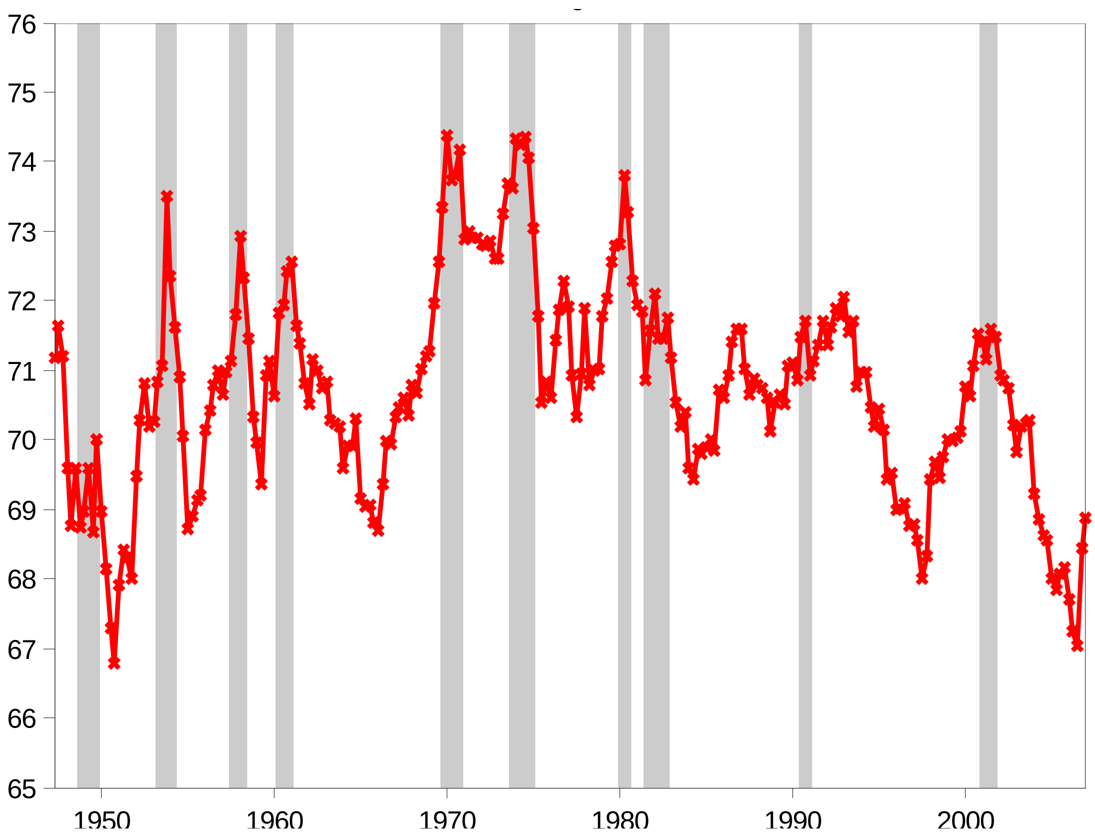

Figure 4: Labor's share of gross income, corporate sector (%).
Source: NIPA and author's calculations.

