The Cost of Unemployment Fluctuations Revisited*

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Abstract

The costs of business cycles depend on the correlation of idiosyncratic risk and aggregate risk, the amount of self-insurance available and the amount of insurance provided by the government. A potentially important ingredient for this correlation might be unemployment risk. However, most papers to date either ignore unemployment risk altogether or exogenously impose a correlation structure. This paper develops a New Keynesian model with matching frictions and liquidity-constrained consumers and estimates the model on six macroeconomic time-series using Bayesian techniques. The estimation procedure accounts for the frequency mismatch between the model and the data. The model replicates the fluctuations of unemployment rates endogenously (without the unemployment series being used in the estimation) and implies reasonable business cycle statistics. We use this model to provide bounds for the costs of business cycles for different assumptions regarding the effectiveness of governmental unemployment benefit schemes and regarding the importance of self-insurance through saving and home-production. We find that the costs of business cycles might run up to 1.5% of steady state consumption.

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1 Introduction

Ever since the seminal work of Lucas (1987) the costs of business cycles have been an important research question. Reviewing the literature Lucas' (2003) preferred estimate remains 0.01% of steady state consumption. This finding suggests that there is little scope for (further) stabilization policy. Consequently, it has been challenged on various grounds. In particular, Krusell and Smith (1999) in an RBC framework with incomplete markets show that workers in the lower part of the wealth distribution might be hit very differently by recessions than the average worker. Their model, like most models to date which address the question, interprets a particular exogenously determined state as "unemployment". In contrast, in this paper we insist on unemployment fluctuations to be generated endogenously. We develop a New Keynesian model with a rich set of real and monetary frictions. The model features equilibrium unemployment and a simple characterization of incomplete markets. We use the model to reassess the welfare costs of business cycles in a sufficiently rich and empirically tractable framework.

Closest to our paper is Costain and Reiter (2005b). They construct a version of the Krusell and Smith RBC economy with endogenous labor markets to study the trade-off between efficiency and optimal insurance. Costain and Reiter arrive at welfare costs of around 0.29% of steady state consumption. We instead develop a richer New Keynesian DSGE model similar to Smets and Wouters (2003), but with Mortensen and Pissarides (1994) type search and matching frictions in the labor market, that we can estimate on US data. New Keynesian DSGE models to date mostly abstract from the functioning of the labor market, see for example the widely cited papers by Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2005). For generating unemployment fluctuations endogenously, we make use of an extensive literature which started with Shimer's (2005) observation that the standard Mortensen-Pissarides framework would not match business cycle fluctuations in labor market variables. In particular, Hall (2005), Costain and Reiter (2005a), Hagedorn and Manovskii (2006), and Jung (2006) provide mechanisms that allow the model to be consistent with observed unemployment variability. For a survey and some extensions of this literature see Mortensen and Nagypal (2006) and Hornstein, Krusell, and Violante (2005).

Essentially, all these mechanisms need to achieve a strongly pro-cyclical profit-share so that firms' hiring activity is also very much procyclical. Within a Nash-bargaining framework this can be generated either by assuming an outside option of the worker which is not much correlated with the business cycle as in Hall and Milgrom (2007), or by a small match surplus as in Jung (2006) or Hagedorn and Manovskii (2006). Alternatively, assumptions on the technology process would suffice. For example, Costain and Reiter (2005a) amplify fluctuations in profits by assuming that in booms better jobs are created than in recessions. In this paper we follow the first two routes. While the precise mechanism by which these fluctuations are induced is not crucial for key moments of labor market variables in the model, for the purpose of this paper the details matter to a great extent. Different mechanisms imply a different value for a crucial feature of business cycle costs: the surplus a worker obtains from being employed relative to being unemployed. At the one extreme, the bargaining setup developed in Jung (2006) and Hagedorn and Manovskii (2006) relies on a small match surplus to generate the right degree of unemployment volatility. This leaves a worker almost indifferent between unemployment and market work merely by assumption – with obvious consequences for the ensuing costs of business cycles. We therefore entertain also other mechanisms which generate unemployment fluctuations but do not imply such a small match surplus. In particular, we show that a form of wage rigidity similar to the mechanism in Hall and Milgrom (2007) generates the same aggregate behavior for unemployment rates. Since it does not rely on a low match surplus, yet, this approach yields higher and arguably more realistic, welfare costs of business cycles. We use the alternative bargaining setups to trace out the dependence of the welfare costs of business cycles on the match surplus.

Our model entertains two groups of workers/consumers in order to assess the importance of business cycle fluctuations for different income/wealth groups. One group of workers lives within a family structure and is fully insured against idiosyncratic risks.[1] There is a second group of workers, who are liquidity-constrained. These workers/consumers in the model do not have access to capital markets.[2] This short-cut allows us to derive a bargaining solution for risk-averse

[1] Under this assumption, workers are perfectly insured against short-falls of consumption by a large "family". The full insurance assumption follows den Haan, Ramey, and Watson (2000) and is used widely, e.g. in Trigari (2006), Christoffel, Kuester, and Linzert (2006) and Krause and Lubik (2005).

[2] In fact, we assume the absence of any storage technology for this part of the population. One might consider that these consumers could still save into cash or durable consumption goods. In our view, omission of these options is not detrimental to our approach. On the one hand, durable consumption goods tend to be rather illiquid and can thus hardly be used to smooth non-durable consumption. Further, storing large amounts of cash literally under one's pillow would not constitute a strikingly prudent savings strategy either – and conflicts with the micro evidence. On the other hand, our results might simply be interpreted as an upper for the welfare costs of business cycles for low-skilled workers. Iacoviello (2005) makes a similar distinction between savers and spenders (in Mankiw's, 2000, terminology). In his framework, a fraction of the households

agents without having to resort to risk-neutrality, a complete insurance or a union-bargaining assumption. As noted by many authors, e.g. Gruber (2001), a sizeable fraction of the labor force does not have enough wealth to smooth out market-traded consumption during an unemployment spell despite the fact that unemployment spells tend to be short-lived in the US. In this paper we use his lower bound estimate of 16% of the labor force as our estimate of the size of this liquidity-constrained group.[3] In the model, we associate this group with lower-skilled agents who in the data face a significant unemployment risk. Since in practice, the composition of the liquidity-constrained group may be varying over time so that not always the same set of consumers/workers is threatened by these constraints, we view this assumption as giving as an upper-bound for the welfare costs of aggregate risk for this part of the population.

The assumption of liquidity-constrained workers, even though introduced in a stylized fashion, enables us to keep the model tractable while still capturing the apparent empirical differences in financial wealth.[4] An advantage of this strict formulation is that we can handle a richer state space and thus allow for more complex (unemployment and aggregate) dynamics than, say, Krusell and Smith (2002) or Costain and Reiter (2005b).

We estimate the model using Bayesian techniques on six macroeconomic time-series primarily to identify the shock processes which are driving the model. To obtain good estimates of business cycle costs it is necessary that the model is able to rather accurately generate key properties of US data that either directly influence utility, as is the case for consumption and hours worked, or which concern the particular risks we wish to be reflected in the model economy, which in our model necessitates an accurate description of the labor market. Given that our model economy works on a monthly time-scale, we show how to aggregate the model by treating monthly observations of the endogenous variables as latent while assuming that only the quarterly averages

is more impatient and thus ends up facing a binding (albeit non-zero) borrowing constraint in equilibrium.

[3] This is in line with other studies on the wealth distribution. Wolff (1998), for example, analyzes the Survey of Consumer Finances in 1995. He finds that 18.5% of households have zero or negative net worth, and that 28.7% of households have zero or negative financial (liquid) wealth. In addition, financial wealth is highly correlated with labor income. The households at the 40% (20%) lower end of the income distribution hold an amount of financial wealth that would enable them to sustain their consumption for an average of just 1 month (0 months).

[4] Johnson, Parker, and Souleles (2005) use the pre-announced 2001 U.S. tax rebates as a natural experiment. Examining answers to a set of questions in the Consumer Expenditure Survey directly targeted at these rebates, they find significant evidence of different spending behavior across different income and wealth groups. Responses are much larger for households with low liquid wealth or low income, consistent with liquidity constraints.

are observable to the econometrician. The estimated model reproduces the cyclical behavior of actual unemployment rates of the US, which were not used in the estimation procedure. Instead the model can predict the entire time-path of unemployment rates almost perfectly without using any shock designed to fit the series. In words, it generates unemployment fluctuations endogenously.

1.1 Relation to the literature

In his by now classic article Lucas (1987) argues that the costs of business cycles are small. Since then many researchers have tried to check the robustness of Lucas' arguments with respect to a variety of changes in his basic assumptions, see Barlevy (2005) for a recent survey. A promising direction was the introduction of idiosyncratic risk, see Imrohoroglu (1989), and pioneered with endogenous equilibrium prices by Krusell and Smith (1999). The latter authors show that parts of the population or even the average consumer may stand to gain from having business cycles. Business cycle costs can, however, be substantial for the bottom part of the wealth distribution who are faced with binding borrowing constraints. Storesletten, Telmer, and Yaron (2001) extend this line of research by carefully calibrating the individual labor income process based on PSID data. As was pointed out by Costain and Reiter (2005b) a possible weakness of above approaches is that these models do not endogenously account for the relation of unemployment with the state of the business cycle but rather assume that "unemployment" is an idiosyncratic but exogenous shock. Filling the gap in the literature the latter authors provide an RBC model with idiosyncratic uncertainty and a labor market with search and matching frictions that allows them to estimate the trade-off between stabilization policy and risk. In their model the cost of business cycle fluctuations is about .29% of steady state consumption, which is 30 times higher than the estimate by Lucas, but still relatively contained. An advantage of their approach is that their model allows for heterogeneity in the wealth distribution, such that they can study the insurance aspect of unemployment in greater detail. Similar to our setup they do not allow the bargaining position to depend on individual wealth. For analytical tractability, in their model unions bargain for equally productive workers. Their setup thus disregards the effects of an individual's wealth on his/her bargaining position. Our setup allows allows for different bargaining positions of the workers who are fully insured by the family and those workers who are liquidity-constrained but at the same time assumes that the former are higher-skilled than the latter. The setup with two distinct groups of workers entertained in the current paper considerably simplifies the model relative to Costain and Reiter's. In order to address the costs of business cycles it may ultimately be important to fit to a reasonable extent key ingredients of the utility function like consumption and hours worked, as well as fluctuations of unemployment and wages, given that it is the interaction of these series with respect to changes in the variance of the underlying shocks that we wish to study.

A further characteristic that differentiates our study from Costain and Reiter (2005b) is that we analyze a New Keynesian setup with considerably more complex business cycle dynamics and a variety of additional frictions which are standard in the New Keynesian literature, cp. for example Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). To the best of our knowledge no work so far has been conducted on the welfare costs of business cycles in a New Keynesian setup with equilibrium unemployment. In terms of techniques our paper heavily draws on the methodology in Schmitt-Grohé and Uribe (2004a) and the second-order approximation method of Schmitt-Grohé and Uribe (2004b).

Business cycles in our model can be costly by increasing the unconditional probability of long unemployment spells and by making unemployment for the low-skilled, liquidity-constrained workers more volatile. They can thus endogenously change the distribution of idiosyncratic risk, which has a bearing on the estimated costs of business cycles. The latter are affected due to their dependance on the wage and consumption loss in downturns and the likelihood of returning back to work. In this paper, we can thus analyze the costs of business cycles in a sufficiently rich model with endogenously determined unemployment, in which lower consumption in state of unemployment could potentially matter for individual welfare. Our bargaining setups allow us to accomplish this goal in a relatively parsimonious parametrization without having to impose assumptions on the correlation structure of labor market shocks as in Mortensen and Nagypal (2006) or on the time path of the outside option,[5] and without resorting to additional assumptions on technology as in Costain and Reiter (2005b), who implicitly use a shock to the profit share that is correlated with the aggregate technology level.

The remainder of the paper is organized as follows. Section 2 lays out the theoretical model that

[5] An earlier working paper version of Hall and Milgrom (2007), for example, relied on a correlated shock to the outside option to achieve matching the fluctuation of unemployment rates. In their current version the parametrization implicitly closely corresponds to the values suggested in Hagedorn and Manovskii (2006) and Jung (2006) – which are used also in this paper.

we will analyze. Section 3 turns to the calibration and the estimation of the model. Section 4 discusses the welfare criteria used and presents estimates of the welfare costs of business cycle fluctuations. A final section concludes. We relegate a summary of the data and an outline of the estimation strategy to the Appendix.

2 The Model

We incorporate search and matching frictions à la Mortensen and Pissarides (1994) into an otherwise standard New Keynesian business cycle model of the Smets and Wouters (2003) type. Consumers fall into two categories: those who can save into bonds, stocks, and physical capital and those who are prevented from access to asset markets.[6] The model's production side features competitive factor markets in the only price-setting sector. The degree of nominal rigidity should thus be interpreted in this light.[7] One time period in the model refers to a calendar time of one month.

2.1 Preferences and Consumers' Constraints

There is a large number of identical families in the economy with measure $\nu \in [0,1]$. Each family consists of a measure of $1-u_t^{(1)}$ employed members and $u_t^{(1)}$ unemployed members. The families hold all assets in the economy. Consequently, profit income in the economy accrues entirely to this part of the population. The representative family pools the income of its working members, unemployment benefits of the unemployed members and financial income from financial assets which they hold via a mutual fund. There is also a measure $1-\nu$ (potentially zero) of individuals not associated with any family. These are assumed not to have access to financial markets. In period t, a measure $u_t^{(2)}$ of these constrained workers are unemployed. We assume that the mass of liquidity-constrained consumers does not vary over time and normalize the total mass of consumers in the economy to one. We index the different types by superscript $(o) \in \{1,2\}$.
Consumers have time-additive expected utility preferences. Preferences of consumer i can be

[6] For technical reasons it is important to ensure a sufficient degree of homogeneity in asset-holdings. For asset-holding workers we entertain a familiy structure which pools all assets. The other group of workers must not hold any assets (not even currency) if the analysis is still to be viable.

[7] See, e.g., Eichenbaum and Fisher (2004) and Altig, Christiano, Eichenbaum, and Linde (2005) about firmspecific factor markets and the interpretation of a certain slope of the New Keynesian Phillips curve.

represented by

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \mathtt{u}^{(o)} \left(c_{i,t}^{(o)}, c_{t-1}^{(o)}, \{h_{i,t}^{(o)}\} \right) \right\}, \tag{1}$$

where E_0 marks expectations conditional on period 0 information. $\mathtt{u}^{(o)}(c_{i,t}^{(o)}, c_{t-1}^{(o)}, h_{i,t}^{(o)})$, $o \in \{1, 2\}$, is a standard period utility function of the form[8]

$$\mathtt{u}^{(o)}(c_{i,t}^{(o)}, c_{t-1}^{o}, h_{i,t}^{(o)}) = \frac{(c_{i,t}^{(o)} - \varrho^{(o)} c_{t-1}^{(o)})^{1-\sigma}}{1-\sigma} - \kappa^L \frac{\left(h_{i,t}^{(o)}\right)^{1+\varphi}}{1+\varphi}, \sigma > 0, \varphi > 0. \tag{2}$$

Here, $c_{i,t}^{(o)}$ denotes consumption of member i and $h_{i,t}^{(o)}$ are hours worked by member i in group o. Utility also depends on external habit persistence, indexed by parameter $\varrho^{(o)} \in [0, 1)$. Note that external habit is assumed to take past aggregate consumption of the respective group of agents, $c_{t-1}^{(o)}$, as the reference point. κ^L is a positive scaling parameter of disutility of work.

2.1.1 The Families of Asset-holding Workers

The representative family maximizes the sum of expected utilities of its individual members,

$$\mathtt{W}_0^{(1)} = \int_0^1 E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \mathtt{u}^{(1)} \left(c_{i,t}^{(1)}, c_{t-1}^{(1)}, h_{i,t}^{(1)} \right) \right\} di. \tag{3}$$

Here "$\mathtt{W}_t^{(1)}$" stands for "welfare" of the family as of period t. Let $\mathtt{U}\left(c_t^{(1)}, c_{t-1}^{1}, u_t^{(1)}, \{h_{i,t}^{(1)}\}\right)$ denote the aggregate per-period utility function of the family:

$$\mathtt{U}\left(c_t^{(1)}, c_{t-1}^{(1)}, u_t^{(1)}, \{h_{i,t}^{(1)}\}\right) := \int_0^1 \mathtt{u}^{(1)}(c_{i,t}^{(1)}, c_{t-1}^{(1)}, h_{i,t}^{(1)}) di, \tag{4}$$

where $c_t^{(1)}$ is the average consumption level of family members and $\{h_{i,t}^{(1)}\}$ is shorthand for a potential distribution of hours contracts. We will later focus on a symmetric equilibrium in which each employed family member indeed works exactly the same hours and receives the same wage. Given its arguments, utility function $\mathtt{U}(\cdot,\cdot,\cdot,\cdot)$ gives the value of per-period family-utility when $c_t^{(1)}$ is optimally distributed among family members; see Appendix A for details. Only part of the consumption goods need to be acquired in the market. $c_t^{(1,m)}$ is the amount of resources spent on acquiring these. Unemployed family members also engage in home production, which is not tradable in the market but can be shared by family members. Total consumption per capita thus is

$$c_t^{(1)} = c_t^{(1,m)} + u_t^{(1)} home^{(1)}, \tag{5}$$

[8] See Jung (2005) for the more general but also less tractable case of utility allowing for balanced growth.

where $home^{(1)}$ marks the state-independent value of home-production by an unemployed family member.

Family members, i.e. workers of type 1, pool their income. Their budget constraint is thus given by

$$c_t^{(1,m)} + i_t + t_t = \int_0^{1-u_t^{(1)}} w_{i,t}^{(1)} h_{i,t}^{(1)} di + u_t^{(1)} b^{(1)} + \frac{1}{\nu}\left[\frac{D_{t-1}}{P_t} R_{t-1}\epsilon_{t-1}^b - \frac{D_t}{P_t}\right] + \Psi_t + r_t^k z_t k_{t-1} - \psi(z_t) k_{t-1}, \tag{6}$$

where i_t marks real investment per family member. So aggregate investment is given by $\nu\, i_t$. Both i_t and $c_t^{(1)}$ are choice variables of the family. $w_{i,t}^{(1)} h_{i,t}^{(1)}$ is the real wage per hour multiplied by hours worked by individual household member i. t_t are lump-sum taxes per capita payable by the family. $b^{(1)}$ are real unemployment benefits paid to unemployed family members.[9] The family holds $\frac{1}{\nu} D_t$ units of a risk-free one-period nominal bond (government debt) with gross nominal return $R_t \epsilon_t^b$. ϵ_t^b denotes a serially correlated shock to the risk premium. It drives a wedge between the return on assets held by households and the interest rate controlled by the central bank, see Smets and Wouters (2007). The household also owns representative shares of all firms in the economy. Ψ_t denotes real dividend income per member of the family arising from these firms' profits:

$$\Psi_t = \frac{1}{\nu}\left\{\Psi_t^C + \nu(1-u_t^{(1)})\Psi_t^{(1)} + (1-\nu)(1-u_t^{(2)})\Psi_t^{(2)}\right\}. \tag{7}$$

Here $\Psi_t^C, \Psi_t^{(1)}$ and $\Psi_t^{(2)}$ are the profits arising in the differentiating industry and in the labor good industry; see Section 2.2. k_t is the amount of physical capital held per member of the family. The family chooses the capacity utilization rate z_t and leases its effective capital, $z_t k_{t-1}$, to wholesale firms in a perfectly competitive capital market. The real rental rate of capital is r_t^k. The increasing, convex function $\psi(z_t)$ denotes the resource cost, in units of consumption goods, of setting the utilization rate to z_t. We assume that

$$\psi(z_t) = \gamma_{z,1}(z_t - 1) + \frac{\gamma_{z,2}}{2}(z_t - 1)^2,$$

where $\gamma_{z,1}$ and $\gamma_{z,2}$ are such that $\psi(1) = 0$, $\psi'(1) = r^k$, $\psi''(1) > 0$, as in Christiano, Eichenbaum, and Evans (2005).[10]

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[9] The difference between unemployment benefits and home production in our setup is that the former are payable in cash and are thus market-tradable, while the latter will not show up in the national accounts.

Capital accumulation is subject to capital adjustment costs summarized by the function $S(\cdot)$.

$$k_t = k_{t-1}(1-\delta) + \left[1 - S\left(\frac{i_t}{i_{t-1}}\right)\right]\epsilon_t^I i_t. \tag{8}$$

Here δ is the monthly rate of capital depreciation and ϵ_t^I is a serially correlated "investment shock" with unit steady state. As in Christiano, Eichenbaum, and Evans (2005) we assume that $S(1) = 0$, $S'(1) = 0$ and $S''(1) > 0$. The functional form we use is

$$S\left(\frac{i_t}{i_{t-1}}\right) = \frac{\kappa^I}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2, \ \kappa^I > 0.$$

2.1.2 The Family's First-order Conditions

The family maximizes (3) by choosing per-capita capital, k_t, investment, i_t, consumption, $c_t^{(1,m)}$, capacity utilization, z_t, and bond-holdings, D_t, subject to (6) and (8). The first-order condition for investment is

$$q_t^k S_t'(\cdot)\frac{\epsilon_t^I i_t}{i_{t-1}} - \beta E_t\left\{q_{t+1}^k \frac{\lambda_{t+1}}{\lambda_t} S_{t+1}'(\cdot)\left(\frac{i_{t+1}}{i_t}\right)^2 \epsilon_{t+1}^I\right\} + 1 = q_t^k(1 - S_t)\epsilon_t^I, \tag{9}$$

where $S_t := S\left(\frac{i_t}{i_{t-1}}\right)$ and q_t^k is the shadow value of installed capital (measured in consumption units). $\lambda_t = \frac{\partial \mathbb{U}(c_t^{(1)},\ldots)}{\partial c_t^{(1)}} = \left(c_t^{(1)} - \varrho^{(1)} c_{t-1}^{(1)}\right)^{-\sigma}$ is the marginal family utility of additional consumption for each of the family members; see again Appendix A. The first-order condition for capital can be written as

$$q_t^k = E_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\left[q_{t+1}^k(1-\delta) + r_{t+1}^k z_{t+1} - \psi(z_{t+1})\right]\right\}. \tag{10}$$

Capacity utilization is chosen so as to equate the real return on capital and the marginal cost of capacity utilization

$$r_t^k = \psi'(z_t). \tag{11}$$

Bonds are chosen so as to intertemporally equate marginal utilities of consumption:

$$1 = E_t\left\{\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{R_t\epsilon_t^b}{\Pi_{t+1}}\right\}. \tag{12}$$

Finally, the optimal consumption plan satisfies the two transversality conditions

$$\lim_{j\to\infty} E_t\left\{\beta^j \frac{\lambda_{t+j}}{\lambda_t} k_{t+j}\right\} = 0, \ \forall t. \tag{13}$$

[10] Here as in the remainder of the paper, endogenous variables which do not carry a time index refer to steady state values. Here, for example, r^k denotes the steady state value of r_t^k.

and

$$\lim_{j\to\infty} E_t\left\{\beta^j \frac{\lambda_{t+j}}{\lambda_t}\frac{D_{t+j}}{P_{t+j}}\right\} = 0,\ \forall t. \tag{14}$$

We turn to describe preferences and budget constraints of liquidity-constrained consumers.

2.1.3 Liquidity-constrained Consumers

Liquidity-constrained consumers are not insured by a family. They do not have access to liquidity-providing services and financial markets. They also cannot insure each other against the risk of becoming unemployed. Unemployed workers in this group also cannot share their home-production with others. Liquidity-constrained consumers seek to maximize expected utility (1), which is reproduced here for type $o = 2$ workers for convenience:

$$E_0\left\{\sum_{t=0}^{\infty} \beta^t \mathbf{u}^{(2)}(c_{i,t}^{(2)}, c_{t-1}^{(2)}, h_{i,t}^{(2)})\right\}, \tag{15}$$

where period utility is of the form (2). Due to being prevented from saving and borrowing, liquidity-constrained consumers always consume their entire after-tax income. Depending on parameter $\chi \in \{0,1\}$, they contribute to lump-sum taxes. Depending on parameter $\chi_2 \in \{0,1\}$ they contribute to group-specific taxes. That is, their budget constraint is given by

$$c_{i,t}^{(2)} = \begin{cases} c_{e,i,t}^{(2)} = w_{i,t}^{(2)} h_{i,t}^{(2)} - \chi t_t - \chi_2 t_t^{(2)} & \text{if employed} \\ c_{u,i,t}^{(2)} = b^{(2)} + home^{(2)} - \chi_2 t_t & \text{if unemployed,} \end{cases} \tag{16}$$

$c_{e,i,t}^{(2)}$ marks consumption of liquidity-constrained consumer i if he is employed. $c_{u,i,t}^{(2)}$ is the consumption level if he is unemployed instead. $b^{(2)}$ are real unemployment benefits paid to unemployed liquidity-constrained workers. Home production of liquidity-constrained workers is denoted by $home^{(2)}$.

2.2 Firms

There are three sectors of production. One sector produces a homogenous intermediate good, which we shall call the "labor good". Firms in this sector need to find exactly one worker in order to produce. They take hours worked as their sole input into production. In the model, searching for a worker is a costly and time-consuming process due to matching frictions. Once a firm and a worker have met, they Nash-bargain over wages and hours on a period-by-period basis. Labor goods are sold to a second sector in a perfectly competitive market. The second sector is a wholesale sector. Wholesale firms take intermediate labor goods and physical capital as inputs, and produce differentiated goods using a constant-returns-to-scale production technology. Subject to price-setting impediments à la Calvo (1983), they sell to a final sector under monopolistic competition.[11] The final sector is a retail sector. Retailers bundle differentiated goods into a homogenous consumption/investment basket, y_t. They sell this final good to consumers and to the government at price P_t. We next turn to a detailed description of the respective sectors in reverse order.

2.2.1 Retail Firms

The retail sector operates in perfectly competitive factor markets. It takes amounts $y_{j,t}$ of wholesale good type $j \in [0,1]$ as an input to production and aggregates all varieties into the final homogenous consumption and investment good, y_t, according to

$$y_t = \left(\int_0^1 y_{j,t}^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}, \epsilon > 1. \tag{17}$$

The cost-minimizing expenditure, P_t, needed to produce one unit of the final good is given by

$$P_t = \left(\int_0^1 P_{j,t}^{1-\epsilon} dj \right)^{\frac{1}{1-\epsilon}}, \tag{18}$$

where $P_{j,t}$ marks the price of good $y_{j,t}$. P_t coincides with the consumer/GDP price index. The demand function for each single good $y_{j,t}$ is given by

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon} y_t. \tag{19}$$

2.2.2 Wholesale Firms

Firms in the wholesale sector have unit mass and are indexed by $j \in [0,1]$. Firm j produces variety j of a differentiated good according to

$$y_{j,t} = k_{j,t}^{\alpha} l_{j,t}^{1-\alpha}, \ \alpha \in (0,1). \tag{20}$$

[11] Following the literature (see e.g. Trigari, 2006) we part the markup pricing decision from the labor hiring decision. For an application which operates with temporarily firm-specific labor and a matching market in the price-setting sector, see Kuester (2007).

Here $k_{j,t}$ denotes demand for capital by wholesale firm j. Capital is homogenous and instantaneously transferable across firms. Demand for capital is satisfied out of the utilization, z_t, of the capital stock formed up to $t-1$, νk_{t-1}, where k_{t-1} denotes the amount of capital to which each member of the family is entitled. Total supply of capital services in period t therefore is $\nu z_t k_{t-1}$. $l_{j,t}$ denotes demand for the intermediate labor good which a wholesale firm j can acquire in a perfectly competitive market at real price x_t^L. Real period profits of firm j, $\Psi_{j,t}^C$, are given by

$$\Psi_{j,t}^C = \frac{P_{j,t}}{P_t} y_{j,t} - \epsilon_t^C \left(k_{j,t} r_t^k + l_{j,t} x_t^L \right).$$

The first term gives wholesale firm revenues, the second term marks real payments for capital and for the labor good. ϵ_t^C represents a wholesale sector "cost-push" shock with unit steady state.[12]

We follow Yun (1996) in assuming that in each period a random fraction $\omega \in [0,1)$ of firms cannot reoptimize their price. As in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003), firms which cannot reoptimize index their price to realized inflation, $\Pi_{t-1} := \frac{P_{t-1}}{P_{t-2}}$. The degree of indexation is measured by parameter $\gamma_p \in [0,1]$. Those firms which reoptimize their price in period t face the problem of maximizing the value of their enterprise by choosing their sales price, $P_{j,t}$, taking into account the pricing frictions, demand function (19) and production function (20). Realizing that for any given demand, the optimal factor input choice leads to marginal costs which are independent of the production level, the price-setting problem simplifies to

$$\max_{P_{j,t}} E_t \left\{ \sum_{s=0}^{\infty} \omega^s \beta_{t,t+s} \left[\frac{P_{j,t}}{P_{t+j}} \prod_{l=0}^{s-1} \left((\Pi_{t+l-1})^{\gamma_p} \Pi^{1-\gamma_p} \right) - mc_{t+s} \right] y_{j,t+s} \right\}. \tag{21}$$

Here Π is the gross inflation rate in steady state and mc_t are real marginal costs[13]

$$mc_t = \epsilon_t^C (r_t^k)^\alpha (x_t^L)^{1-\alpha} \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)}. \tag{22}$$

$\beta_{t,t+s} := \beta^s \frac{\lambda_{t+s}}{\lambda_t}$ is the equilibrium stochastic discount factor. The typical reoptimizing wholesale

[12] In the literature this shock frequently is also labeled a "price-markup" shock. Both representations are identical up to first-order.

[13] Due to the assumption of competitive factor markets and constant returns to scale, all firms in the wholesale sector face the same level of marginal costs in equilibrium. Especially, in this specification marginal costs are independent of each firm's output. Similar to Altig, Christiano, Eichenbaum, and Linde (2005) one could also make firms' marginal costs depend on the level of own output by assuming firmspecific production factors, say capital. This would introduce an internal motive to keep prices constant and so require less Calvo stickiness; see also Eichenbaum and Fisher (2004) and Woodford (2005).

firm's first order condition for price-setting is:

$$E_t\left\{\sum_{s=0}^{\infty}\omega^s\beta_{t,t+s}\left[\frac{P_t^*}{P_{t+s}}\prod_{l=0}^{s-1}\left((\Pi_{t+l-1})^{\gamma_p}\,\Pi^{1-\gamma_p}\right)-\frac{\epsilon}{\epsilon-1}mc_{t+s}\right]y_{j,t+s}\right\}=0, \tag{23}$$

where P_t^* marks the optimal price. The demand functions of individual firms for the labor good and capital are, respectively,

$$l_{j,t}=mc_t\frac{1-\alpha}{x_t^L\,\epsilon_t^C}y_{j,t} \tag{24}$$

and

$$k_{j,t}=mc_t\frac{\alpha}{r_t^k\,\epsilon_t^C}y_{j,t}. \tag{25}$$

Total real profits of the wholesale (Calvo) sector are $\Psi_t^C=\int_0^1\Psi_{j,t}^C dj$, where

$$\Psi_{j,t}^C=\left\{\frac{P_{j,t}}{P_t}-mc_t\right\}y_{j,t} \tag{26}$$

denotes the period profits of firm j.[14] These profits flow to the families of asset-holding workers.

2.2.3 Labor Good Firms

The labor good is homogenous. Each firm in this sector consists of one and only one worker matched with an entrepreneur. In period t there is thus a mass $\nu(1-u_t^{(1)})$ of labor firms with workers of type $o=1$ and a mass $(1-\nu)(1-u_t^{(2)})$ with workers of type $o=2$. Match i can produce amount $l_{i,t}$ of the labor good according to

$$l_{i,t}=A_t^{(o)}h_{i,t}^{(o)}. \tag{27}$$

Labor productivity $A_t^{(o)}$ depends on which type of the worker is employed at the respective firm. Throughout the paper we assume that liquidity-constrained workers are lower-skilled and thus relatively less productive. In particular, we assume that the productivity levels of low- and high-skilled workers are linked by a constant factor of proportionality a:

$$A_t^{(2)}=aA_t^{(1)},\ a\in(0,1).$$

[14] Real profits in equilibrium thus depend on the distribution of $P_{j,t}$:

$$\Psi_t^C=\left[1-mc_t\int_0^1\left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon}dj\right]y_t.$$

In equilibrium, labor good demand by the wholesale sector must match the labor good sector's supply:

$$l_t := \int_0^1 l_{j,t} dj = \int_0^{\nu(1-u_t^{(1)})} l_{i,t} di + \int_0^{(1-\nu)(1-u_t^{(2)})} l_{i,t} di. \tag{28}$$

2.3 Labor Market

We now turn to the specification of the labor market in our model. We first describe the matching technology and then focus on the bargaining and vacancy posting decisions for each class of worker $o \in \{1, 2\}$.

2.3.1 Matching Firms and Workers

There is a separate matching market for the two types of workers. Or, put differently, there are jobs exclusively suited for lower-skilled workers and other jobs exclusively suited for higher-skilled workers. The matching process in each market is governed by a standard Cobb-Douglas matching technology

$$m_t^{(o)} = \sigma_m^{(o)} (u_t^{(o)})^{\xi^{(o)}} (v_t^{(o)})^{1-\xi^{(o)}}, \ \sigma_m^{(o)} > 0, \xi^{(o)} \in (0, 1). \tag{29}$$

Here $m_t^{(o)}$ is the number of new matches of workers of type o, $v_t^{(o)}$ is the number of vacancies of type o. With probability $q_t^{(o)} = \frac{m_t^{(o)}}{v_t^{(o)}}$ a firm with a vacant position finds a worker in period t. Unemployed workers always search for a job. With probability $s_t^{(o)} = \frac{m_t^{(o)}}{u_t^{(o)}}$ a worker of type o will find a job. For future reference, we define "market tightness" in sector o from the firms' point of view as $\theta_t^{(o)} = \frac{v_t^{(o)}}{u_t^{(o)}}$.

In the US, most of the variation of employment over the business cycle is explained by variations in vacancy posting, see Hall (2005), while the separation rate is rather stable. We therefore assume that separations occur with a constant, exogenous probability $\vartheta^{(o)} \in (0, 1)$ in each period. New matches in t, $m_t^{(o)}$, become productive for the first time in $t+1$. As a consequence of these assumptions, the employment rate $n_t^{(o)} := 1 - u_t^{(o)}$ evolves according to

$$n_t^{(o)} = (1 - \vartheta^{(o)}) n_{t-1}^{(o)} + m_{t-1}^{(o)}. \tag{30}$$

2.3.2 Bargaining of Asset-holding Families

Due to both a skill-dependent cost $\kappa^{(1)}$ of posting a vacancy and the time-consuming matching process, formed matches entail economic rents. Firms and workers bargain about their share of the overall match surplus. Since the family perfectly insures its members against unemployment risks, individual members would not take up work voluntarily. We follow den Haan, Ramey, and Watson (2000) in assuming that the family takes the labor supply decision for its workers. We start by describing the gain of a representative family from having an additional, marginal member i in employment. This is (see Appendix A.1 for a derivation)

$$\begin{aligned}\Delta_t^{(1)} &= \lambda_t\left(w_{i,t}^{(1)}h_{i,t}^{(1)} - b^{(1)} - home^{(1)} - strike^{(1)}\right) - \kappa^L\frac{\left(h_{i,t}^{(1)}\right)^{1+\varphi}}{1+\varphi} \\ &\quad +(1-s_t^{(1)}-\vartheta^{(1)})E_t\left\{\beta\Delta_{t+1}^{(1)}\right\}.\end{aligned} \tag{31}$$

The first term describes the difference between the net wage earned by the marginal member when employed and non-employment income, $b^{(1)}$. This difference is converted to marginal utility units by λ_t. In the welfare analysis presented later on in this paper, we entertain different mechanisms which achieve fluctuations in unemployment of a size consistent with the data. In our estimated benchmark, we follow Hagedorn and Manovskii (2006) and Jung (2006). Their calibration relies on a high replacement rate for the worker. We then also consider achieving a high outside option in the bargaining process by means of a lower replacement rate propped up by positive home production when unemployed. These modeling schemes imply relatively high (implicit) replacement rates and thus relatively low welfare costs of business cycles. In order to allow for a larger gap between market work and non-market income, we entertain a further modeling device: Parameter $strike^{(1)} \geq 0$ is meant to capture the fact that the bargaining position of the worker may be high without this being directly mirrored by consumption accruing to the worker in the state of unemployment. A variety of institutional features or different bargaining structures might be used to rationalize this assumption. Appendix E illustrates, for example, that this scheme is very closely linked to a bargaining setup suggested by Hall and Milgrom (2007) in which the outside option of both parties is delaying the bargaining process – and not quitting it altogether. This parameter will be used to assess the sensitivity of our welfare results at a later stage. The second term describes the increase in the disutility of work. The final term pertains to the continuation value.

We assume that firms cease to exist when they separate from a worker. The market value, $J_t^{(1)}$, of a representative firm with a worker of type $o = 1$ is given by

$$J_t^{(1)} = x_t^L A_t^1 h_{i,t}^{(1)} - w_{i,t}^{(1)} h_{i,t}^{(1)} - overhead^{(1)} + (1 - \vartheta^{(1)}) E_t \left\{ \beta_{t,t+1} J_{t+1}^{(1)} \right\}, \tag{32}$$

where $overhead^{(1)}$ denotes state t overhead tax costs.[15] Each period, wages and hours worked are determined by means of Nash-bargaining over the match surplus:

$$\arg \max_{w_{i,t}^{(1)}, h_{i,t}^{(1)}} \left(\Delta_t^{(1)} \right)^{\mu^{(1)}} \left(J_t^{(1)} \right)^{1-\mu^{(1)}} \tag{33}$$

where $\mu^{(1)} \in (0,1)$ denotes the family's bargaining power. In a symmetric equilibrium, all firms with workers pertaining to asset-holding families hire the same amount of hours, $h_t^{(1)}$, and pay the same wage, $w_t^{(1)}$. The associated first-order condition for the wage choice is

$$\frac{\mu^{(1)} \lambda_t}{\Delta_t^{(1)}} = \frac{1 - \mu^{(1)}}{J_t^{(1)}}. \tag{34}$$

The associated first-order condition for hours worked

$$\frac{\kappa^L \left(h_t^{(1)} \right)^{\varphi}}{\lambda_t} = x_t^L A_t^{(1)}, \tag{35}$$

which states that the marginal rate of substitution between consumption and hours worked at the family level is equal to the marginal product of labor. The resulting period profits of the representative firm with a worker of type 1, $\Psi_t^{(1)} = x_t^L A_t^1 h_t^{(1)} - w_t^{(1)} h_t^{(1)} - overhead^{(1)}$, accrue to the family.