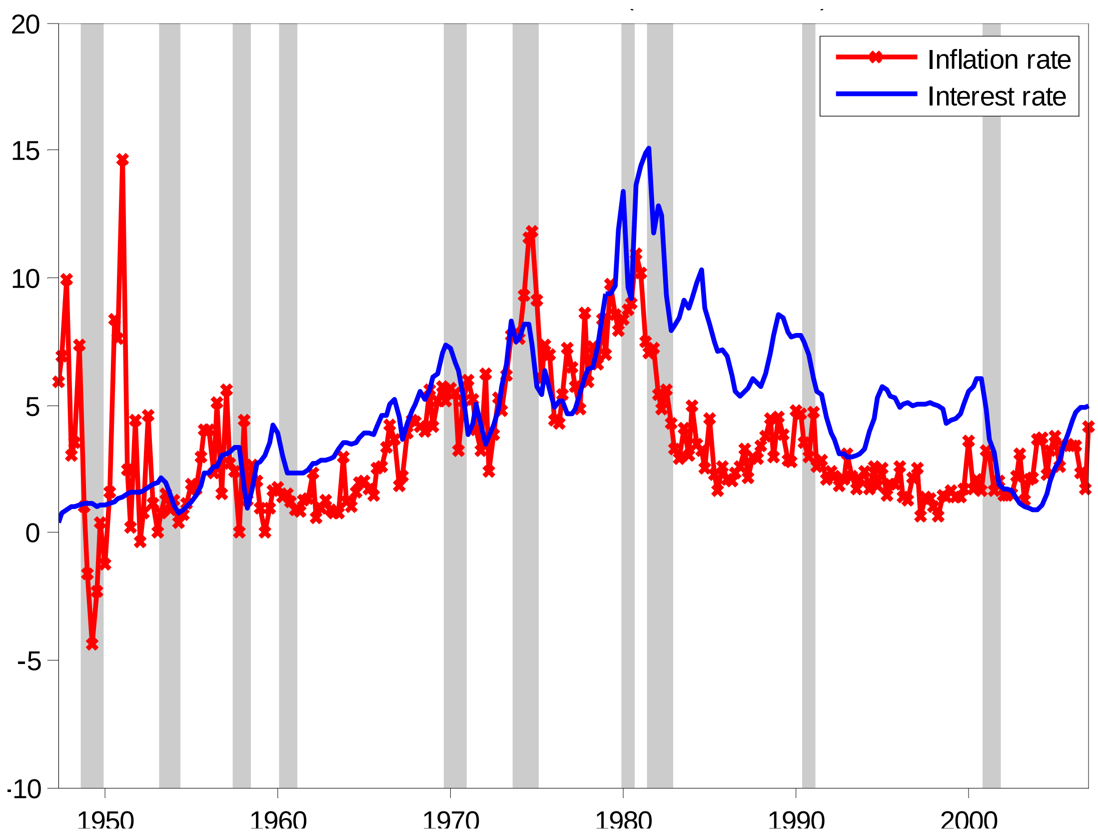

Figure 5: Inflation and nominal interest rates (% annual).
Source: NIPA and St. Louis Fed (FRED).

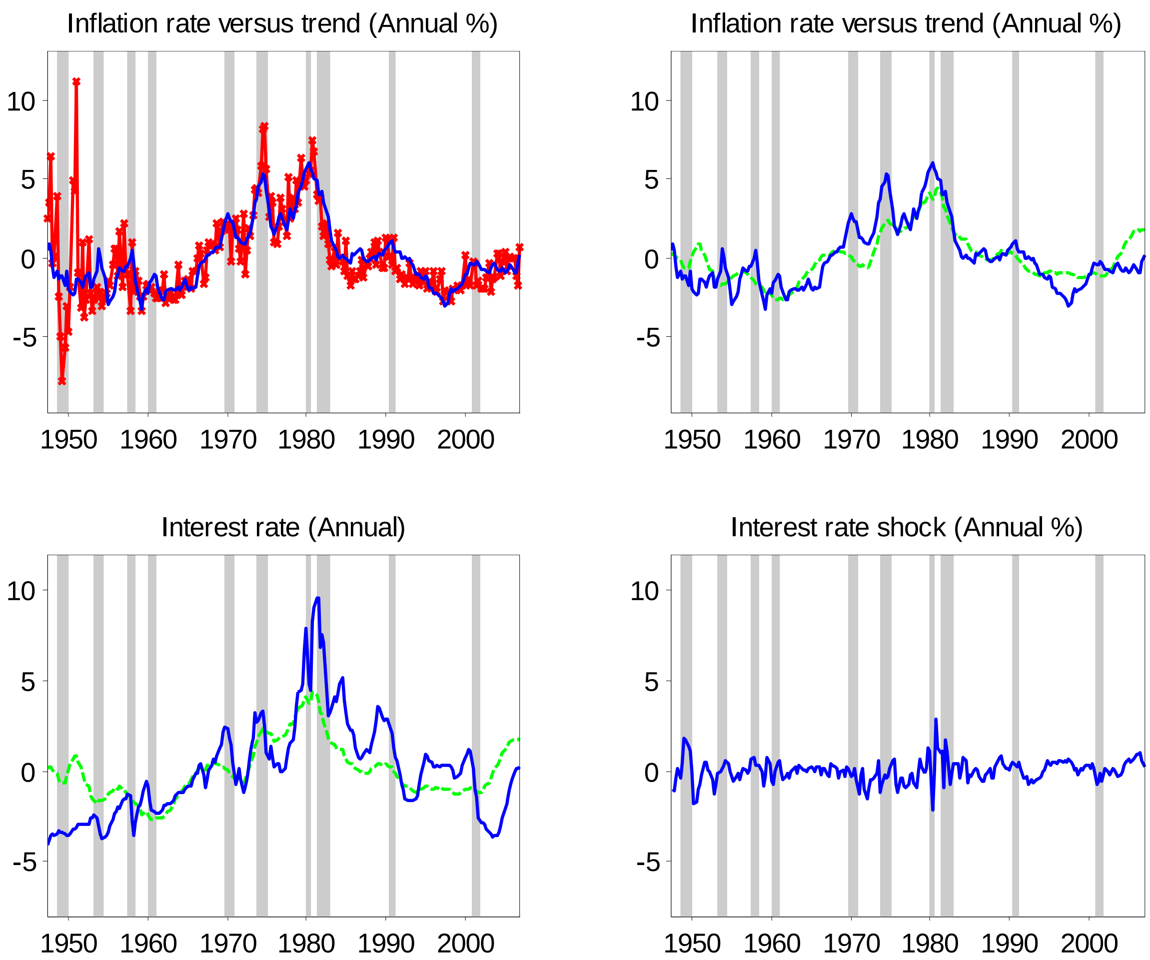

Figure 6: Estimated nominal driving processes (% deviation) – Baseline. Observed inflation is shown in red; trend inflation is shown in green. Gray bars indicate recessions.