Using the vacancy posting condition derived below in (37), one can show that the following wage equation obtains.

$$\begin{aligned} w_t^{(1)} h_t^{(1)} \quad = \quad & \mu^{(1)} \quad \left(A_t^{(1)} h_t^{(1)} x_t^L - overhead^{(1)} + \theta_t^{(1)} \kappa^{(1)} \right) \\ & + (1 - \mu^{(1)}) \quad \left(b^{(1)} + home^{(1)} + strike^{(1)} + \tfrac{1}{1+\varphi} mrs_t^{(1)} h_t^{(1)} \right) \end{aligned} \tag{36}$$

where $mrs_t^{(1)} := \kappa^L \frac{\left(h_t^{(1)} \right)^{\varphi}}{\lambda_t^{(1)}}$ is the marginal rate of substitution of the family. Wage income is therefore a convex combination of firm revenue plus the savings from not having to re-post a vacant position and the outside option defined as the real benefit to the worker from staying at home plus the value of leisure expressed in terms of marginal consumption. The better the bargaining position of the worker is, captured here by a higher $\mu^{(1)}$, the closer is the wage rate to the marginal productivity of the worker and therefore to the standard competitive model.

[15] See Mortensen and Nagypal (2006) for intuition. They cite Braun (2005), Nagypal (2005), Silva and Toledo (2005) and Yashiv (2005) for including the idea of fixed turnover costs (say training and separation costs). This squeezes profits without increasing the outside option of the worker.

2.3.3 Vacancy Posting for Workers of Type 1

In order to stand a chance of finding a worker associated with a family, firms need to post a vacancy for higher-skilled workers. Vacancy posting costs enter the economy's resource constraint as pure waste. Closing our description of the labor market for asset-holding workers, we assume free entry into the vacancy posting market as is standard in the literature. This guarantees that expected profits of new entrants, once properly discounted, are zero. The cost of posting a vacancy, $\kappa^{(1)}$ in equilibrium thus equals the discounted expected profits

$$\kappa^{(1)} = E_t \left\{ \beta_{t,t+1} q_t^{(1)} J_{t+1}^{(1)} \right\}, \tag{37}$$

where $\beta_{t,t+1}$ is the economy's pricing kernel, $q_t^{(1)}$ is the probability of finding a worker of type 1 once a vacancy has been posted and J_{t+1} is the real value of the firm in $t+1$.

2.3.4 Bargaining of Liquidity-Constrained Workers

Liquidity-constrained workers do not live in a family which provides consumption insurance. Once matched, they bargain directly and individually with the firm, taking their own consumption when unemployed as the threshold. The utility difference of a representative liquidity-constrained worker can be written as

$$\begin{aligned} \Delta_t^{(2)} &= \left(\mathtt{u}^{(2)}(c_{e,t}^{(2)}, c_{t-1}^{(2)}, h_t^{(2)}) - \mathtt{u}^{(2)}(c_{u,t}^{(2)} + strike^{(2)}, c_{t-1}^{(2)}, 0) \right) + (1 - s_t^{(2)} - \vartheta^{(2)}) E_t \left\{ \beta \Delta_{t+1}^{(2)} \right\} \\ &\equiv \Delta \mathtt{u}(c_{e,t}^{(2)}, c_{t-1}, u_t^2, h_t^{(2)}) + (1 - s_t^{(2)} - \vartheta^{(2)}) E \left\{ \beta \Delta_{t+1}^{(2)} \right\}. \end{aligned} \tag{38}$$

Where $c_{e,t}^{(2)}$ and $c_{u,t}^{(2)}$, defined in (16), are the consumption levels of the representative low-skilled worker when employed and unemployed, respectively. We take last month's average consumption of the liquidity-constrained population, $c_{t-1}^{(2)} = (1 - u_{t-1}^{(2)}) c_{e,t-1}^{(2)} + u_{t-1}^{(2)} c_{u,t-1}^{(2)}$, as the reference point for habit formation. As with the unconstrained worker's bargaining, parameter $strike^{(2)}$ is meant to capture an exogenous shift in the outside option of the worker not related to any real consumption flows but rather to elements of the bargaining setup not directly reflected in the model. A type 2 firm discounts future profit streams using the capital market's pricing kernel, which is the one of the typical asset-holding family. To shorten notation, denote period profits of a firm associated with a liquidity-constrained worker by

$$\Psi_t^{(2)} = x_t^L A_t^{(2)} h_t^{(2)} - w_t^{(2)} h_t^{(2)} - overhead^{(2)}, \tag{39}$$

where $A_t^{(2)}$ is the time-varying productivity level of a liquidity-constrained, lower-skilled worker. The market value of a firm with a low-skilled worker is given by

$$J_t^{(2)} = \Psi_t^{(2)} + (1 - \vartheta^{(2)}) E_t \left\{ \beta_{t,t+1} J_{t+1}^{(2)} \right\}, \tag{40}$$

The Nash bargaining process defines how the joint match surplus is split among worker and firm. A low-skilled worker and its employer set their real wage rate, $w_t^{(2)}$, and hours worked, $h_t^{(2)}$, as

$$\arg \max_{w_t^{(2)}, h_t^{(2)}} (\Delta_t^{(2)})^{\mu^{(2)}} (J_t^{(2)})^{1-\mu^{(2)}}, \tag{41}$$

where $\mu^{(2)} \in (0,1)$ is the bargaining power of low-skilled workers. The wage-setting first-order condition is

$$\frac{\mu^{(2)} \lambda_t^{(2)}}{\Delta_t^{(2)}} = \frac{(1 - \mu^{(2)})}{J_t^{(2)}}, \tag{42}$$

where $\lambda_t^{(2)} := (c_{e,t}^{(2)} - \varrho^{(2)} c_{t-1}^{(2)})^{-\sigma}$. The first-order condition with respect to the hour choice yields

$$\frac{\mu^{(2)} \left(\lambda_t^{(2)} w_t^{(2)} - \kappa^L \left(h_t^{(2)} \right)^{\varphi} \right)}{\Delta_t^{(2)}} = \frac{(1 - \mu^{(2)})(w_t^{(2)} - x_t^L A_t^{(2)})}{J_t^{(2)}}. \tag{43}$$

Rearranging gives that also in the low-skilled sector, the marginal product of labor equals the marginal disutility of work. The liquidity-constrained worker and the firm do not agree on the evaluation of their future joint surplus since the discounting kernels of the owner of the firm (the asset-holding representative family) and the liquidity-constrained worker differ. We cannot, therefore, derive a closed form expression for the wage in terms of current variables only. The current wage depends positively on both current and future profits which in turn depend on labor productivity, similar to (81). Since the liquidity-constrained worker is not insured against unemployment by a family, however, his attitudes towards risk as represented by the curvature of the utility function play a direct and important role in the wage bargaining process.

2.3.5 Vacancy Posting for Workers of Type 2

Vacancy posting proceeds as for asset-holding workers. In order to have a chance, $q_t^{(2)}$, to find a worker, firms looking to recruit low-skilled workers need to post a vacancy at real cost $\kappa^{(2)} > 0$. To close the description of the labor market, we assume free entry into the vacancy posting market for liquidity-constrained workers ensuring zero *ex-ante* profits:

$$\kappa^{(2)} = E_t \left\{ \beta_{t,t+1} q_t^{(2)} J_{t+1}^{(2)} \right\}. \tag{44}$$

2.4 Government

The monetary authority is controls the one-month risk-free interest rate on nominal bonds, R_t, apart from the risk premium shock. The empirical literature (see, e.g. Clarida, Galí, and Gertler, 2000) finds that simple generalized Taylor-type rules of the form

$$\begin{aligned} \log(R)_t &= \log(\overline{\Pi}/\beta)(1-\gamma_R) + \log(R)_{t-1}(\gamma_R) + (1-\gamma_R)\left\{\gamma_\pi \log(\Pi_t/\overline{\Pi}) + \gamma_y \log\left(y_t/y\right)\right\} \\ &\quad + \gamma_{\Delta_y} \log(y_t/y_{t-1}) + \log(\epsilon_t^{money}), \end{aligned} \tag{45}$$

once linearized are a good representation of monetary policy in recent decades. ϵ_t^{money} is an iid log-normal shock to the monetary policy stance with unit steady state. The specific form of the rule is similar to the one used by Smets and Wouters (2005).

"Government spending", g_t, is exogenous and follows the following AR(1) process

$$g_t = (1-\rho_g)\overline{g} + \rho_g g_{t-1} + g\epsilon_t^g,\ \rho_g \in [0,1). \tag{46}$$

$\overline{g}$ is the long-run target for government expenditures, ϵ_t^g is a Gaussian shock to fiscal policy with zero mean. In the calibration below, we set g_t equal to the sum of government expenditures and the net export component of GDP. The government budget constraint is given by

$$\begin{aligned} &\nu\left[t_t + \left(1-u_t^{(1)}\right) overhead^{(1)}\right] + (1-\nu)\left[\chi t_t + \left(1-u_t^{(2)}\right)\left\{\chi_2 t_t^{(2)} + overhead^{(2)}\right\}\right] \\ &+\frac{D_t}{P_t} + (\epsilon_t^C - 1)\left(\nu k_{t-1} z_t r_t^k + x_t^L l_t\right) = \nu u_t^{(1)} b^{(1)} + (1-\nu) u_t^{(2)} b^{(2)} + \frac{D_{t-1}}{P_t} R_{t-1} + g_t. \end{aligned} \tag{47}$$

The government generates revenue from lump-sum taxes, from special taxes paid only by the poorer part of the population and from overhead tax costs paid in the labor good sector; see the first row of (47). It also earns income from new debt issues, $\frac{D_t}{P_t}$. The final term on the left-hand side of (47) clarifies the "tax" nature of the cost-push shock. On the expenditure-side appear unemployment benefits (the terms involving $b^{(1)}, b^{(2)}$), debt repayment and coupon as well as the government expenditure.[16]

Let t_t^{tot} be total tax revenue in period t:

$$t_t^{tot} = \nu\left[t_t + \left(1-u_t^{(1)}\right) overhead^{(1)}\right] + (1-\nu)\left[\chi t_t + \left(1-u_t^{(2)}\right)\left\{\chi_2 t_t^{(2)} + overhead^{(2)}\right\}\right]. \tag{48}$$

[16] In the US, unemployment insurance is mostly paid for directly by employers instead of by the employees. Since bargaining is efficient, the exact modalities do, however, not influence our results.

Following Schmitt-Grohé and Uribe (2004b) we assume that total tax revenues, t_t^{tot}, adjust in order to assure that real debt, D_{t-1}/P_{t-1}, does not deviate too much from the long-run debt target, $\overline{d}$, of the fiscal authority. If $\chi_2 = 1$, in each period low-skilled, liquidity-constrained workers foot the bill for the unemployment insurance of low-skilled workers themselves without having to ask for funding by the families of higher-skilled workers. So

$$(1 - u_t^{(2)})\, t_t^2 = u_t^{(2)} b^{(2)}. \tag{49}$$

2.5 Market Clearing

The aggregate retail good is used for consumption by the two types of consumers, for investment by asset-holding households and for government spending. In addition vacancy posting activity in the two labor markets requires ressources. Total demand is

$$\begin{aligned} y_t &= c_t^{(m)} + \nu \left[i_t + \psi(z_t) k_{t-1} \right] + g_t \\ &+ \nu \kappa^{(1)} v_t^{(1)} + (1-\nu) \kappa^{(2)} v_t^{(2)}, \end{aligned} \tag{50}$$

where aggregate market-tradable consumption demand, $c_t^{(m)}$, is given by

$$c_t^{(m)} = \nu c_t^{(1,m)} + (1-\nu) \left[(1 - u_t^{(2)}) c_{e,t}^{(2)} + u_t^{(2)} \left(c_{u,t}^{(2)} - home^{(2)} \right) \right]. \tag{51}$$

Market clearing in the retail market requires that above demand of retail goods equals total supply, which is given by

$$y_t = \left[\int_0^1 \left(y_{j,t}^d \right)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}. \tag{52}$$

For each firm j in the wholesale sector, its supply

$$y_{j,t} = (k_{j,t})^{\alpha} (l_{j,t})^{1-\alpha}, \tag{53}$$

must be matched by the corresponding demand

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon} y_t \tag{54}$$

in order to clear the wholesale market.

Total demand for the labor good is

$$l_t = \int_0^1 l_{j,t} dj, \tag{55}$$

where $l_{j,t}$ is given by (24). Market clearing in the labor good market requires that this demand equals the supply of the labor good which is given by

$$l_t = \nu(1 - u_t^{(1)})l_t^{(1)} + (1 - \nu)(1 - u_t^{(2)})l_t^{(2)}, \text{ where} \tag{56}$$

$$l_t^{(o)} = A_t^{(o)} h_t^{(o)}, \ o \in \{1, 2\}. \tag{57}$$

Total demand for capital is given by

$$k_t = \int_0^1 k_{j,t} dj, \tag{58}$$

where $k_{j,t}$ is given by (25). Total supply of capital is given by

$$k_t = \nu z_t k_{t-1}. \tag{59}$$

In equilibrium both quantities are equated.

3 Estimation of the Benchmark Model

For the analysis of the costs of business cycles not least the structure and relative size of shocks will be important. We conduct a Bayesian estimation exercise in which we use quarterly data for the US from 1964:q1 to 2005:q4. The start of the sample is dictated by the first date at which the index of average weekly hours worked which we employ is available. We treat output per capita, consumption per capita, investment per capita, the nominal interest rate, GDP inflation and total hours worked as observable variables. Consumption is measured as the sum of consumption of non-durable goods and services. Consequently, investment is the sum of fixed private investment and consumption of durable goods. All data are obtained from the Federal Reserve Bank of St. Louis' database FRED II. Data on total compensation per capita, vacancies (measured by the help-wanted index) and unemployment rates are used for validation purposes. For the exact sources of the data, the definitions linking the data to our model variables and key properties of the data, we refer to Appendix B.

The volatility of many aggregate variables has decreased considerably since the early 1980s.[17] We therefore use the data until 1983:q4 only as a burn-in sample and let the observation sample

[17] Kim and Nelson (1999) locate the break date in the amplitude of US GDP growth rates and the volatility of shocks to US GDP growth rates at 1984:q1 (their posterior mode). The same break date is found by McConnell and Perez-Quiros (2000). Stock and Watson (2002) document that this evidence is not limited to real GDP growth but can be found in a great number of US macroeconomic time series. This is apparent also in Figure 4 in Appendix B.2, where we plot our data.

start in 1984:q1. Calibrated steady state values are computed using data from the latter part of the sample. We follow Shimer (2005) in detrending our data with a very low-frequency HP-filter with a weight of 100,000. Appendix B shows the raw data and their filtered business-cycle component. Agents in our model economy take decisions at a monthly frequency while the data we observe are quarterly. The estimation algorithm deals with this frequency mismatch. Appendix C shows how to aggregate the model by treating monthly observations of the endogenous variables as latent while assuming that only the quarterly averages are observable to the econometrician. Autocorrelation coefficients, the Calvo price-setting parameter, ω, and the interest rate smoothing coefficient have been rescaled to quarterly terms for better comparability with the literature. In the tables and the subsequent text, this is indicated by a superscript q, so, for example $\omega \equiv (\omega^q)^{1/3}$.

We discuss our calibration strategy in Section 3.1. Section 3.2 discusses the priors on the remaining parameters. Section 3.3 reports the parameter values at the mode of the posterior distribution. Section 3.4 assesses to which extent the model fulfills its task and matches the standard deviations of the data and, in particular, the evolution of the labor market over the business cycle. Towards this aim, we analyze the implied evolution of unemployment rates for the different skill groups, vacancies and wages.

3.1 Calibration

In order to reduce the burden of the estimation we calibrate some parameters to long run averages or outside information. Table 1 summarizes our choices and gives the targets we match. Table 2 reports the resulting steady state. It is understood that in a general equilibrium model all parameters typically determine jointly all endogenous variables. In order to build intuition, our discussion focuses on those parameters that have the "biggest" economic impact on a particular target. In the following we elaborate on some of the crucial parameters chosen.

We follow Shimer (2005) in setting a constant destruction rate of jobs of $\vartheta^{(o)} = 3\%$ each month both for the higher- and for the lower-skilled workers (see section 'Labor market' in Table 1). We normalize $\sigma_m^{(o)}$, the scaling parameter in the respective matching functions, so as to match the steady state probability of finding a worker, $q^{(o)}$, to the value used in den Haan, Ramey, and Watson (2000). We assume an equal-surplus-sharing-rule, setting the bargaining power to $\mu^{(o)} = 0.5$. This matches the value of the matching elasticity, $\xi^{(o)} = 0.5$, which, in the absence

Table 1: Calibration Strategy

Parameter	Value	Target/reference	Economic Meaning
Preferences and composition			
β	.9975	Annual real rate of 3 percent.	time-discount factor.
σ	1.5	Estimates by Smets and Wouters (2007).	risk-aversion.
φ	2.0	Estimates by Domeij and Flodén (2006).	1/labor supply elasticity.
κ^L	64.74	Average hours worked, $h^{(1)} = 1/3$.	scaling parameter disutility of work.
$\varrho^{(2)}$	0	No consumption habits for the poor.	habit persistence group 2.
$1-\nu$	0.16	Estimates by Gruber (2001).	share of liquidity-constr. consumers.
Production			
$A^{(1)}$	.65	Normalize output, y, to unity.	productivity of high-skilled workers.
a	0.50	$\frac{w^{(2)}h^{(2)}}{w^{(1)}h^{(1)}}$, relative wage income of 50%.	relative productivity low-skilled.
$overhead^{(o)}$	0	Calibration with high replacement rate.	overhead production costs, $o \in \{1,2\}$.
α	0.33	Conventional configuration.	capital elasticity of production .
δ	.0081	(Investm.+durable cons.)/GDP = 24%.	depreciation rate (monthly).
ϵ	21	Avg. price markup of 5%.	demand elasticity wholesale goods.
γ_z	.0106	$z = 1$, full steady state capacity util.	steady state marg. capac. util. cost.
ρ_A^q	.85	Std. deviation output, y_t.	autocorrelation technology (quarterly)
Labor market			
$\vartheta^{(1)}$	0.03	Shimer (2005) for aggregate economy.	monthly separation rate unconstr.
$\vartheta^{(2)}$	0.03	- " -	monthly sep. rate constr. workers.
$\sigma_m^{(1)}$	.63	$q^{(1)} = 0.7$, den Haan et al. (2000).	effic. of matching unconstr. worker.
$\sigma_m^{(2)}$	.43	$q^{(2)} = 0.7$, - " for aggr. economy -	effic. of matching constr. worker.
$\mu^{(1)}$	0.5	Hosios condition.	bargaining power asset holders.
$\mu^{(2)}$	0.5	- " -	bargaining power liq.-constr.
$\xi^{(1)}$	0.5	Estimates of aggr. matching function ...	elasticity of matches w.r.t. unempl.
$\xi^{(2)}$	0.5	... (Petrongolo and Pissarides, 2001).	elasticity of matches w.r.t. unempl.
$\kappa^{(1)}$	.043	Economy-wide unemployment rate: 5.8%.	Vacancy posting costs unconstr.
$\kappa^{(2)}$	.053	Low-skilled unemployment rate: 10%.	Vacancy posting costs constr. worker.
$b^{(1)}$	.45	Std. deviation economy-wide u-rate, u_t.	real unempl. benefit unconstr. worker.
$b^{(2)}$	.25	Std. deviation low-skilled u-rate, $u_t^{(2)}$.	real unempl. benefit constr. worker.
$strike^{(o)}$	0	Calibration with high replacement rate.	strike option bargaining, $o \in \{1,2\}$.
$home_t^{(o)}$	0	Calibration with high replacement rate.	home-production, $o \in \{1,2\}$.
Government			
$\overline{g}$	.17	Cons. (non-dur.+services)/GDP = 59%.	target level gov. spending.
χ	0	Ricardian equivalence.	No taxation of poor consumers.
χ_2	0	All benefits paid for by high skilled.	No taxation of poor consumers.

Notes: Calibration strategy. For the figures reported, the data span is 1984:1 to 2005:4. Investment includes fixed private investment and durable consumption. Consumption includes non-durable consumption and services. Parameter κ^L is adjusted so as to insure $h^{(1)} = 1/3$. Strictly speaking κ^L therefore depends on the estimated value for the family's habit persistence. Here we use the value of κ^L which is implied by the value of habit persistence at the posterior mode, for the latter see in Table 3.

of other frictions, would imply an efficient allocation, see Hosios (1990).

As mentioned previously, we assume that one group of workers does not hold any liquid assets at all. Given that the goal of this paper is the provision of an upper bound for business cycle costs for workers who might be strongly affected by unemployment spells, we entertain a joint hypothesis and identify these liquidity-constrained workers also with relatively lower skills. Intuitively this mirrors the fact that the likelihood of being liquidity-constrained strongly decreases with the individual skill level. A natural candidate proxy for unemployment fluctuations among low-skilled workers is the unemployment rate among high-school drop-outs. The Bureau of Labor Statistics series for the unemployment rate for high-school drop-outs is available from 1992:q1 onwards. This sample seems too short to corroborate the economic fit of the extended model (which is done in Section 3.4). Consequently, we select the unemployment rate of those who are 16 to 24 years old as representing unemployment among low-skilled, liquidity-constrained consumers, which is almost perfectly correlated with the one for high-school drop outs during their period of overlap.[18] We set the average unemployment rate among the low-skilled (and by assumption liquidity-constrained) workers to 10 percent which lies in between the means of the two above-mentioned series. We target this value and the average economy-wide unemployment rate in the economy of $u = 5.8\%$ to pin down the cost of posting a vacancy, $\kappa^{(o)}$, for both types of firms in the labor sectors. We adjust the threat point of the worker to match the right unemployment volatility. In the benchmark calibration this is done by adjusting the respective replacement income, $b^{(o)}$. Depending on the different wage setting mechanisms in use in this paper, we reinterpret the cause of a high outside option of the worker in the bargaining process either as a cost of delaying the bargaining process to the next period (strike cost) or as the true outside option value of being unemployed. Since bargaining is efficient and workers and firms never break up their match voluntarily, the threat point in the bargaining process can never be observed in practice. We use this degree of freedom to generate a high enough outside option for the worker, such that wages are sticky and the model is consistent with unemployment fluctuations. This trick generates the right labor market volatility structure, which, for the purpose of this paper, is a crucial feature.

[18] High-school drop-outs and workers at the lower range of the skill-distribution are over-represented in this series. Those who seek higher education enter the relevant labor force only at around age 20 or older. Apart from the length of the sample, our results are not affected by this choice.

Turning to the low-skilled sector, a notable share of the US population is liquidity-constrained. Gruber (2001) puts the share of the population whose savings cannot cover the cost of an unemployment spell to at least 16%. Consequently, we set the size of the liquidity-constrained group of workers to $1 - \nu = 0.16$ (see section 'Preferences and composition' in Table 1).[19] Consumers in the different skill groups share the same preferences. We set the Frisch elasticity to the value of 0.5 estimated by Domeij and Flodén (2006) which implies $\varphi = 2$. Consumers' preferences differ only in their consumption habits. Liquidity-constrained consumers are highly dependent on their current income. They therefore do not develop consumption habits at all, $\varrho^2 = 0$. In our model, we introduce consumption habits mainly so as to be in line with much of the recent New Keynesian literature, see Christiano, Eichenbaum, and Evans (2005) for example. Yet we see consumption habits more as a modeling device which allows to introduce some further endogenous persistence in the model economy. We do not wish to let our welfare estimates for the low-skilled, liquidity-constrained group of consumers be influenced by the choice of this parameter.

Of key importance is the relative skill/productivity level of the two groups, a. The OECD Labour Market Statistics (2001 Edition) report compensation before taxes in the US for different income deciles. We use this information as follows. The low-skilled, liquidity-constrained consumers range, by assumption, at the lower end of the income distribution. We approximate their average income by a weighted average of the income at the 10th percentile and the 20th income percentile. The average income in the asset-holding group is approximated by the 58th percentile (16%+84%/2) of the wage distribution. Dividing these two numbers and averaging over the years, we obtain an average wage in the low-skilled, liquidity-constrained population of around 50% relative to the asset-holding population.[20] Consequently, we set the relative technology to $a = 0.5$ (see section 'Production' in Table 1). To guarantee that our model generates the right size of output fluctuations, we set the autocorrelation of the technology shock such that the implied standard deviation of the estimated model with respect to output matches the data.

[19] Gruber (2001) obtains this number by using total wealth as the relevant pool of assets. If only liquid assets are taken into account the share rises significantly. This number therefore represents a lower bound for the share of liquidity-constrained workers.

[20] In computing this number, we use the entire span of data at our disposal. For the income deciles our data range from the years 1973 to 2000. Given the well documented rise in wage inequality that started in the 1980s. Our estimate of relative productivity might therefore be rather conservative towards the upside.

Table 2: Steady State

Variable	Value	Economic meaning
Labor market - stocks and flows		
$u^{(1)}$	.05	high-skilled unemployment rate.
$u^{(2)}$	.10	low-skilled unemployment rate.
$v^{(1)}$	.040	high-skilled vacancies.
$v^{(2)}$	.039	low-skilled vacancies.
$s^{(1)}$	.57	probability of finding a job, high-skilled worker.
$s^{(2)}$	.27	probability of finding a job, low-skilled worker.
Labor market - replacement rate		
$b^{(1)}/(w^{(1)}h^{(1)})$	.62	replacement rate high-skilled worker.
$b^{(2)}/(w^{(2)}h^{(2)})$	.70	replacement rate low-skilled worker.
Labor market - profits		
$\Psi^{(1)}/(l^{(1)})$	.0093	profit to output ratio high-skilled worker.
$\Psi^{(2)}/(l^{(2)})$	.023	profit to output ratio low-skilled worker.
Per capita consumption		
$c^{(1)}$	.64	consumption by high-skilled consumer.
$c_e^{(2)}$	.36	consumption by low-skilled employed consumer.
$c_u^{(2)}$	.25	consumption by low-skilled unemployed consumer.
Hours worked when employed		
$h^{(1)}$	.33	hours worked by high-skilled worker.
$h^{(2)}$	.30	hours worked by low-skilled worker.
Use of GDP		
i/y	.24	investment to GDP ratio.
c/y	.59	consumption to GDP ratio.
g/y	.17	consumption to GDP ratio.
$\frac{\nu\kappa^{(1)}v^{(1)}+(1-\nu)\left(\kappa^{(2)}v^{(2)}\right)}{y}$	.0018	total vacancy posting costs to GDP.
Income side of GDP		
whn/y	.64	share of all labor income in GDP.
$\nu r^k k/y$	.31	capital income share.
Ψ/y	.05	profit share (wholesale and labor sector).

Notes: Selected features of the steady state. All values refer to a monthly frequency. In so far as the steady state is affected by the values of estimated parameters, all values reported here pertain to parameters evaluated at their posterior mode, which is reporterd in Table 3.

This choice is intended so as to ensure that the model reflects the right amount of aggregate risk and allows a meaningful calculation of business cycle costs.

We simplify our analysis by assuming that liquidity-constrained consumers are not subject to lump-sum taxation, which may be a good first-order approximation for low-income households (see section 'Government' in Table 1). Then $\chi_2 = 0$, which means that only the richer population pays for unemployment insurance. Without taxation of the liquidity-constrained workers also $\chi = 0$, so lump-sum taxes fall entirely on the asset-holding households, which ensures that Ricardian equivalence holds. As such, the nature of the tax rule is irrelevant for the allocations in our model as long as the tax rule is debt-stabilizing which is the case.

3.2 Priors

We focus our estimation on parameters that we have little information about and that are not easily pinned down by economic arguments. These are mainly parameters related to the shock processes, the behavioral rule of the central bank and parameters that characterize some deviations from the frictionless neoclassical world. No general agreement has been established on their precise values in the literature. The first four columns in Table 3 present summary statistics of the prior distribution for each of these estimated parameters. We report the mean of the prior distribution, the standard deviation and the class of density which we use to model the prior. The marginal priors are assumed to be independent.

The central bank's behavioral equation is parameterized similar to Smets and Wouters (2007). The smoothing coefficient γ_R^q is distributed beta with mean 0.70 and standard deviation 0.15. The reaction coefficients to inflation and output follow the proposal of Taylor (1993). For the reaction to output growth we choose a prior mean of zero. The habit persistence parameter, $\varrho^{(1)}$, is assigned a beta prior with mean 0.7 as in Smets and Wouters (2005) and a similar standard deviation of 0.15. The Calvo probability, ω^q, *a priori* lies around 0.75 at the quarterly frequency, implying an average duration of a year in line with the results by Galí and Gertler (1999).[21]

[21] A duration of six months (half a year/two quarters) as in the micro-data of Bils and Klenow (2004) would correspond to $\omega^q = 0.5$. Recently, there has been an active literature how to reconcile these macro results with the evidence of higher nominal flexibility in micro-data. For example assuming that production factors are firmspecific as in Altig, Christiano, Eichenbaum, and Linde (2005) and Eichenbaum and Fisher (2004) helps to dampen the response of inflation to marginal costs. The only feature working in this direction which our model entertains is variable capacity utilization. As highlighted by Smets and Wouters (2005), however, the data do not support this feature as economically very important once one moves to general equilibrium. Most prominently, for the bargaining framework when the labor good and the retail good are produced in different

The degree of indexation of these prices to lagged inflation, γ_p, is assigned a mean of 0.4, close to the estimates of Smets and Wouters (2005). Turning to the investment adjustment costs and capacity utilization costs, we use the posterior mode estimates of Smets and Wouters (2005) as our priors. The scaling parameter of investment adjustment costs, κ^I, is assigned a gamma prior with a mean equal to 5 and a standard deviation of 0.5. The curvature of capacity utilization costs, $\gamma_{z,2}$, has a gamma prior with mean 0.3 and a standard deviation of 0.025.

The standard deviations of the innovations to the structural shocks $A_t^{(1)}$, ϵ_t^C, ϵ_t^g, ϵ_t^I and ϵ_t^b are assumed to follow inverse gamma distributions. With regard to the standard deviation of the innovation to the monetary policy shock ϵ_t^{money} we entertain a prior mean of 0.015. This corresponds to 1.5 basis points at a monthly rate. Given that the mean of any of the shock processes is not invariant to the scaling and structure of the model imposing identical, say, prior distributions would likely generate very unequal initial prior weights on the relative importance of some shocks. We therefore experimented a little with the model and chose means that allow the data to be informative without putting excessive weight on a particular shock a priori. The persistence parameters of the estimated AR(1) shock-processes are assumed to follow beta distributions and are harmonized as much as possible. The auto-correlations of the shock processes carry a prior mean of 0.85 (at a quarterly frequency) with a standard deviation of 0.1. With regard to the cost-push shock we entertain a prior mean correlation of 0.5 in quarterly terms, halfway between the choices in Smets and Wouters (2003) and Smets and Wouters (2007).

3.3 Posterior Mode

This subsection presents the parameter estimates at the posterior mode. All persistence parameters of shocks, the Calvo frequency and the coefficient of interest rate smoothing have been brought to a quarterly frequency to allow for comparisons with the literature. In columns 5 to 6, Table 3 displays the posterior mode estimate together with an approximated standard deviation. The estimates of the monetary policy reaction function are in line with the literature, albeit at the higher end for the response of interest rates to inflation. Habits, $\varrho^{(1)}$, are estimated to a value well below 0.7 – and even lower than the estimates that Smets and Wouters (2005) obtain on a

sectors, the literatue so far has not come up with a way to build rigidity into x_t^L, the price of the labor good. In particular, wage rigidity does not help to achieve this, see Krause and Lubik (2005).

similar sample for the US at a quarterly frequency. The estimated value of the Calvo parameter, ω^q, of roughly 0.77 implies an average price duration of more than a year. While this is above the average duration of half a year obtained in Bils and Klenow (2004), a high value is in line with much of the empirical macroeconomic literature. As a comparison, Smets and Wouters

Table 3: Parameters at the Posterior Mode

Parameter	prior			posterior	
	mean	std	distr.	mode	std
Parameters of structural model					
γ_R	0.70	0.150	beta	0.84	0.031
γ_π	1.50	1.000	gamma	3.59	0.73
γ_y	0.50	0.200	gamma	0.64	0.19
$\gamma_{\Delta y}$	0.00	0.100	norm	0.041	0.0092
$\varrho^{(1)}$	0.70	0.150	beta	0.29	0.087
ω^q	0.75	0.150	beta	0.70	0.057
γ_p	0.40	0.200	beta	0.12	0.12
κ^I	5.00	0.500	gamma	4.44	0.48
$\gamma_{z,2}$	0.30	0.025	gamma	0.30	0.025
Correlation of shocks					
ρ_g^q	0.85	.100	beta	0.81	0.052
ρ_I^q	0.85	.100	beta	0.73	0.067
ρ_b^q	0.85	.100	beta	0.81	0.042
ρ_C^q	0.50	.200	beta	0.55	0.097
Standard deviation of shocks					
σ^b	.200	Inf	invgamma	0.060	0.0089
σ^A	.100	Inf	invgamma	0.472	0.035
σ^C	5.00	Inf	invgamma	2.000	0.717
σ^g	.500	Inf	invgamma	1.807	0.136
σ^m	.015	Inf	invgamma	0.031	0.0029
σ^I	.100	Inf	invgamma	0.910	0.122

Notes: Estimates of the posterior mode. The standard deviation is obtained by a Gaussian approximation at the posterior mode. The observation sample is 1984:q1 to 2005q4. Data from 1964:q1 to 1983:q4 are used as a burn-in sample. A superscript ^{q} highlights that the parameter has been re-scaled to quarterly frequency for better comparability with the literature. For example, $\rho_g^q = \rho_g^3$.

(2005) estimate an average duration of more than two and a half years for the US. Our estimate of the price indexation parameter, γ_p, is more on the low side. The curvature of investment adjustment costs as captured by κ^I moves slightly below its prior mode. The curvature of capacity utilization costs is not well identified. This squares with the findings by Smets and Wouters (2005) who find that this term is not a crucial feature of their economy. As mentioned above, the technology shock had been assigned a serial correlation of 0.85 in quarterly terms. The serial correlation coefficients of all other shocks (apart from the monetary policy shock, which is white noise) point to equally mild serial correlation of these shocks. While the posterior mode of the standard deviation of each of the innovations is hard to interpret, we remark that unconditionally, none of the shock processes has a standard deviation larger than 5 percent.

Having touched upon the parameter estimates, we next look deeper into the economic fit of the benchmark model economy.[22]

3.4 Economic Evaluation

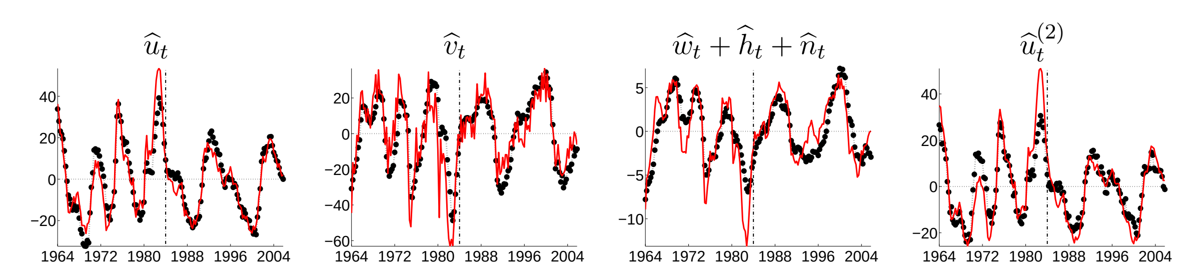
The information of labor-market-related time series so far has not been exploited systematically in the estimation of the model parameters and the shock processes. In particular, we reserved data for nation-wide unemployment, $\widehat{u}_t$, low-skilled unemployment, $\widehat{u}_t^{(2)}$, aggregate vacancies, $\widehat{v}_t$, and total wages, $\widehat{w}_t + \widehat{h}_t + \widehat{n}_t$, for validation purposes. Towards this aim, Figure 1 plots the actual data for these variables against the Kalman-smoothed model-based estimates evaluated at the parameters of the posterior mode. Dots mark the actual observations and red solid lines depict the counterfactual time series implied by the model. All information refers to quarterly aggregates, the derivation of which are the subject of Appendix C.3. A vertical dashed line marks the start of our observation sample.

As we have discussed in Section 3.1, in our calibration we set the workers' outside option in such a way that we achieve the right size of the unconditional standard deviations of the two unemployment rates in our model relative to the standard deviations observed in the data. This does not by itself ensure though that the model replicates the entire cyclical pattern of the respective unemployment rates. Replication of this pattern depends on the interplay of the model structure and the estimated shocks. In addition, no information about fluctuations of vacancies nor any information about the cyclical pattern of wages has been crafted into our calibration targets, nor has the information in any of these two series been used in the estimation

[22] Further statistics referring to the fit of the model are summarized in Appendix D.

process. As such, if the model is able to replicate closely the evolution of vacancies and wages further to the evolution of the two unemployment rates, it does a convincing job to capture labor market co-movements. That this in fact is the case can be witnessed from Figure 1. The

Figure 1: Kalman-Smoothed Estimates of Variables Not Used in Estimation



Notes: The graphs show the actual data (black dotted line marked by larger dots) against the (Kalman-smoothed) estimates originating from the model (red solid line) when parameters are evaluated at the posterior mode. These are used as independent evidence of the model's fit. The data is of quarterly frequency. All four series are HP(100,000) filtered log series and scaled by 100 to represent percent deviations. From left to right: nationwide unemployment rate, vacancies, real total wages, low-skilled unemployment rate. A vertical dashed line marks the beginning of the sample period in 1984:q1.

model replicates both the variability of the unemployment and vacancy data and their cyclical behavior as depicted in the first, second and fourth panel of Figure 1. The key mechanism of the model which endogenously generates labor market fluctuations relies on a not too cyclical outside option of workers paired with a small steady state profit share in the labor good sector. Small profits in steady state mean that a given real fluctuation in profits causes large percentage fluctuations. A high outside option of the worker causes wages to vary less pro-cyclically than in the benchmark RBC model or in a New Keynesian model without wage rigidity. These two features together imply that any increase in revenue translates into a noticeable increase in percentage profits. Since expected profits are the driving force of vacancy posting activity in our model, large percentage fluctuations in profits induce as strong fluctuations in employment as found in the data. The model also captures the cycles in the actual data for total wages (third panel of Figure 1).

In Table 4, finally, we report standard deviations of key model variables relative to the standard deviations of the respective time series. The model is able to rather accurately generate key properties of the US data that either directly influence utility, such as consumption and hours worked, or which concern the particular labor market risks we wish to study, for example unemployment. Note that apart from the standard deviation of unemployment and output, these moments are not a direct target of our calibration. Consumption and hours worked are a bit more volatile than in the data and so are wages but their volatility is still well below the levels of volatility we seen in the period pre 1984. The volatility of unemployment and vacancies is matched within tight bounds. We conclude that the model economy provides a suitable representation of the interplay of individual labor market risks and aggregate risks in the US economy.