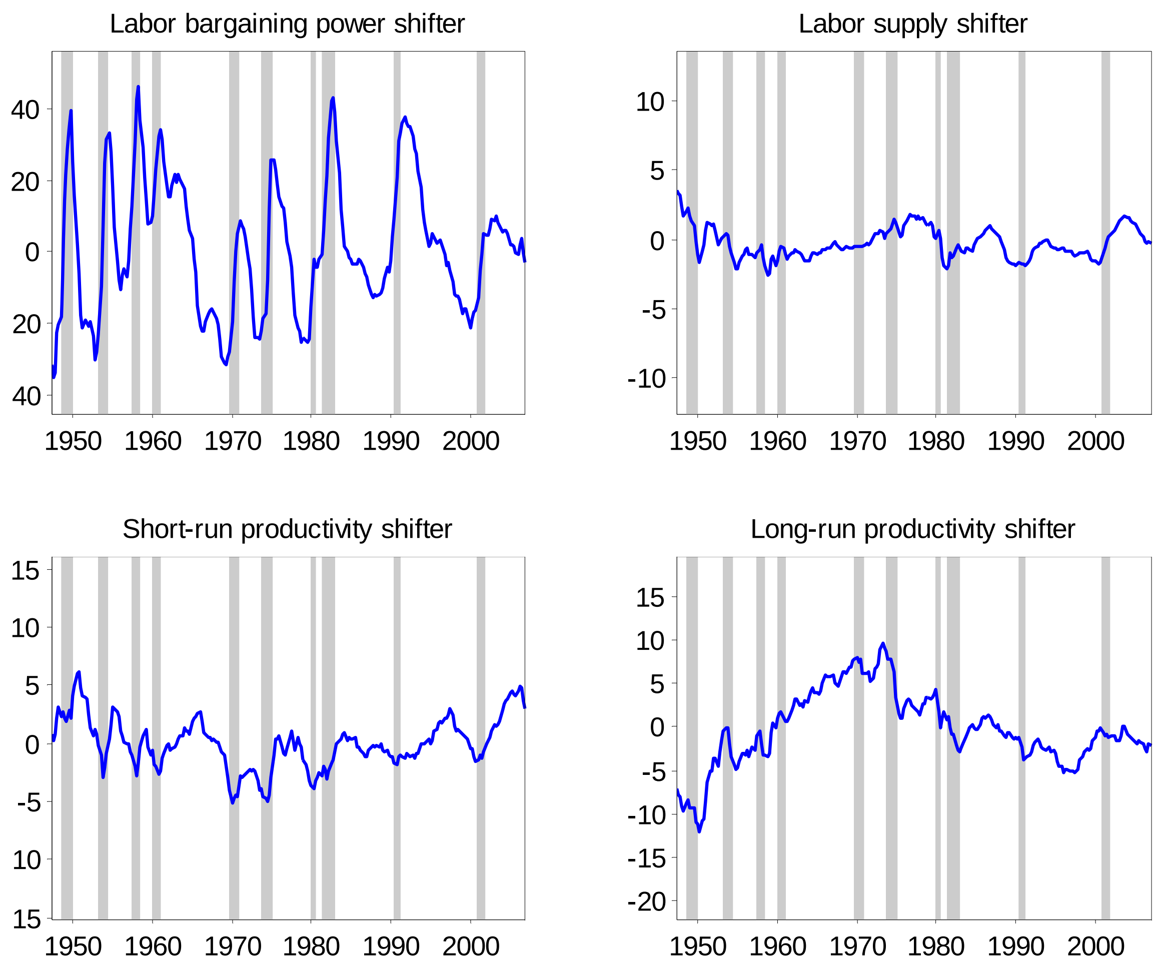

Figure 7: Estimated real driving processes (% deviation) – Baseline. The solid blue lines show the filtered estimates. Gray bars indicate recessions.