Table 4: Standard Deviations in the Model Compared to the Data

Variable	data	benchmark model
$\widehat{y}_t$	1.61	1.71
$\widehat{c}_t$	1.15	1.34
$\widehat{R}_t$	0.38	0.47
$\widehat{\pi}_t$	0.24	0.38
$\widehat{i}_t$	6.39	5.92
$\widehat{h}_t + \widehat{n}_t$	1.20	1.59
$\widehat{w}_t + \widehat{h}_t + \widehat{n}_t$	3.05	3.43
$\widehat{w}_t$	2.33	2.03
$\widehat{u}_t$	13.89	13.61
$\widehat{u}_t^{(2)}$	12.41	12.16
$\widehat{v}_t$	18.81	18.53

Notes: The table compares standard deviations of model variables with standard deviations in the data. For the latter, all values are computed from 1984q1 to 2005q4. For the former, parameters are evaluated at the posterior mode. All variables are in logs, HP(100.000) filtered and multiplied by 100 in order to express them in percent deviation from trend. All data are in quarterly terms. From top to bottom: log output per capita, log consumption per capita, nominal interest rate, GDP inflation rate, investment per capita, total hours worked, total wages, hourly wage rate, unemployment rate, unemployment rate population 16-24, vacancies. Investment includes durable consumption. Consequently, consumption is computed as non-durable consumption plus consumption of services.

3.5 Alternative Labor Market Calibration

Our calibration relies on a relatively high outside option of workers in the bargaining process which ensures low steady state profits of labor market firms and thereby significant percentage fluctuations in profits and hiring activity. The baseline calibration followed Jung (2006) and Hagedorn and Manovskii (2006) by adjusting the replacement rate of workers accordingly. As illustrated, this renders the model consistent with the business cycle evidence on labor markets fluctuations. Yet a replacement rate of 60-70% (cf. the numbers in section 'Labor market - replacement rate' in Table 2) might strike some readers as too high. In particular, Engen and Gruber (2001) report an average replacement ratio of 43% percent rather than the levels used in our baseline.[23]

In this section, we therefore present six alternative calibrations, scenario a) to f) which achieve a low steady state profit of firms with a more conventional size for the replacement rate. These constitute alternative explanations for the business cycle dynamics witnessed in the US. In particular, they explain fluctuations in the economy just as well as our benchmark calibration does: unconditional standard deviations for key variables remain very similar to the benchmark (cp. Table 5). We note that by construction none of these scenarios changes the targeted steady state values. These alternative scenarios serve to provide bounds for the estimates of the welfare costs of business cycles which we will present below. In particular, we entertain the following scenarios:

a) replacement rates for both types of workers are 40% of steady state wage income, and thus lower than in the benchmark. The remainder in the outside option is taken up by non-market-tradable home production, $home^{(o)}$. We set $home^{(1)} = 0.1573$ and $home^{(2)} = 0.1076$, which preserves the same value of the outside option of the respective workers as in the benchmark calibration.

b) replacement rates are 40%. The remainder in the outside option relative to our benchmark calibration is taken up by setting a sufficiently high value for parameter $strike^{(o)}$. In other words, the outside option in the bargaining process now does not reflect consumption when unemployed anymore. Further to this, in this scenario the costs of unemployment insurance are not exclusively borne by the family. Instead in each period employed liquidity-constrained consumers have to pay the insurance costs of unemployed liquidity-constrained consumers.[24] This shows, to some extent, how the welfare costs of business cycles for both

[23] Eligibility for unemployment insurance and benefit amounts in the US are determined by the State law under which unemployment insurance claims are established. Unemployment insurance in the US replaces on average 45% of a covered worker's lost earnings (Engen and Gruber, 2001). The exact amount replaced depends on pre-unemployment earnings and State law. Minimum and maximum replacement income levels exist. In addition, unemployment insurance claims are typically limited to 26 weeks. Unemployment insurance is considered taxable income and must be reported as such on federal income tax forms.

[24] This scenario has a one-to-one mapping into a scenario in which the employers of low-skilled workers pay their unemployment insurance, which consequently will depress these workers' wages in the bargaining process.

the liquidity-constrained group and for the family depend on the redistribution embodied in the benchmark calibration. We set $strike^{(1)} = 0.1573$, $strike^{(2)} = 0.08751$ and $\chi_2 = 1$.

Table 5: Standard Deviations in the Model under Different Scenarios Compared to the Data

Variable	data	benchmark	a)	b)	c)	d)	e)	f)
$\widehat{y}_t$	1.61	1.71	1.74	1.71	1.72	1.72	1.72	1.72
$\widehat{c}_t$	1.15	1.34	1.29	1.35	1.35	1.36	1.36	1.37
$\widehat{R}_t$	0.38	0.47	0.48	0.47	0.47	0.47	0.47	0.47
$\widehat{\pi}_t$	0.24	0.38	0.38	0.38	0.38	0.38	0.38	0.38
$\widehat{i}_t$	6.39	5.92	5.75	5.87	5.90	5.88	5.88	5.87
$\widehat{h}_t + \widehat{n}_t$	1.20	1.59	1.65	1.58	1.60	1.60	1.60	1.61
$\widehat{w}_t + \widehat{h}_t + \widehat{n}_t$	3.05	3.43	3.52	3.44	3.44	3.45	3.45	3.45
$\widehat{w}_t$	2.33	2.03	2.05	2.05	2.03	2.03	2.03	2.03
$\widehat{u}_t$	13.89	13.61	13.89	13.69	13.64	13.66	13.67	13.68
$\widehat{u}_t^{(2)}$	12.41	12.16	12.08	12.14	12.11	12.13	12.11	12.11
$\widehat{v}_t$	18.81	18.53	19.11	18.65	18.60	18.63	18.64	18.66

Notes: The table compares standard deviations of model variables with standard deviations in the data. For the latter, all values are computed from 1984q1 to 2005q4. All variables are in logs, HP(100.000) filtered and multiplied by 100 in order to express them in percent deviation from trend. All data are in quarterly terms. Parameters are evaluated at the posterior mode of the estimated benchmark and otherwise follow Table 1 and the scenarios for the parameters set in the respective scenario a) to f). From top to bottom: output per capita, consumption per capita, gross nominal interest rate, gross GDP inflation rate, investment per capita, total hours worked, total wages, unemployment rate, unemployment rate population 16-24, vacancies. Investment includes durable consumption. Consequently, consumption is computed as non-durable consumption plus consumption of services.

In order to highlight the role which the relative value of employment to unemployment plays for the costs of business cycles, in scenarios c) to f) we successively reduce the replacement rate relative to the benchmark calibration, but assure that the model delivers the right amount of unemployment fluctuations by adjusting the strike value appropriately. A formal justification for our approach is derived in Appendix E. No further adjustments are made to the benchmark calibration.

c) replacement rates for both types of workers are 40% of steady state wage income. When unemployed, liquidity-constrained consumers fall back on their unemployment insurance only and cannot make up part of the consumption loss by home-production. We set $strike^{(1)} = 0.1573$, $strike^{(2)} = 0.1076$, which preserves the value of the outside bargaining options in the benchmark model. We expect higher business cycle costs for liquidity-constrained workers than in the benchmark since their replacement consumption is lower.

d) same calibration as in c) but with a lower replacement rate of 20%. This provides a higher bound for the welfare costs of business cycles. We set $strike^{(1)} = 0.3035$ and $strike^{(2)} = 0.1805$. Welfare costs of liquidity-constrained consumers should rise relative to scenario c).

e) same calibration as in c) and d) but with a lower replacement rate of 15%. This provides a higher bound for the welfare costs of business cycles. We set $strike^{(1)} = 0.3401$ and $strike^{(2)} = 0.19869$. Welfare costs of liquidity-constrained consumers should rise relative to c) and d).

f) is the same calibration as in c), d) and e) but with a lower replacement rate of 10%. This provides a higher bound for the welfare costs of business cycles. We set $strike^{(1)} = 0.3767$ and $strike^{(2)} = 0.2169$. Welfare costs of liquidity-constrained consumers should rise relative to c), d) and e).

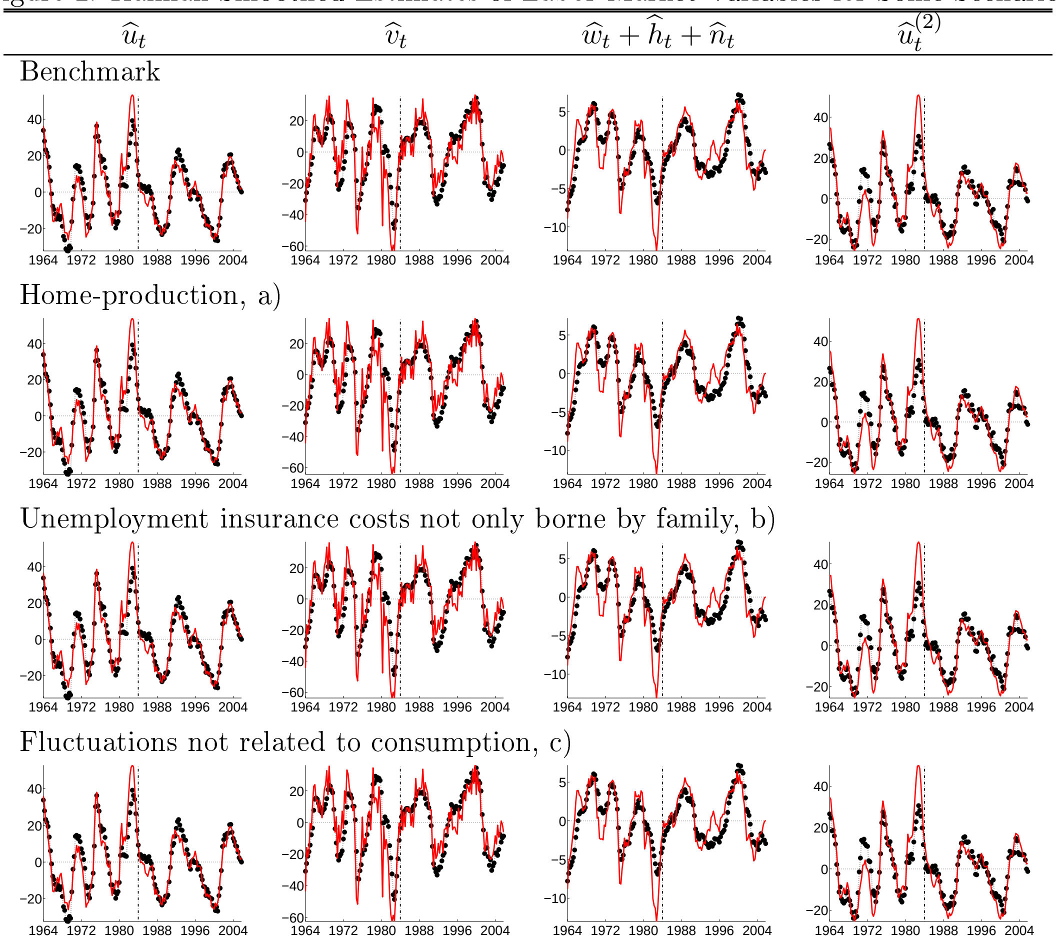
Figure 2 computes the fluctuations of labor market variables over the recent decades in the model when using the alternative calibration embedded in three of the scenarios described above to the benchmark calibration.[25]

4 The Costs of Business Cycles

We evaluate the welfare costs of business cycles in terms of consumption-equivalents. In particular, we ask which share of steady state consumption a consumer would be willing to give up in order to swap the actual state-dependent allocation against the steady state allocation, i.e. the allocation prevailing in the absence of aggregate business cycle shocks. For the calculation of our welfare measure we thus switch off all six aggregate shocks. We do, however, take into account that even in the absence of business cycles workers will fluctuate into and out of employment. Furthermore, by assumption, low-skilled, liquidity-constrained consumers remain in this group

[25] The remaining three scenarios d) to f) are omitted from the Figure since the corresponding graphs are indistinguishable to the human eye from those for scenario c).

Figure 2: Kalman-Smoothed Estimates of Labor Market Variables for Some Scenarios



Notes: The graphs show the actual data (black dotted line marked by larger dots) against the (Kalman-smoothed) estimates originating from the model (red solid line) when parameters are evaluated at the posterior mode. These are used as independent evidence of the model's fit. The data is of quarterly frequency. All four series are HP(100,000) filtered log series and scaled by 100 to represent percent deviations. From left to right: nationwide unemployment rate, vacancies, real total wages, low-skilled unemployment rate. A vertical dashed line marks the beginning of the sample period in 1984:q1. Scenarios d), e) and f) are omitted as the graphs look virtually identical to those of scenario c).

also in the absence of aggregate shocks. That is, we eliminate all aggregate risk but retain an individual's risk. Our welfare measure refers to the unconditional mean of consumption-equivalents, the computation of which is explained below.

4.1 Welfare criterion: Asset-holding households

The welfare of asset-holding households is given by

$$W_t^{(1)} = \frac{\left(c_t^{(1)} - \varrho^{(1)} c_{t-1}^{(1)}\right)^{1-\sigma}}{1-\sigma} - \kappa^L (1 - u_t^{(1)}) \frac{\left(h_t^{(1)}\right)^{1+\varphi}}{1+\varphi} + \beta E_t \left\{ W_{t+1}^{(1)} \right\}.$$

Assigning $\lambda_t^{\text{equiv},1}$ times steady state consumption and the steady state allocation of unemployment and hours worked, counterfactual welfare for this group is given by

$$\overline{W}_t^{(1)} = \left(\lambda_t^{equiv,1}\right)^{1-\sigma} \frac{1}{1-\beta} \left[\frac{\left(c - \varrho^{(1)} c\right)^{1-\sigma}}{1-\sigma} \right] - \frac{1}{1-\beta} \left[\kappa^L (1 - u^{(1)}) \frac{\left(h^{(1)}\right)^{1+\varphi}}{1+\varphi} \right].$$

Our measure of welfare defines the consumption-equivalent by equating actual welfare with welfare under the counterfactual allocation:

$$W_t^{(1)} \equiv \overline{W}_t^{(1)} \Rightarrow \lambda_t^{equiv,1}.$$

The welfare measure reported in Table 6 refers to the expected unconditional percent consumption-equivalent welfare, $-E\left\{\log(\lambda_t^{equiv,1})\right\} * 100$. In order to obtain an estimate of the welfare costs of business cycles, we use second-order approximations as in Schmitt-Grohé and Uribe (2004b).[26]

4.2 Welfare criterion: Liquidity-constrained workers

For liquidity-constrained consumers we also compute consumption-equivalents. In doing so, we assume that a worker would need to forfeit the same percentage of consumption relative to steady state in both states of employment. Counterfactual welfare-equivalents can depend on the current employment state of the worker.

[26] In more detail, our programs build on Matlab code for second-order approximations by Paul Klein (available at http://economics.uwo.ca/faculty/klein/personal/code). Differentiation in the code is done numerically. The code is described in Gomme and Klein (2006).

4.2.1 Welfare of Unemployed and Employed workers

The welfare of an unemployed, liquidity-constrained worker is given by

$$W_{u,t}^{(2)} = \frac{\left(c_{u,t}^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma}}{1-\sigma} + \beta s_t^{(2)} E_t \left\{ W_{e,t+1}^{(2)} \right\} + \beta(1-s_t^{(2)}) E_t \left\{ W_{u,t+1}^{(2)} \right\}.$$

The welfare of an employed, liquidity-constrained worker is given by

$$W_{e,t}^{(2)} = \frac{\left(c_{e,t}^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma}}{1-\sigma} - \kappa^L \frac{\left(h_t^{(2)}\right)^{1+\varphi}}{1+\varphi} + \beta(1-\vartheta^{(2)}) E_t \left\{ W_{e,t+1}^{(2)} \right\} + \beta\vartheta^{(2)} E_t \left\{ W_{u,t+1}^{(2)} \right\}.$$

Welfare evaluated at welfare-equivalent consumption for the respective liquidity-constrained worker is given by

$$\begin{bmatrix} \overline{W}_u^{(2)} \\ \overline{W}_e^{(2)} \end{bmatrix} = \frac{1}{[1-\beta(1-s^{(2)})]\,[1-\beta(1-\vartheta^{(2)})]-\beta^2\vartheta^{(2)}s^{(2)}} \begin{bmatrix} 1-\beta(1-\vartheta^{(2)}) & \beta s^{(2)} \\ \beta\vartheta^{(2)} & 1-\beta(1-s^{(2)}) \end{bmatrix} \cdot \left[\left(\lambda_t^{equiv,2,x}\right)^{1-\sigma} \begin{bmatrix} \frac{\left(c_u^{(2)}-\varrho^{(2)}c^{(2)}\right)^{1-\sigma}}{1-\sigma} \\ \frac{\left(c_e^{(2)}-\varrho^{(2)}c^{(2)}\right)^{1-\sigma}}{1-\sigma} \end{bmatrix} - \begin{bmatrix} 0 \\ \kappa^L \frac{\left(h^{(2)}\right)^{1+\varphi}}{1+\varphi} \end{bmatrix} \right].$$

Superscript x in $\lambda_t^{equiv,2,x}$ indicates that we entertain three different concepts of welfare measures for low-skilled, liquidity-constrained workers. One of these asks for the willingness to pay by an unemployed worker:

$$W_{u,t}^{(2)} \equiv \overline{W}_u^{(2)} \Rightarrow \lambda_t^{equiv,2,u}.$$

Similarly, one can ask for the willingness to pay an employed worker:

$$W_{e,t}^{(2)} \equiv \overline{W}_e^{(2)} \Rightarrow \lambda_t^{equiv,2,e}.$$

Alternatively, one can target the average liquidity-constrained worker:

$$u_t^{(2)} W_{u,t}^{(2)} + (1-u_t^{(2)}) W_{e,t}^{(2)} \equiv u^{(2)} \overline{W}_u^{(2)} + (1-u^{(2)}) \overline{W}_e^{(2)} \Rightarrow \lambda_t^{equiv,2}.$$

Also here the welfare measures reported in Table 6 refer to the unconditional percent consumption-equivalent, $-E\left\{\log(\lambda_t^{equiv,2,x})\right\} * 100$.

4.3 Abstracting from hours worked in calculating welfare

Fluctuations in hours worked may be of key importance for the business cycle dynamics. In our model though, they do not only have an important role to play in the bargaining process but they also have a strong, direct effect on workers' (dis)utility. As such, fluctuations in hours worked could have a potentially significant impact on our estimates of the welfare costs of business cycles. It is, however, not entirely clear whether this impact is actually warranted. In particular, other reasonable mechanisms could be envisaged through which hours worked would still play a role in the wage bargaining process but in which this role would not directly work through the worker's utility function. Furthermore, we do not consider hours spent working (or the cyclical fluctuations thereof) when unemployed be it, say, searching for a new job or in home-production. We therefore wish to safeguard ourselves against misrepresenting the welfare costs of business cycles. Consequently we examine the robustness of our results by also reporting counterfactual welfare measures when "switching off" the disutility of work term in the evaluation of the utility difference (but not in the bargaining process).