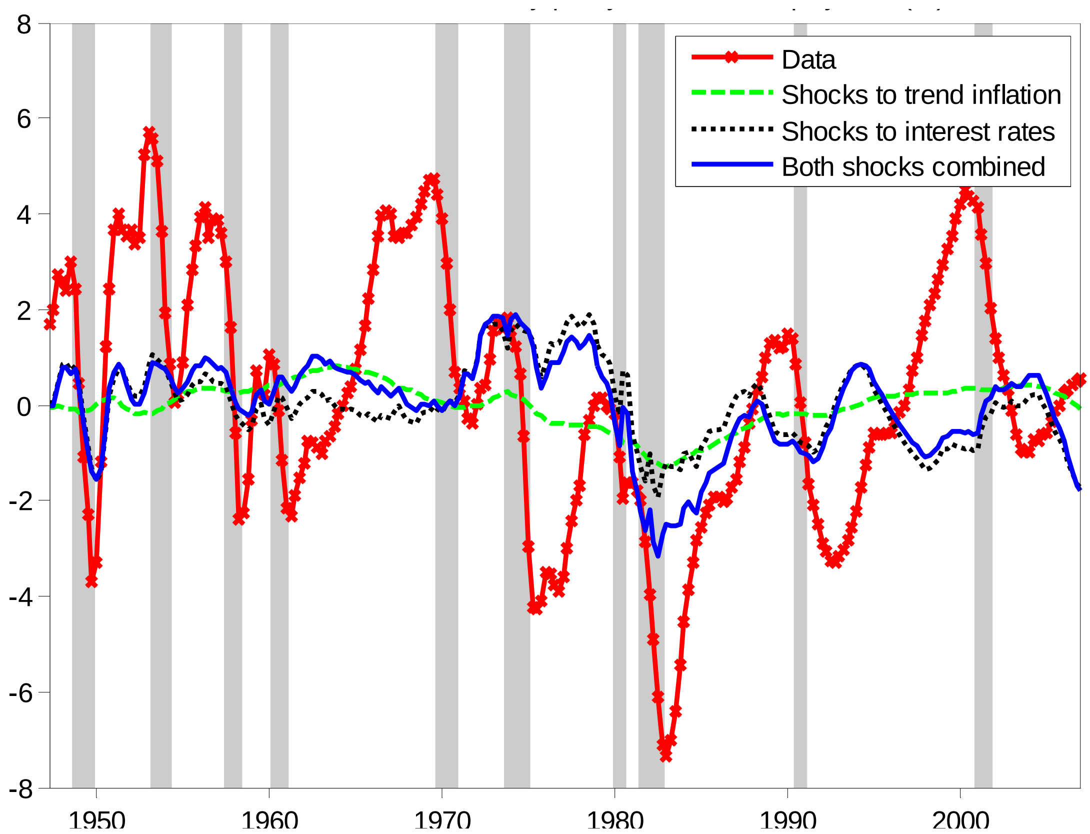

Figure 8: Estimated real effects of monetary policy shocks – Baseline. The red line depicts detrended employment (not HP filtered). Gray bars indicate recessions.

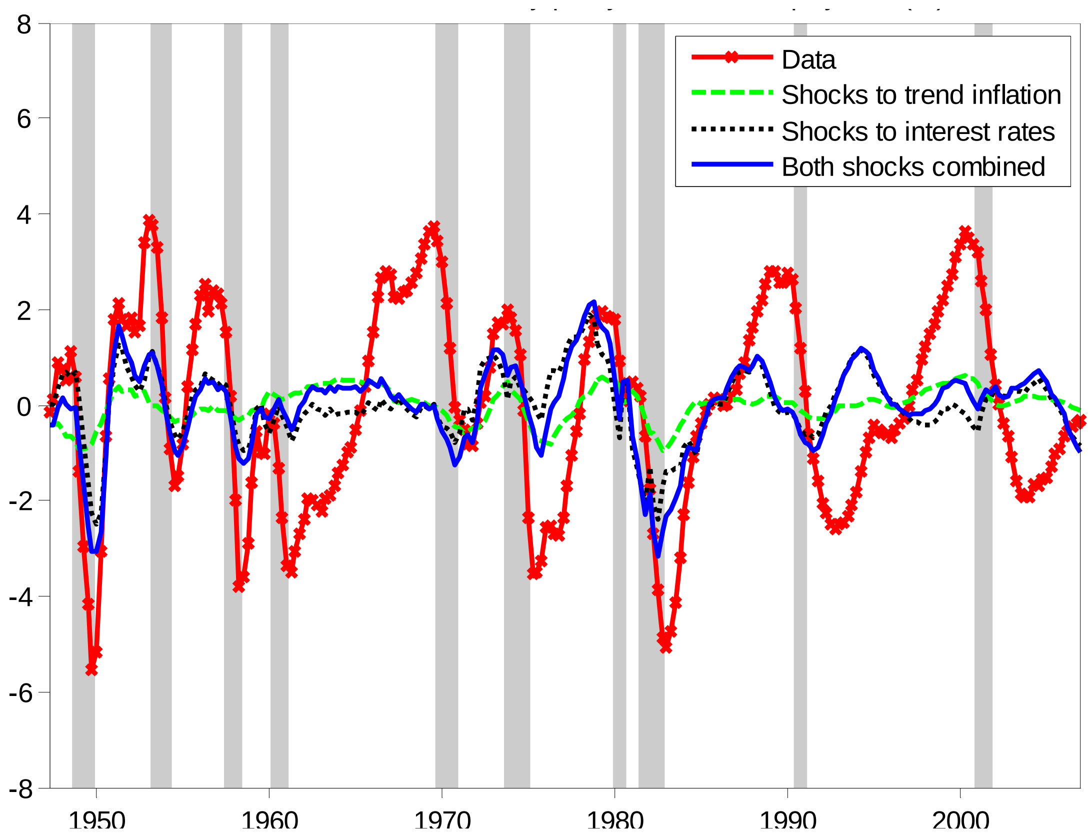

Figure 9: Estimated real effects of monetary policy shocks – RBC calibration. The red line depicts detrended employment (HP filtered, λ = 100,000). Gray bars indicate recessions.