4.4 Results

Table 6 reports the welfare costs of business cycles in the respective scenarios. The entries can be interpreted as counterfactual premia for insurance against business cycle risk. For example,

Table 6: Welfare costs of Business Cycles (in percent)

Variable	benchmark	a)	b)	c)	d)	e)	f)
Family	.513	.554	.382	.606	.389	.489	.588
Average liquidity-constr.	.196	.198	.738	.475	.859	1.135	1.292
Employed liquidity-constr.	.196	.198	.733	.470	.847	1.119	1.271
Unemployed liquidity-constr.	.194	.196	.753	.490	.893	1.182	1.342
Family no hours	.398	.330	.337	.298	.387	0.340	0.294
Avg. type 2 no hours	.302	.309	.664	.549	.975	1.110	1.462
Empl. type 2 no hours	.300	.306	.656	.541	.960	1.092	1.439
Unempl. type 2 no hours	.308	.315	.688	.569	1.015	1.156	1.524

Notes: Welfare costs of business cycles. The table reports for the benchmark model and all six scenarios the welfare costs of business cycles. These are computed as the mean percent of steady state consumption which the agent would be willing to forego if business cycles were eliminated. For a description of scenarios a) to f) please refer to Section 3.5.

in the benchmark model the representative family member would be willing to forego 0.513% of steady state consumption if in return all business cycle risk would be eliminated (see the first entry of Table 6, i.e. row 2, column 2). Eliminating the direct effect of hours worked on the calculation of the costs of business cycles results in smaller costs which do, however, still run up to 0.398% of steady state consumption for the family member (Table 6, row 5, column 2).

A couple of results are worth mentioning: First, all of our welfare numbers are significantly higher than Lucas' (1987) and, for the benchmark calibration, are in the same range of numbers reported by Costain and Reiter (2005b). The latter authors obtain similar numbers for a real business cycle model with heterogeneous agents and equilibrium unemployment. The reason why we find higher numbers than Lucas (1987) even for the family members (who insure each other against unemployment risk) is primarily due to the fact that, in a second-order approximation, the policy functions are influenced by the shock structure, while in Lucas's experiment the exogenous consumption process has no general equilibrium feedback. In our case, however, a reduction in volatility will have an effect on the average level of endogenous variables.[27] As an example, Table 7 reports the mean value of selected key variables in the benchmark calibration and compares these to the steady state in this calibration (columns 2 to 4). As is apparent from this table, unemployment rates are on average slightly higher than in steady state and consumption and output are significantly lower, by 0.33% and 0.23%, respectively. In addition, all workers, when employed work more hours.

Second, and perhaps surprisingly, the welfare costs for the liquidity constrained workers are not uniformly higher than that of their family counterparts. In particular, in the benchmark calibration the family suffers two and a half times more costs of business cycles than the liquidity-constrained worker. This effect is due to our assumption that the outside option of the worker is close to its wage income. Once this assumption is relaxed we see that the liquidity-constrained worker does suffer quite a bit more from unemployment due the drop in consumption when unemployed; compare the benchmark with scenarios c), d), e) and f) which, in this order, feature replacement rates from over 60% (benchmark) to 10%. For a low replacement rate, in particular, liquidity-constrained workers would pay up to three times as much as the family for avoiding the business cycle (five times as much when abstracting from hours worked in the evaluation of welfare).

Third, the way unemployment benefits are financed, is of utmost importance. Experiment b)

[27] Put differently, the economy does not spend its time on average at the steady state.

Table 7: Moments in the Benchmark Model

Variable	$E\{x_t\}$	$E\{x_t\}-x$	$\frac{E\{x_t\}-x}{x}\cdot 100$	$std(x_t)\cdot 100$	$\frac{std(x_t)}{x}\cdot 100$
y_t	0.997	-.0023	-0.233	1.73	1.73
c_t	0.588	-.0019	-0.327	0.79	1.35
$c_t^{(1)}$	0.633	-.0021	-0.335	0.86	1.36
$c_t^{(2)}$	0.352	-.0009	-0.259	0.71	2.01
$c_{e,t}^{(2)}$	0.363	-.0006	-0.169	0.66	1.82
$c_{u,t}^{(2)}$	0.253	-.0000	-0.000	0.00	0.00
$c_{m,t}$	0.588	-.0019	-0.327	0.79	1.35
$c_{m,t}^{(1)}$	0.633	-.0021	-0.335	0.86	1.36
i_t	0.284	-.0007	-0.243	1.70	5.95
ks_t	29.679	-.0511	-0.171	63.15	2.12
R_t	1.005	.0000	0.003	0.16	0.15
π_t	1.002	.0000	0.005	0.14	0.14
$h_t n_t$	0.308	-.0003	-0.083	0.51	1.66
$h_t^{(1)}$	0.333	.0005	0.147	0.40	1.22
$h_t^{(2)}$	0.295	.0001	0.021	0.05	0.20
$w_t h_t n_t$	0.634	-.0015	-0.229	2.32	3.64
w_t	2.058	-.0036	-0.174	4.51	2.18
$w_t^{(1)}$	2.190	-.0043	-0.195	4.79	2.18
$w_t^{(2)}$	1.231	-.0023	-0.188	2.39	1.94
u_t	0.060	.0021	3.595	0.80	13.89
$u_t^{(1)}$	0.051	.0018	3.510	0.74	14.93
$u_t^{(2)}$	0.103	.0038	3.818	1.22	12.25
$s_t^{(1)}$	0.561	-.0088	-1.537	9.43	16.55
$s_t^{(2)}$	0.262	-.0072	-2.651	4.05	15.00

Notes: This table reports moments of the model variables in levels for the benchmark scenario. Column 2 reports the unconditional mean, $E\{x_t\}$. Column 3 reports the mean deviation from steady state $E\{x_t\}-x$. Column 4 reports the mean percent deviation from steady state $(E\{x_t\}-x)/x*100$. Column 5 reports the standard deviation (multiplied by 100 for better readability), $std(x_t)$. Column 6 reports the percent standard deviation from steady state $std(x_t)/x$. Note: all variables are in *monthly* terms.

and c) both feature a replacement rate of 40% and no home production. Experiment c) assigns the financing of all unemployment insurance to the family while experiment b) has the low-skilled (and poorer) workers pay for their own unemployment insurance. We see that on the other hand the family might suffer quite a bit when having to pay the full tax burden for the low-skilled workers and that the costs of business cycles for the liquidity-constrained workers are substantially higher when they are not subsidized by the family.

Fourth, for the family the costs of business cycles increase from experiment e) to f). While the utility difference between employment and unemployment increases, family members fully insure each other against becoming unemployed. This result is thus not entirely intuitive at first glance. This may have to do with the mean levels of consumption, hours worked and unemployment in the respective calibrations. We are currently investigating this further.

Fifth, as we would expect, the increase in the utility differences between employment and unemployment causes increasing costs of business cycles for liquidity-constrained workers as exemplified when passing through scenarios c) through f). Here the difference is quite substantial and almost triples across the scenarios.

In interpreting the replacement rate it is important to note that even though the worker receives, say, only 20% of his steady state wage income, in our current calibration he fully enjoys his leisure time. The value of leisure in our calibration is roughly equivalent to one third of wage income per month. This implies that the overall monthly value of staying at home in this example would correspond to around 55% of total wage income. To put our experiment into perspective, in our case d) we therefore exceed the replacement rate assumed by Shimer (2005) by a full 13%. In particular, only the low replacement rate in case f) would roughly correspond to Shimer's calibration. This is due to the fact that Shimer (2005) does not consider a choice of hours worked, so his replacement rate (he argues for 40% of wage income) might best be interpreted as the joint gain from unemployment benefits and leisure time minus the cost of searching for a new job.[28] Given the unanimity and variety of calibrations regarding this value in the literature, we feel that virtually all of the alternative scenarios could be supported by some existing calibration in the literature. For this reason we prefer to report an entire range for this surplus and for the

[28] We abstract from modeling search costs explicitly. Since these are unobservable a precise number is hard to come by. One could, for example, reconcile a factual replacement rate of 40% with Shimer's calibration if one were to allow for a cost of searching which roughly amounts to half the utility cost of working in each month. In this case experiment d) would capture the correct setup.

ensuing estimates of the welfare costs of business cycles.

Finally, in summarizing our results, we would like to point out that even for the scenarios featuring lower replacement rates, our estimates of the welfare costs of business cycles appear to be contained after all. In particular, even workers who face on average very high, very volatile and strongly counter-cyclical unemployment rates and who cannot self-insure at all against unemployment risk but rather depend exclusively on unemployment benefits when they lose their job would be willing to spend at most 1.5% of their monthly consumption stream to buy business-cycle insurance. Of course, our model abstracts from a number of features that still might increase the actual costs of business cycles. In particular, it does not capture the fear of workers of hitting the maximum duration of unemployment insurance if they have not found a job rapidly enough. The model is does not include the risk of becoming borrowing-constrained only in a recession (starting from a high consumption level) – yet, it also does not include the countervailing gains from leaving the constrained group more easily in a boom period. We furthermore rule out by assumption any possible costs that might originate from a loss of skills or firm-specific human capital off the job and which might lead to a persistent transition from a higher skill and earnings group to a lower income group. These caveats notwithstanding, our results suggest that the welfare costs of business cycles are larger than negligible for policymakers but that they still do not run to prohibitively high numbers.

Here a nice graph tracing out the welfare costs for different replacement rates.

5 Conclusion

The costs of business cycles crucially depend on the correlation of idiosyncratic risk and aggregate risk, the amount of self-insurance available and the amount of insurance provided by the government. A potentially important ingredient for this correlation might be unemployment risk. This paper developed a New Keynesian model with matching frictions and liquidity-constrained consumers. The model was estimated on US data with Bayesian techniques. The estimation procedure accounted explicitly for the frequency mismatch between the model and the data. We illustrated that the model constitutes a good representation of the relationship between aggregate risk and individual unemployment risk. In particular, the model replicates the fluctuations of unemployment rates endogenously (without the unemployment series being used in the estimation) and implies reasonable business cycle statistics for many important endogenous variables.

Given this, in our view, acceptable fit of the model for key variables we used this model to provide bounds for the costs of business cycles for different assumptions regarding the effectiveness of governmental unemployment benefit schemes and regarding the importance of self-insurance through saving and home-production.

Our lowest estimates for the costs of business cycles are an order of magnitude larger than the estimates provided by Lucas (1987). Namely consumers would voluntarily forego 0.19% of steady state consumption if in return all aggregate risk would be eliminated. If the gain from working relative to being unemployed is assumed to be higher, the costs for low-skilled, liquidity-constrained workers increase up to 1.5% of steady state consumption.

Overall, thus even for low-skilled workers who face a significant unemployment risk the estimated costs of business cycles do not appear to be prohibitively high. While our estimates neglect a number of other potential sources of business cycle costs (but also a number of mitigating forces), as far as being part of the bottom of the wealth and skill distribution is a persistent phenomenon and if the likelihood of moving in and out of this group is low, we view our estimates as a suggestive upper bound for the business cycle costs in the presence of equilibrium unemployment for these relatively poor agents.

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A Derivation of Family Utility Function $\mathtt{U}$

In each period the family optimally provides consumption allocations to its members. Consumption allocations are optimal if all members receive the same marginal utilities with respect to consumption. The optimality condition is given by

$$(c_{e,i,t}^{(1)} - \varrho^{(1)} c_{t-1}^{(1)})^{-\sigma} = (c_{u,t}^{(1)} - \varrho^{(1)} c_{t-1}^{(1)})^{-\sigma}, \tag{60}$$

where $c_{e,i,t}^{(1)}$ denotes consumption of an employed member i and $c_{u,t}^{(1)}$ denotes the consumption of unemployed members. Therefore, since marginal utility of consumption does not depend on hours worked, we have

$$c_{e,i,t}^{(1)} = c_{u,t}^{(1)} = c_t^{(1)}.$$

Consequently, inner-period family utility can be expressed as

$$\mathtt{U}(c_t^{(1)}, c_{t-1}^{(1)}, \{h_{i,t}^{(1)}\}, u_t^{(1)}) = \frac{\left(c_t^{(1)} - \varrho^{(1)} c_{t-1}^{(1)}\right)^{1-\sigma}}{1-\sigma} - \kappa^L \int_0^{1-u_t^1} \frac{\left(h_{i,t}^{(1)}\right)^{1+\varphi}}{1+\varphi} di. \tag{61}$$

A.1 Derivation of Utility Difference

The utility difference for the family can be derived by computing the value of a marginal family member in employment. Towards that aim, we compute the change in (3) subject to an optimal allocation of resources among family members (61), budget constraint (6) and the employment flow constraint (30) which states that the fraction of employed members in the family evolves according to

$$n_t^{(1)} = (1 - \vartheta^{(1)}) n_{t-1}^{(1)} + s_{t-1}^{(1)} u_{t-1}^{(1)}.$$

The utility difference, Δ_t, for family utility (61) then can be expressed as

$$\begin{aligned} \frac{\partial \mathtt{W}_t^{(1)}}{\partial(-u_t^{(1)})} : \quad &= \Delta_t \\ &= \Bigg[\left(c_t^{(1)} - \varrho^{(1)} c_{t-1}^{(1)} \right)^{-\sigma} \left(w_{i,t}^{(1)} h_{i,t}^{(1)} - b^{(1)} \right) \\ &\quad - \kappa^L \frac{\left(h_{i,t}^{(1)} \right)^{1+\varphi}}{1+\varphi} \Bigg] + (1 - s_t^{(1)} - \vartheta^{(1)}) E_t \left\{ \beta \Delta_{t+1}^{(1)} \right\}. \end{aligned} \tag{62}$$

B Data

B.1 Source and Definition of Data

Table 8: Description of Raw Data

	Mnemonic	Data description
Consumption of services	PCESV	Personal Consumption Expenditures: Services quarterly, seasonally adjusted annual rates billions of dollars.
Consumption of non-durables	PCND	Personal Consumption Expenditures: Nondurable Goods quarterly, seasonally adjusted annual rates billions of dollars.
Consumption of durables	PCDG	Personal Consumption Expenditures: Durable Goods quarterly, seasonally adjusted annual rates billions of dollars.
Fixed investment	FPI	Fixed Private Investment quarterly, seasonally adjusted annual rates billions of dollars.
GDP deflator	GDPDEF	Gross Domestic Product: Implicit Price Deflator quarterly, seasonally adjusted annual rate index 2000=100.
Interest rate	FEDFUNDS	Effective Federal Funds Rate monthly average, % p.a. quarterly average of monthly figures (own aggregation).
Labor force	CNP16OV	Civilian Noninstitutional Population thousands, quarterly average of monthly figures (own aggregation).
Output	GDP	Gross Domestic Product quarterly, seasonally adjusted annual rates billions of dollars.
Total hours worked	AWHNONAG	Average Weekly Hours: Total Private Industies (index) monthly, seasonally adjusted, quarterly average of monthly figures (own aggregation).
Total wages	WASCUR	Compensation of Employees: Wages and Salary Accruals, billions of dollars, quarterly, seasonally adjusted at annual rate.
Unemployment rate	UNRATE	Civilian Unemployment Rate monthly, seasonally adjusted, quarterly average of monthly figures (own aggregation).
Unempl. rate low-skilled	LNS14027659	Unempl. Rate - Less than High School Diploma, 25 yrs and over monthly, seasonally adjusted, source: Bureau of Labor Statistics, quarterly average of monthly figures (own aggregation).
Vacancies	HELPWANT	Index of Help-Wanted Advertising base year 1987=100, seasonally adjusted quarterly average of monthly figures (own aggregation).
Youth unemployment rate	LNS14024887	Unemployment Rate - 16-24 yrs, monthly, seasonally adjusted, source: Bureau of Labor Statistics. quarterly average of monthly figures (own aggregation).

Notes: All data are obtained from the Federal Reserve Bank of St. Louis database FRED unless explicitly stated otherwise.

Table 9: Data Used for Estimation and Verification

Variable	Formula
Consumption per capita	$c_t = (\text{PCESV+PCND})_t/(4 \times \text{GDPDEF}_t \cdot \text{CNP16OV}_t)$.
Investment per capita	$i_t = (\text{PCDG+FPI})_t/(4 \times \text{GDPDEF}_t \cdot \text{CNP16OV}_t)$.
Output per capita	$y_t = \text{GDP}_t/(4 \times \text{GDPDEF}_t \cdot \text{CNP16OV}_t)$.
Quarterly federal funds rate	$R_t = 1 + \text{FEDFUNDS}_t/400$.
Quarterly inflation rate	$\Pi_t = \text{GDPDEF}_t/\text{GDPDEF}_{t-1}$.
Total hours worked	$h_t \cdot n_t = \text{AWHNONAG}_t \cdot (1 - \text{UNRATE}_t/100)$.
Total wages	$w_t \cdot h_t \cdot n_t = \text{WASCUR}_t/(4 \times \text{GDPDEF}_t \cdot \text{CNP16OV}_t)$.
Unemployment rate	$u_t = \text{UNRATE}_t/100$.
Unemp. rate liquidity-constr.	$u_t^{(2)} = \text{LNS14024887}_t/100$.
Vacancies	$v_t = \text{HELPWANT}_t$.

Notes: Mnemonics in the formulae refer to the definitions in Table 8.

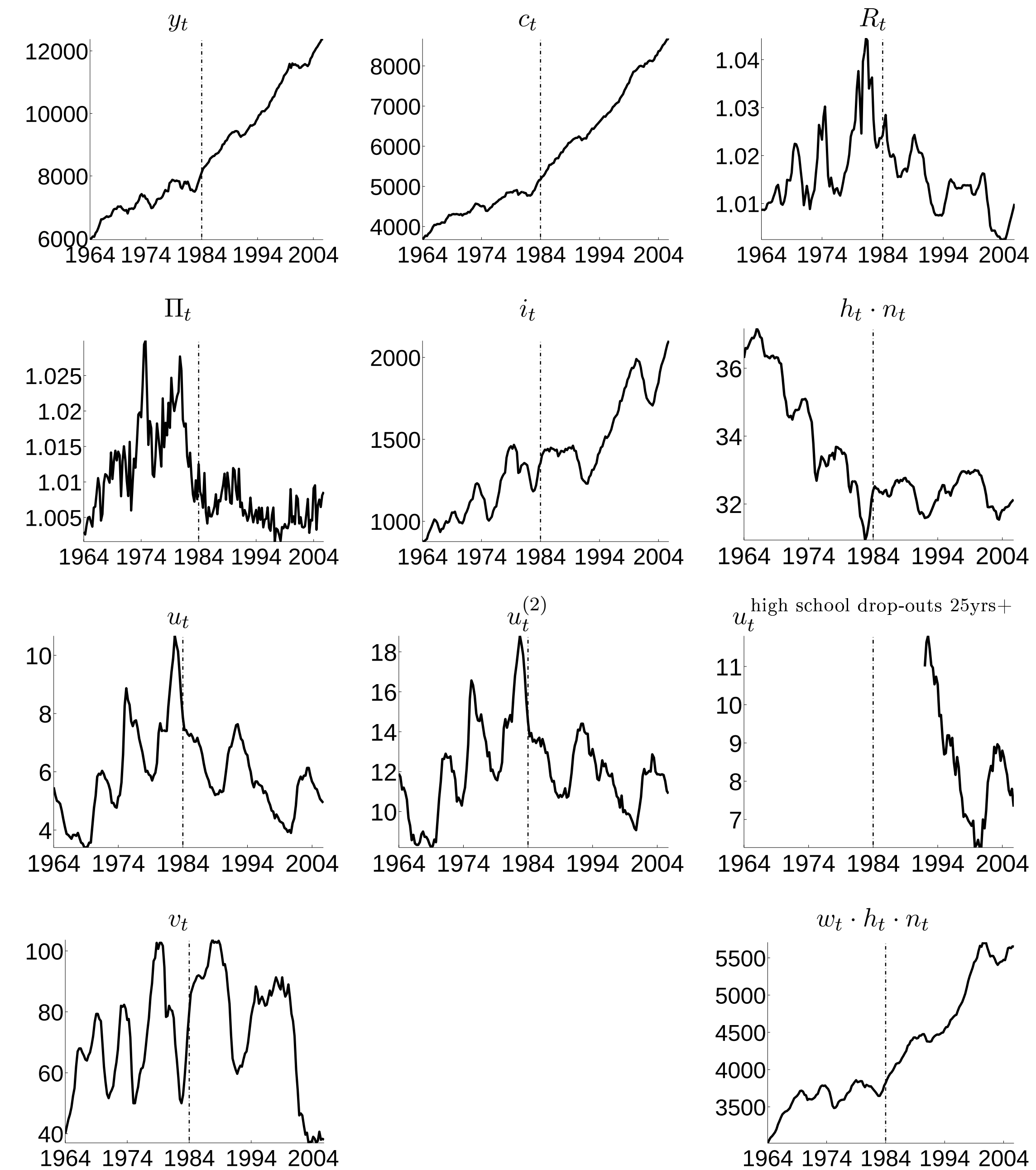
B.2 Moments and Plots of the Data

Table 10: Moments of Data (1984:q1 to 2005:q4)

Variable	Meaning	std	std to y	corr with y	mean ratio to y
$\widehat{y}_t$	output	1.61	1	1	1
$\widehat{c}_t$	consumption	1.15	0.71	0.73	0.59
$\widehat{i}_t$	investment	6.39	3.98	0.81	0.24
		std	std to y	corr with y	mean
$\widehat{R}_t$	nom. interest rate (gross)	0.38	0.24	0.59	1.013
$\widehat{\pi}_t$	GDP inflation rate (gross)	0.24	0.15	-0.04	1.006
$\widehat{h}_t + \widehat{n}_t$	total hours worked	1.20	0.75	0.86	—
$\widehat{w}_t + \widehat{h}_t + \widehat{n}_t$	total wage income	3.05	1.90	0.86	—
$\widehat{w}_t$	wage per hour	2.33	1.45	0.68	—
$\widehat{u}_t$	unemployment rate (all)	13.89	8.64	-0.92	5.79
$\widehat{u}_t^{(2)}$	u. rate 16-24 (proxy low-skill)	10.02	6.23	-0.91	11.94
$\widehat{u}_t^{(2)}$	u. rate high-school drop-out	12.41	7.72	-0.90	8.47
$\widehat{v}_t$	vacancies (help-wanted index)	18.81	11.70	0.82	—

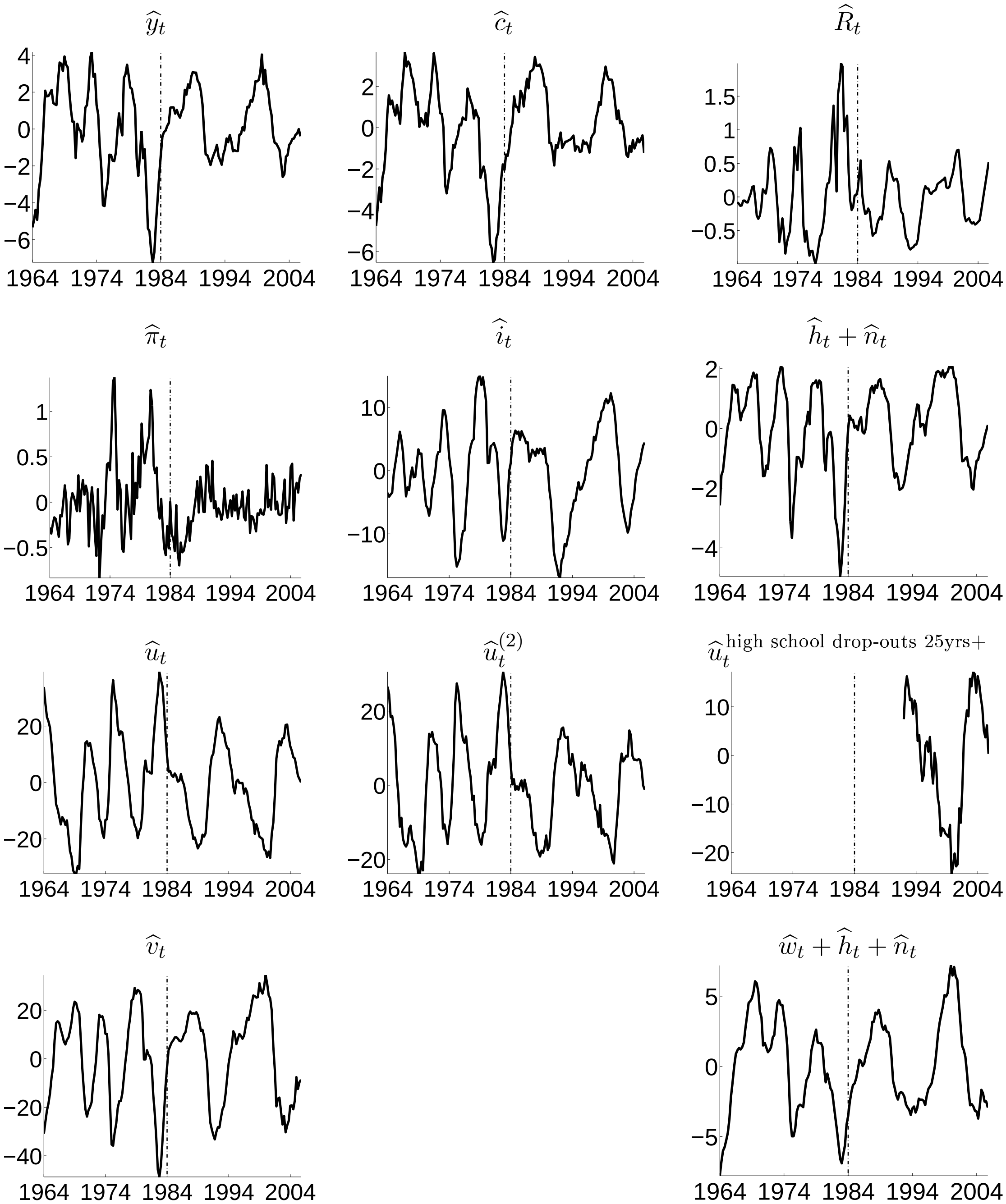
Notes: The table reports summary statistics of the data. The third to fifth column show statistics for HP(100.000) filtered data. The third column reports the standard deviation of the series, the fourth its standard deviation relative to GDP. The fifth column shows the cross-correlation with GDP. For GDP components, the final column reports the mean share in GDP. For all other series, the mean of the series in levels is shown. The computations are performed on the sample from 1984:q1 to 2005:q4. The data is HP-filtered from 1964:q1 to 2005:q4. The reported investment GDP ratio is calculated as the ratio of fixed private investment plus durable consumption to GDP. The consumption output ratio consequently is computed as the ratio of non-durable consumption plus services to GDP.

Figure 3: Plots of the Raw Data



Notes: The graphs plot the raw data in levels. A vertical dashed line marks the start of the observation sample in 1984:q1.

Figure 4: Plots of HP(100,000) Filtered Data



Notes: The graphs plot the business cycle component of the data in Figure 3. The data have been logged, HP(100,000)-filtered and multiplied by 100. A vertical dashed line marks the start of the observation sample in 1984:q1.

C Estimation Algorithm

For the estimation of our model we apply Bayesian techniques as in Smets and Wouters (2005). The estimation methodology consists of five steps. In step one we solve the linearized rational expectations model for a given set of parameters. A non-standard feature is that the economy is modeled at a monthly frequency in order to achieve consistency of the employment stock and flow data but estimated using data at a quarterly frequency. In step two we thus derive a state-equation in quarterly terms and a measurement equation which links the seven observable variables to the vector of state variables. In step three the likelihood function is evaluated using the Kalman filter. Step four involves combining this likelihood function with a prior distribution over the parameters to form the posterior density function. The final step consists of numerically deriving the posterior distribution of the parameters. We compute the posterior mode and the Laplace approximation to the marginal data density. This appendix summarizes the approach taken.

C.1 Observation and State Equation

We start by deriving our observation equation and the state equation for the Kalman filter. Using these, the Kalman filter is standard; see e.g. Hamilton, 1994, ch. 13.

Observation Equation

For a particular set of parameters, the equilibrium law of motion of the linearized model takes the form

$$\mathbf{y}_t = F_{\mathbf{x}}\mathbf{x}_t + F_{\mathbf{u}}\mathbf{u}_t, \tag{63}$$

where $\mathbf{y}_t$ ($n_{\mathbf{y}}$ x 1) collects the endogenous variables of the model in percent deviation from steady state, $\mathbf{x}_t$ ($n_{\mathbf{x}}$ x 1) collects the endogenous states of the model, $n_{\mathbf{x}} < n_{\mathbf{y}}$, and $\mathbf{u}_t$ (n_u x 1) collects the innovations of the model. Here a time index t refers to one month. The conformable matrizes $F_{\mathbf{x}}$ and $F_{\mathbf{u}}$ are functions of the model parameters. The endogenous states of the monthly model in equilibrium evolve according to

$$\mathbf{x}_t = A_{\mathbf{x}}\mathbf{x}_{t-1} + B_{\mathbf{u}}\mathbf{u}_t,\ \mathbf{u}_t \overset{iid}{\sim} N(0,\Omega), \tag{64}$$

where $A_{\mathbf{x}}$ and $B_{\mathbf{u}}$ are again functions of the model parameters. By assumption, the econometrician can observe data only at a quarterly frequency. Let $n_{\mathbf{z}}$ be the number of series which are observable each quarter. Let t_q be the month at the end of an arbitrary quarter, q, and let $\mathbf{z}_q$ denote the observation of the vector $\mathbf{z}$ in quarter q. The observable variables are defined as

$$\mathbf{z}_q = W_0\mathbf{y}_{t_q} + W_1\mathbf{y}_{t_q-1} + W_2\mathbf{y}_{t_q-2} + \nu_q. \tag{65}$$

Here $\mathbf{z}_q$ is ($n_{\mathbf{z}}$ x 1), and $\nu_q \overset{iid}{\sim} N(\mathbf{0}, \Sigma)$ is a conformable measurement error which is orthogonal to the structural innovations, $\mathbf{u}_t$, contemporaneously and at all lags and leads. Conformable matrices W_0, W_1 and W_2 are of dimension (n_z x $n_{\mathbf{y}}$). They appropriately weight monthly endogenous variables for the quarterly observations. For the construction of the weighting matrices using the precise empirical exercise of our paper see Appendix C.3. Rewriting (65) in matrix form yields

$$\mathbf{z}_q = W \begin{pmatrix} \mathbf{y}_{t_q} \\ \mathbf{y}_{t_q-1} \\ \mathbf{y}_{t_q-2} \end{pmatrix} + \nu_q, \tag{66}$$

where weighting matrix $W = [W_0, W_1, W_2]$. Define the state vector $\tilde{\mathbf{x}}_t$ by stacking endogenous states in t and the innovations,

$$\tilde{\mathbf{x}}_t \equiv \begin{pmatrix} \mathbf{x}_t \\ \mathbf{u}_t \end{pmatrix}.$$

Using this definition, we can rewrite (63) as

$$\mathbf{y}_t = F\tilde{\mathbf{x}}_t, \tag{67}$$

where $F = [F_{\mathbf{x}}, F_{\mathbf{u}}]$. As a results, the vector of observable variables in (66), $\mathbf{z}_q$, can be expressed as

$$\mathbf{z}_q = W_{\tilde{\mathbf{x}}} \begin{pmatrix} \tilde{\mathbf{x}}_{t_q} \\ \tilde{\mathbf{x}}_{t_q-1} \\ \tilde{\mathbf{x}}_{t_q-2} \end{pmatrix} + \nu_q, \tag{68}$$

where weighting matrix $W_{\tilde{\mathbf{x}}} = [W_0F, W_1F, W_2F]$. Define $\tilde{\mathbf{x}}_q^{\text{long}} \equiv \tilde{\mathbf{x}}_{t_q}^{\text{long}} \equiv \begin{pmatrix} \tilde{\mathbf{x}}_{t_q} \\ \tilde{\mathbf{x}}_{t_q-1} \\ \tilde{\mathbf{x}}_{t_q-2} \end{pmatrix}$. Using this notation, the following equation (68) is our observation equation:

$$\mathbf{z}_q = W_{\tilde{\mathbf{x}}}\tilde{\mathbf{x}}_q^{\text{long}} + \nu_q. \tag{69}$$

State Equation

Stack $\mathbf{x}_t$ in (64) and $\mathbf{u}_t$, so

$$\tilde{\mathbf{x}}_{t_q} = A_{\tilde{\mathbf{x}}}\tilde{\mathbf{x}}_{t_q-1} + B_{\tilde{\mathbf{u}}}\mathbf{u}_{t_q}. \tag{70}$$

Here $A_{\tilde{\mathbf{x}}} = \begin{bmatrix} A_{\mathbf{x}} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{bmatrix}$ and $B_{\tilde{\mathbf{u}}} = \begin{bmatrix} B_{\mathbf{u}} \\ I_{n_{\mathbf{u}}} \end{bmatrix}$. Here $I_{n_{\mathbf{u}}}$ denotes an identity matrix of dimension $n_{\mathbf{u}}$. Stacking further in order to produce a law of motion for $\tilde{\mathbf{x}}_{t_q}^{\text{long}}$ gives

$$\tilde{\mathbf{x}}_{t_q}^{\text{long}} = A_{\tilde{\mathbf{x}}^{\text{long}}}\tilde{\mathbf{x}}_{t_q-1}^{\text{long}} + B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q}, \tag{71}$$

where $A_{\tilde{\mathbf{x}}^{\text{long}}} = \begin{bmatrix} A_{\tilde{\mathbf{x}}} & \mathbf{0} & \mathbf{0} \\ I_{n_{\mathbf{x}}+n_{\mathbf{u}}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & I_{n_{\mathbf{x}}+n_{\mathbf{u}}} & \mathbf{0} \end{bmatrix}$ and $B_{\tilde{\mathbf{u}}^{\text{long}}} = \begin{bmatrix} B_{\tilde{\mathbf{u}}} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix}$. Now substitute (71) iteratively in (71) to obtain

$$\begin{aligned} \tilde{\mathbf{x}}_{t_q}^{\text{long}} &= A^3_{\tilde{\mathbf{x}}^{\text{long}}}\tilde{\mathbf{x}}_{t_q-3}^{\text{long}} \\ &\quad + A^2_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q-2} + A_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q-1} + B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q}. \end{aligned} \tag{72}$$

Collecting terms in (72) we have that

$$\tilde{\mathbf{x}}_{t_q}^{\text{long}} = A^3_{\tilde{\mathbf{x}}^{\text{long}}}\tilde{\mathbf{x}}_{t_q-3}^{\text{long}} + \epsilon_q, \tag{73}$$

where

$$\epsilon_q \equiv A^2_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q-2} + A_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q-1} + B_{\tilde{\mathbf{u}}^{\text{long}}}\mathbf{u}_{t_q}.$$

Since $\mathbf{u}_t \overset{iid}{\sim} N(\mathbf{0}, \Omega)$, from a quarterly perspective $\epsilon_q \overset{iid}{\sim} N(\mathbf{0}, \Xi)$ with

$$\begin{aligned} \Xi &= A^2_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\Omega B_{\tilde{\mathbf{u}}^{\text{long}}}{}' A^2_{\tilde{\mathbf{x}}^{\text{long}}}{}' \\ &\quad + A_{\tilde{\mathbf{x}}^{\text{long}}}B_{\tilde{\mathbf{u}}^{\text{long}}}\Omega B_{\tilde{\mathbf{u}}^{\text{long}}}{}' A_{\tilde{\mathbf{x}}^{\text{long}}}{}' \\ &\quad + B_{\tilde{\mathbf{u}}^{\text{long}}}\Omega B_{\tilde{\mathbf{u}}^{\text{long}}}{}'. \end{aligned} \tag{74}$$

Our observation equation at a quarterly frequency is therefore given by

$$\tilde{\mathbf{x}}_{q}^{\text{long}} = A^3_{\tilde{\mathbf{x}}^{\text{long}}}\tilde{\mathbf{x}}_{q-1}^{\text{long}} + \epsilon_q, \tag{75}$$

with $\epsilon_q \overset{iid}{\sim} N(\mathbf{0}, \Xi)$ and Ξ given by (74).

C.2 Bayesian Estimation

Let $\boldsymbol{\theta}$ denote the vector of parameters we estimate. $\boldsymbol{\theta}$ contains all the model parameters, including the second moments in variance-covariance matrix Ω. $\boldsymbol{\theta}$ also contains the standard deviation of the measurement error in quarterly terms as summarized by variance-covariance matrix Σ. Let the prior be given by $p(\boldsymbol{\theta})$. Marginal priors are assumed to be independent. Conditional on the parameters, $\boldsymbol{\theta}$, and an initial state, $\tilde{\mathbf{x}}_0^{\text{long}} = 0$, the endogenous variables are normally distributed; compare (69) and (75). Let $\mathcal{L}(\{\mathbf{z}_q\};\boldsymbol{\theta})$ denote the Gaussion likelihood of sample $\{\mathbf{z}_q\}$ given $\boldsymbol{\theta}$. The likelihood is evaluated using a standard Kalman filter with the observation and state equation defined in Appendix C.1. The posterior is given by

$$p(\boldsymbol{\theta}|\{\mathbf{z}_q\}) = \frac{p(\boldsymbol{\theta})\mathcal{L}(\{\mathbf{z}_q\};\boldsymbol{\theta})}{p(\{\mathbf{z}_q\})} \propto p(\theta)\mathcal{L}(\{\mathbf{z}_q\};\theta).$$

The marginal data density is given by

$$p(\{\mathbf{z}_q\}) = \int p(\boldsymbol{\theta})\mathcal{L}(\{\mathbf{z}_q\};\boldsymbol{\theta})d\boldsymbol{\theta}.$$

In our paper we compute the marginal data density by means of a Laplace approximation around the posterior mode.