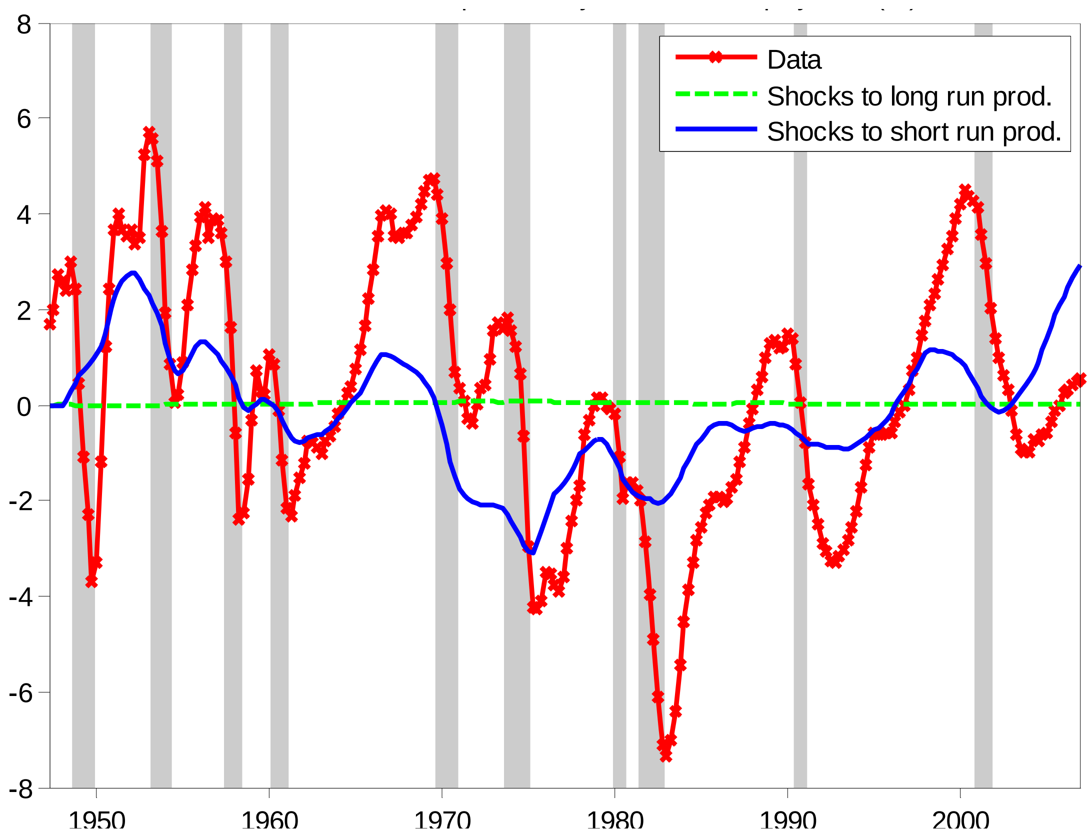

Figure 10: Estimated real effects of productivity shocks – Baseline. The red line depicts detrended employment (not HP filtered). Gray bars indicate recessions.

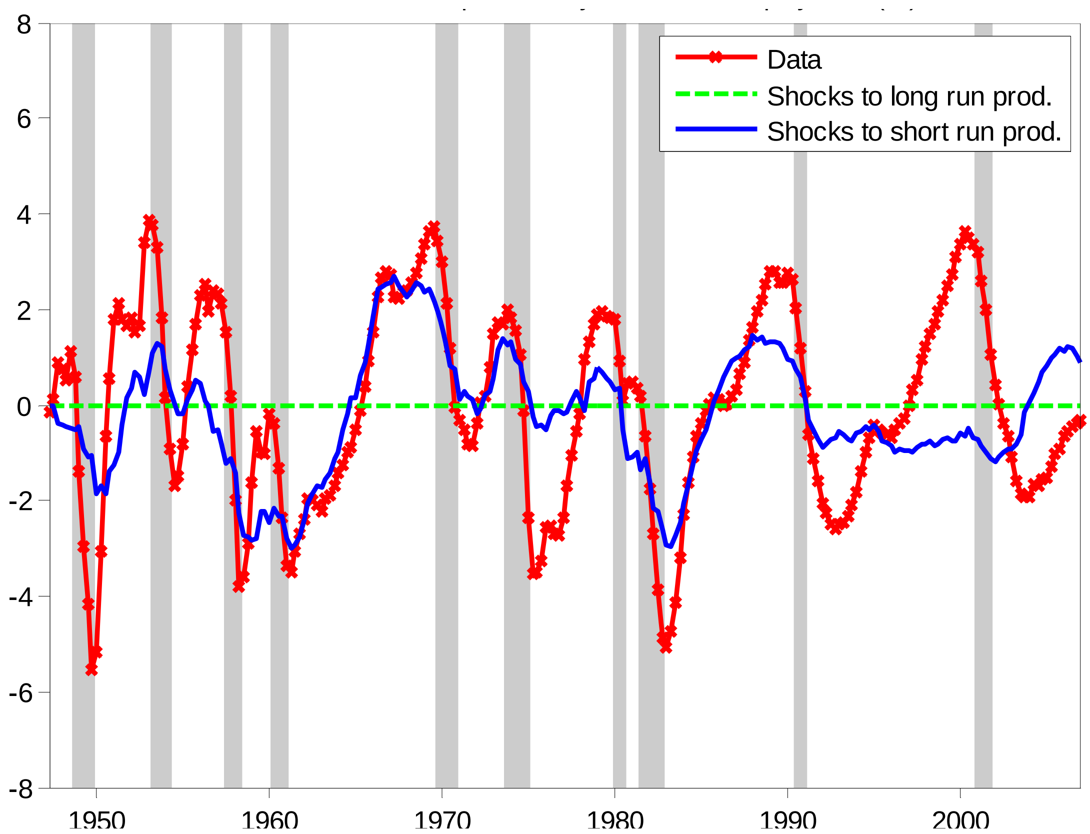

Figure 11: Estimated real effects of productivity shocks – RBC calibration. The red line depicts detrended employment (HP filtered, λ = 100,000). Gray bars indicate recessions.

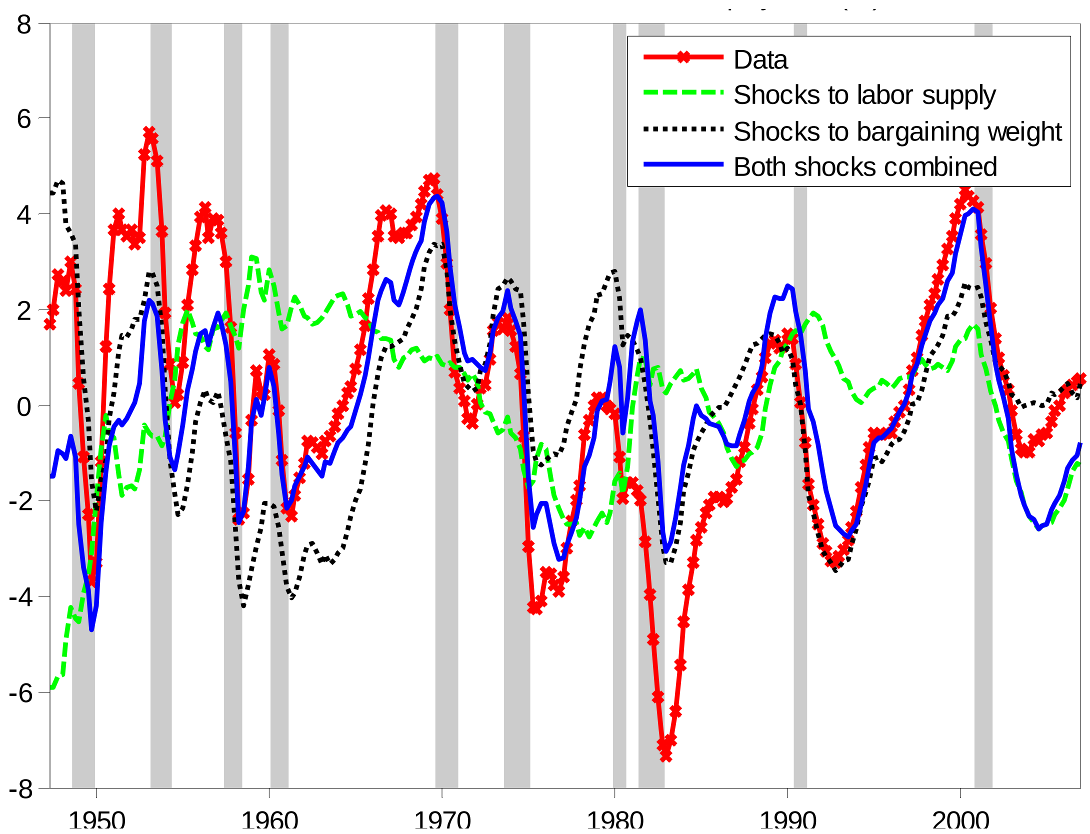

Figure 12: Estimated real effects of labor market shocks – Baseline. The red line depicts detrended employment (not HP filtered). Gray bars indicate recessions.

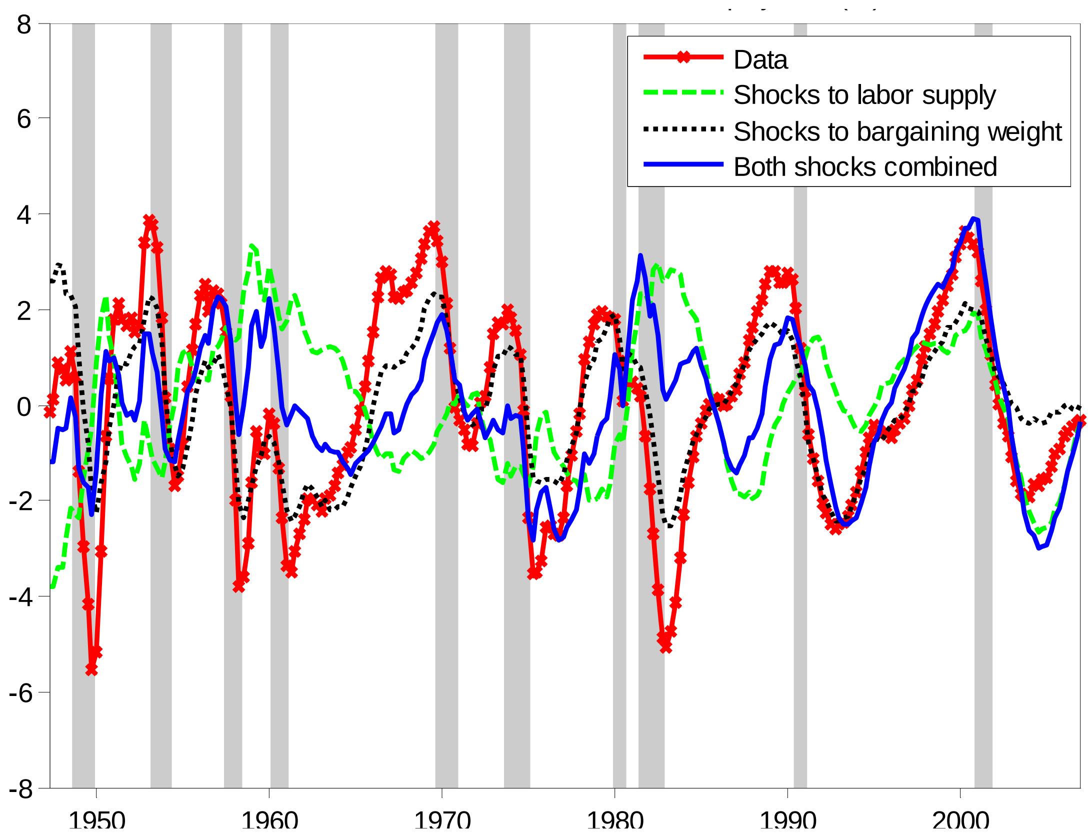

Figure 13: Estimated real effects of labor market shocks – RBC calibration. The red line depicts detrended employment (HP filtered, λ = 100,000). Gray bars indicate recessions.

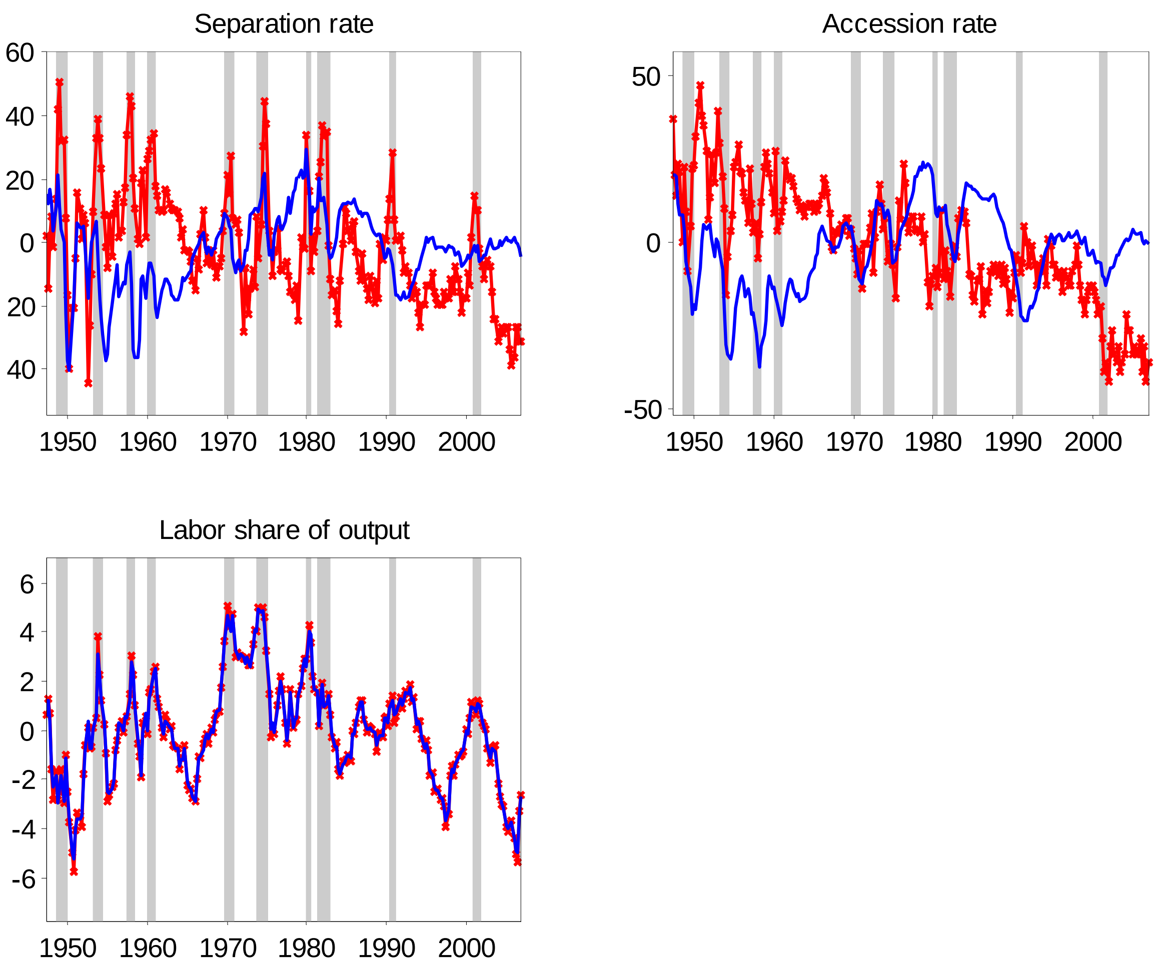

Figure 14: Filtered versus actual job flows and labor share (% deviation) – Baseline. The red lines depict detrended raw data (not filtered), and blue lines show filtered data. Gray bars indicate recessions.

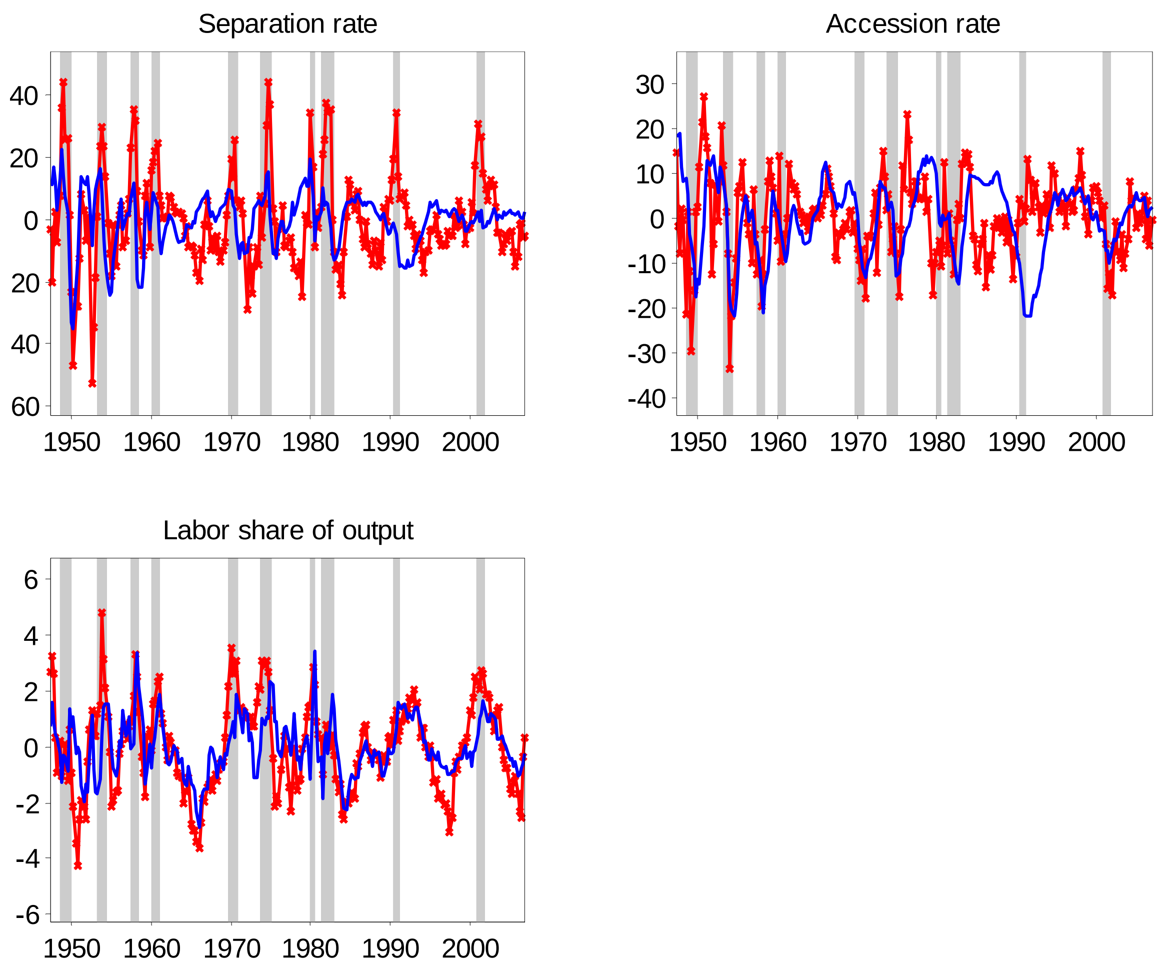

Figure 15: Filtered versus actual job flows and labor share (% deviation) – RBC calibration. The red lines depict detrended raw data (HP filtered, λ = 100,000), and blue lines show filtered data. Gray bars indicate recessions.