C.3 Aggregation

This subsection discusses the time-aggregation conducted by matrix $W_{\tilde{\mathbf{x}}}$ in equation (68). In the following let x_q^{quart} denote the observation in quarter q of a quarterly transformation of the monthly variables x_{t_q}, x_{t_q-1} and x_{t_q-2}. x_q^{quart} is one of the elements of the vector of observable variables, z_q. Hats, in $\widehat{x}_q^{\text{quart}}$ for example, denote percent deviations of a variable from its steady state. Quarterly gross interest rates and gross inflation rates are not annualized and thus computed as the product of their monthly counterparts. Consequently, log-linearized, we have

$$\widehat{R}_q^{\text{quart}} = \widehat{R}_{t_q} + \widehat{R}_{t_q-1} + \widehat{R}_{t_q-2}.$$

In each of the matrices W_0, W_1, and W_2, in the row pertaining to $\widehat{R}_q^{\text{quart}}$ the weight in the column belonging to $\widehat{R}_{t_q}$ is therefore unity. Similarly,

$$\widehat{\Pi}_q^{\text{quart}} = \widehat{\Pi}_{t_q} + \widehat{\Pi}_{t_q-1} + \widehat{\Pi}_{t_q-2}.$$

As an example for a *stock variable*, the percent deviation of the average unemployment rate over the quarter is (up to a first-order approximation)

$$\begin{aligned}
\widehat{u}_q^{\text{quart}} &= \frac{u_q^{\text{quart}}-u^{\text{quart}}}{u^{\text{quart}}} \\
&= \frac{\frac{1}{3}\left(u_{t_q}+u_{t_q-1}+u_{t_q-2}\right)-\frac{1}{3}(u+u+u)}{\frac{1}{3}(u+u+u)} \\
&= \frac{\frac{1}{3}\left((u_{t_q}-u)+(u_{t_q-1}-u)+(u_{t_q-2}-u)\right)}{\frac{1}{3}(u+u+u)} \\
&= \frac{(u_{t_q}-u)+(u_{t_q-1}-u)+(u_{t_q-2}-u)}{(u+u+u)} \\
&= \frac{(u_{t_q}-u)+(u_{t_q-1}-u)+(u_{t_q-2}-u)}{3u} \\
&= \frac{1}{3}\left(\frac{u_{t_q}-u}{u}+\frac{u_{t_q-1}-u}{u}+\frac{u_{t_q-2}-u}{u}\right) \\
&= \frac{1}{3}\left(\widehat{u}_{t_q}+\widehat{u}_{t_q-1}+\widehat{u}_{t_q-2}\right).
\end{aligned}$$

Here u^{quart} refers to the steady state of the average unemployment rate of a quarter, and u to the steady state unemployment rate in an arbitrary month. Naturally, these two values coincide. In each of the matrices W_0, W_1, and W_2, in the row pertaining to $\widehat{u}_q^{\text{quart}}$ the weight in the column belonging to $\widehat{u}_{t_q}$ are therefore equal to $\frac{1}{3}$. Following the same lines, the percentage deviation of average stock variables over the quarter is in general computed as the mean of the monthly deviation. Consequently, the average vacancy posting activity is given by

$$\widehat{v}_q^{\text{quart}} = \frac{1}{3}\left(\widehat{v}_{t_q}+\widehat{v}_{t_q-1}+\widehat{v}_{t_q-2}\right)$$

and the average wage rate over a quarter is

$$\widehat{w}_q^{\text{quart}} = \frac{1}{3}\left(\widehat{w}_{t_q}+\widehat{w}_{t_q-1}+\widehat{w}_{t_q-2}\right).$$

As an example for a *flow variable*, the percent deviation of quarterly GDP from steady state (up to a first-order approximation) is

$$\begin{aligned}
\widehat{y}_q^{\text{quart}} &= \frac{y_q^{\text{quart}}-y^{\text{quart}}}{y^{\text{quart}}} \\
&= \frac{\left(y_{t_q}+y_{t_q-1}+y_{t_q-2}\right)-3y}{3y} \\
&= \frac{(y_{t_q}-y)+(y_{t_q-1}-y)+(y_{t_q-2}-y)}{3y} \\
&= \frac{1}{3}\left(\frac{y_{t_q}-y}{y}+\frac{y_{t_q-1}-y}{y}+\frac{y_{t_q-2}-y}{y}\right) \\
&= \frac{1}{3}\left(\widehat{y}_{t_q}+\widehat{y}_{t_q-1}+\widehat{y}_{t_q-2}\right).
\end{aligned}$$

In the row pertaining to $\widehat{y}_q^{\text{quart}}$, the weights on $\widehat{y}_{t_q}$ are therefore equal to $\frac{1}{3}$ in each of the matrices W_0, W_1, and W_2. Percent deviations of quarterly flow variables are hence also computed as the mean of the corresponding monthly observations. Consequently, the deviation of quarterly consumption from steady state is

$$\widehat{c}_q^{\text{quart}} = \frac{1}{3}\left(\widehat{c}_{t_q} + \widehat{c}_{t_q-1} + \widehat{c}_{t_q-2}\right),$$

the deviation of quarterly investment from steady state is

$$\widehat{i}_q^{\text{quart}} = \frac{1}{3}\left(\widehat{i}_{t_q} + \widehat{i}_{t_q-1} + \widehat{i}_{t_q-2}\right)$$

and, finally, the deviation of total hours worked in quarter q is given by

$$\widehat{(h \cdot n)}_q^{\text{quart}} = \frac{1}{3}\left(\widehat{(h \cdot n)}_{t_q} + \widehat{(h \cdot n)}_{t_q-1} + \widehat{(h \cdot n)}_{t_q-2}\right).$$

D Traditional Performance Measures

This appendix formally evaluates the statistical performance of the model. Table 11 shows the marginal data density of the model using a Laplace approximation around the posterior mode.

As an empirical benchmark we report the marginal data density for Bayesian VARs up to

Table 11: Log Marginal Data Density

VAR(1)		VAR(2)		VAR(3)		Model
Exact	Laplace	Exact	Laplace	Exact	Laplace	Laplace
-247.47	-248.32	-238.23	-240.50	-250.32	-254.75	-315.02

Notes: Marginal data density of Bayesian VARs with one to three lags under flat priors, using the Laplace approximation and the exact formula each. The model marginal data density is computed using the Laplace approximation.

a lag of order three. Judging from a purely statistical perspective, the data density does not come close to the data density of the non-structural competitors[29] although section 3.4 presented compelling economic evidence in the model's favor.

Table 12 contrasts the in-sample root-mean-squared forecast errors of the observable time-series when using the model (column two) with those obtained in a VAR(1) (column three). Apart from the RMSE for investment, the model in terms of forecast errors does not look too far apart

[29] Like in the estimation of the model, the VARs feature a long burn-in sample, from 1964:q1 to 1983:q4. They do not feature deterministics, i.e. especially no constant term.

Table 12: Model RMSE and Second Moments Compared to Data

Variable	RMSE (model)	RMSE (VAR)	std (model)	std (data)
$\widehat{y}_t$	0.55	0.46	1.71	1.61
$\widehat{c}_t$	0.41	0.33	1.33	1.15
$\widehat{R}_t$	0.11	0.11	0.47	0.38
$\widehat{\pi}_t$	0.23	0.20	0.38	0.24
$\widehat{i}_t$	1.81	1.33	5.92	6.39
$\widehat{h}_t+\widehat{n}_t$	0.46	0.30	1.59	1.20

Notes: The table compares root mean squared forecast errors of the model (in sample) at the posterior mode to those of a VAR(1) with flat priors at the posterior mode (second and third column). All values are computed from 1984q1 to 2005q4. The fourth to fifth columns compare the standard deviations of the observable variables implied by the model (column four) to those obtained from the data directly (column five). All variables are in logs, HP(100.000) filtered and multiplied by 100 in order to express them in percent deviation from trend. All data are in quarterly terms. From top to bottom: log output per capita, log consumption per capita log gross nominal interest rate, log gross GDP inflation rate, log investment per capita, log total hours worked. Investment includes durable consumption. Consequently, consumption is computed as non-durable consumption plus consumption of services.

from the VAR. Columns four and five of compare the unconditional standard deviations of the observable variables as implied by the model to those of the data.

E Alternative Wage Bargaining

This appendix is meant to rationalize our strike setup in the main text. The literature has entertained a variety of possible threat points in the bargaining process, each having its appeal. In this section, we follow Hall and Milgrom (2007) who argue that wages may not depend on market tightness since quitting the bargaining process towards being unemployed would simply not constitute a credible threat. Many assumptions have been made which yield similar wage equations although starting from fairly different economic assumptions about the bargaining process. For example, Pissarides (2006) assumes that the wage is a weighted average of firm revenue and fixed unemployment benefits, which in our notation, would give

$$w_t^{(o)} = \mu^{(o)} x_t^L A_t^{(o)} h_t^{(o)} + (1-\mu^{(o)}) b^{(o)}. \tag{76}$$

while Hall and Milgrom's assumptions rely on a threat point unrelated to unemployment benefits which results in

$$w_t^{(o)} = \mu^{(o)} x_t^L A_t^{(o)} h_t^{(o)} + (1-\mu) delay^{(o)} \tag{77}$$

where $delay^{(o)}$ is the worker's remuneration of delaying the bargaining process for a full period (in their case a day), see Hall and Milgrom (2007).[30]

To be more precise, we think of the *delay* above as strike money supplied by the family. That is the worker does not threaten to become unemployed as in the standard Nash-bargaining, but is threatening to put zero effort during one period. Both parties know that the wage negotiation will resume in the next period, unless exogenous separation occurs. Here the assumption of subgame perfection is crucially important. The formulation in above papers allows us to continue to rely on the same mechanism as in the main text, namely the one employed in Hagedorn and Manovskii (2006) and Jung (2006), who use a small match surplus to generate the right degree of unemployment volatility. As argued in the main text, the benchmark calibration achieves a small match surplus due to a high explicit or implicit replacement rate. This might lead us to seriously underestimate the costs of business cycles and, as pointed out in Hall and Milgrom (2007) and Costain and Reiter (2005a), to induce an over-reaction of employment to putative changes in unemployment benefits. We therefore follow Hall and Milgrom (2007) and assume that the outside option of the worker and firm is to delay the bargaining, not returning directly to non-employment. For our purpose, we focus on the implication for the final wage setting equation. We assume that workers receive strike pay (which we will label $b^{(o)} + strike^{(o)}$ to make clear the similarity to the setup entertained in the main text) during the bargaining process while the firm does not produce. In case the match is not separated, both parties reconvene in the next period. Note that the outside option of delay/strike will never occur in equilibrium. The strike money thus will not constitute a binding constraint on anybody's resources in equilibrium. It is not a coincidence that Hall and Milgrom (2007) implicitly choose a similar value of delaying as the outside option chosen by Hagedorn and Manovskii (2006). As shown in Jung (2005), crucial for the mechanism are small equilibrium profits such that the percentage deviations during the cycle are big.

[30] Note that Hall and Milgrom (2007) employ a different alternating offer bargaining game to rationalize the above equation, in particular for newly employed workers. However, the final reduced form wage equation would take a form like the one given above. Crucial to their argument is that a worker has a flow gain from delaying, while the firm has a flow cost of not producing.

The worker's surplus in the bargaining is

$$\Delta_t^{(1)} = \left(w_{i,t}^{(1)} h_{i,t}^{(1)} - \kappa^L \frac{\left(h_{i,t}^{(1)}\right)^{1+\varphi}}{\lambda_t(1+\varphi)} - b^{(1)} - strike^{(1)} \right). \tag{78}$$

The firm's surplus is

$$S_t^{(1)} = x_t^L A_t^{(1)} h_{i,t}^{(1)} - w_{i,t}^{(1)} h_{i,t}^{(1)}. \tag{79}$$

Note that both the firm's and the worker's surplus do not depend on the continuation value anymore. By assumption, future wages and hours are taken as given and beyond the control of workers and firms who bargain this period. Through this assumption of Markov-perfection the continuation values of the "delay" option and the agreement option are equal.

Nash bargaining over the surplus

$$\arg \max_{w_t^{(1)}, h_t^{(1)}} (\Delta_t^{(1)})^{\mu^{(1)}} (S_t^{(1)})^{1-\mu^{(1)}}, \tag{80}$$

results in the same first-order condition for hours worked as in our benchmark model:

$$\frac{\kappa^L \left(h_t^{(1)}\right)^{\varphi}}{\lambda_t} = x_t^L A_t^{(1)}.$$

And also the wage equation looks remarkably similar:

$$\begin{aligned} w_t^{(1)} h_t^{(1)} = & \quad \mu^{(1)} \left(A_t^{(1)} h_t^{(1)} x_t^L \right) \\ & + (1 - \mu^{(1)}) \left(b^{(1)} + strike^{(1)} + \tfrac{1}{1+\varphi} mrs_t^{(1)} h_t^{(1)} \right) \end{aligned} \tag{81}$$

The only term that is missing relative to the model entertained in the main text is the reference to market tightness. This is due to the fact that the outside option in the bargaining game is no longer unemployment but rather delaying the process of agreement. All other equations are unaffected.

This modeling choice makes the wage setting, which is the primary mechanism in our model for generating unemployment fluctuations, independent of the realized utility differential between employment and unemployment. By varying this difference we can provide bounds for business-cycle costs without running into Shimer's (2005) puzzle of low unemployment fluctuations.

For the liquidity-constrained consumers, the utility difference between employment and delaying now reflects the strike premium, changing to

$$\Delta \mathrm{u}(c_{e,t}^2, c_{t-1}, u_t^2, h_t^{(2)}) = \left[\frac{\left(c_{e,t}^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma} - \left(b^{(2)} + strike^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma}}{1-\sigma} - \kappa^L \frac{\left(h_t^{(2)}\right)^{1+\varphi}}{1+\varphi} \right].$$

The worker's surplus in the wage bargaining process changes to

$$\Delta_t^{(2)} \quad = \quad \Delta \mathtt{u}(c_{e,t}^{(2)}, c_{t-1}, u_t^{(2)}, h_t^{(2)}). \tag{82}$$

The firm's surplus is

$$S_t^{(2)} = x_t^L A_t^{(2)} h_t^{(2)} - w_t^{(2)} h_t^{(2)}. \tag{83}$$

The bargaining

$$\arg \max_{w_t^{(2)}, h_t^{(2)}} (\Delta_t^{(2)})^{\mu^{(2)}} (S_t^{(2)})^{1-\mu^{(2)}}, \tag{84}$$

results in a FOC for hours worked, which is unchanged relative to the benchmark

$$\kappa^L \frac{\left(h_t^{(2)}\right)^{\varphi}}{\lambda_t^{(2)}} = x_t^L A_t^{(2)},$$

while the FOC for the wage also does not reflect any continuation value anymore

$$\frac{\mu^{(2)} \left(\lambda_t^{(2)} w_t^{(2)} - \kappa^L \left(h_t^{(2)}\right)^{\varphi}\right)}{\Delta_t^{(2)}} = \frac{(1-\mu^{(2)})(w_t^{(2)} - x_t^L A_t^{(2)})}{J_t^{(2)}}. \tag{85}$$

This implies

$$\mu^{(2)} \left(x_t^L A_t^{(2)} h_t^{(2)} - w_t^{(2)} h_t^{(2)}\right) \quad = \quad \left(1-\mu^{(2)}\right) \quad \left(\frac{1}{\lambda_t^{(2)}} \frac{\left(c_{e,t}^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma} - \left(b^{(2)} + strike^{(2)} - \varrho^{(2)} c_{t-1}^{(2)}\right)^{1-\sigma}}{1-\sigma} - \kappa^L \frac{\left(h_t^{(2)}\right)^{1+\varphi}}{\lambda_t^{(2)}(1+\varphi)}\right).$$

Again, apart from the missing continuation value, the resulting wage equation is economically similar to our benchmark, and the underlying mechanism, making profits small and strongly procyclical, is the same.

F List of Symbols

F.1 Roman Lower Case

a : ratio of labor productivity in labor good firms of type 2 to those of type 1. $a \in (0, 1)$.

$b^{(o)}$: real unemployment benefits in group o.

$c_{i,t}^{(o)}$: consumption of individual i which belongs to group o.

$c_t^{(o)}$: consumption per capita in group o.

$c_{e,i,t}^{(1)}$: consumption of an employed asset-holding consumer i.

$c_{e,t}^{(2)}$: consumption of an employed liquidity-constrained consumer.

$c_{u,i,t}^{(1)}$: consumption of an unemployed asset-holding consumer i.

$c_{u,t}^{(2)}$: consumption of an unemployed liquidity-constrained consumer.

$\overline{d}$: target level for real government debt.

$\overline{g}$: target level for real government expenditure.

$h_{i,t}^{(o)}$: hours worked by individual i which belongs to group o.

$home_t^{(o)}$: home production of non-traded consumption good by an individual which belongs to group o.

i_t : investment per capita in asset-holding family.

k_t : capital stock at the end of t per capita of the asset-holding family.

$k_{j,t}$: demand for capital by firm j in wholesale sector.

l_t : total supply of the labor good.

$l_{j,t}$: demand for the labor good by firm j in wholesale sector.

$l_{i,t}$: production of labor good by firm i in labor good sector.

$m_t^{(o)}$: new matches of firms and workers of type o.

mc_t : real marginal cost in wholesale sector.

$n_t^{(o)}$: employment rate in group o.

o : index for type of consumer. $o = 1$: asset-holding consumer. $o = 2$: liquidity-constrained consumer.

$overhead_t^{(o)}$: fixed overhead production costs by a firm which belongs to group o.

$q_t^{(o)}$: probability of finding a worker of type o.

q_t^k : shadow value of installed capital.

r_t^k : real rental rate of capital.

$s_t^{(o)}$: probability of finding a job of type o.

$strike^{(o)}$: fixed parameter that pushes outside option of working in bargaining without influencing consumption, group o.

t_t : per capita lump-sum taxes.

t_t^{tot} : per capita total tax revenue.

u_t : economy-wide unemployment rate.

$u_t^{(o)}$: unemployment rate in group o.

$v_t^{(o)}$: vacancies for worker of type o.

$w_{i,t}^{(o)}$: real wage per hour earned by individual i in group o.

x_t^L : real price of the labor good.

y_t : GDP.

$y_{j,t}$: output of variety j of the differentiated good.

z_t : capacity utilization. Steady state: $z = 1$.

F.2 Roman Upper Case

$A_t^{(o)}$: labor productivity in labor good firms of type o.

D_t : nominal amount of risk-free bonds (government debt) held by asset-holding family per member of the family.

$J_t^{(o)}$: value of firm with a matched worker of type o.

P_t : consumption/GDP price index.

P_t^* : optimal price set by resetting wholesale firms.

$P_{j,t}$: price of one unit of variety j of differentiated good.

$\overline{\Pi}$: the central bank's inflation target.

R_t : nominal gross rate of return on bonds from t to $t+1$.

$S(\cdot)$: capital adjustment costs.

F.3 Greek Lower Case

α : elasticity of production with respect to capital in wholesale sector ($y_{j,t} = k_{j,t}^{\alpha} l_{j,t}^{1-\alpha}$). $\in (0,1)$.

β : time discount factor $\in (0,1)$.

$\beta_{t,t+s}$: stochastic real discount factor between t and $t+s$.

γ_D : response of tax revenue to deviations of government debt from debt target.

γ_g : response of tax revenue to deviations of government expenditure from target.

γ_p : degree of inflation indexation for firms which cannot update $\in [0,1]$.

γ_π : interest rate response to inflation in Taylor rule.

γ_R : interest rate response to lagged interest rate.

γ_u : interest rate response to unemployment in Taylor rule.

γ_y : interest rate response to output in Taylor rule.

$\gamma_{z,1}$: linear response of utilization cost to excess utilization.

$\gamma_{z,1}$: quadratic response of utilization cost to excess utilization.

δ : monthly rate of capital depreciation.

ϵ : elasticity of demand for wholesale good, $\epsilon > 1$.

ϵ_t^b : shock to risk-premium with steady state value of unity.

ϵ_t^C : "cost-push shock" with steady state value of unity.

ϵ_t^g : "goverment spending shock" with steady state value of zero.

ϵ_t^I : "investment shock" with steady state value of unity.

ϵ_t^{money} : "monetary policy shock" with steady state value of unity.

$\theta_t^{(o)}$: market tightness from the viewpoint of type o firms.

$\boldsymbol{\theta}$: vector of parameters (symbol used in estimation algorithm section).

$\vartheta^{(o)}$: monthly destruction rate of jobs of type o. $\vartheta^{(o)} \in (0,1)$.

κ^I : parameter governing slope of investment adjustment costs, $\kappa^I > 0$.

κ^L : scaling parameter to disutility of work.

$\kappa^{(o)}$: real costs of posting a vacancy for a worker of type o.

λ_t : marginal period utility of consumption of the family (and thus of asset-holders).

$\lambda_t^{(2)}$: marginal utilityof a liquidity-constrained worker of additional consumption when employed.

$\mu^{(o)}$: bargaining power of workers of type o. $\mu^{(o)} \in (0,1)$.

ν : share of asset holding households in the economy. $\nu \in (0,1]$.

$\xi^{(o)}$: elasticity of matches w.r.t. unemployment for type o workers. $\xi^{(o)} \in (0,1)$.

$\varrho^{(o)}$: degree of habit persistence for group o. $\varrho^{(o)} \in [0,1)$.

σ : degree of risk aversion. $\sigma > 0$.

$\sigma_m^{(o)}$: efficiency of matching for type o workers. $\sigma_m > 0$.

τ^L : labor tax rate.

φ : inverse of labor supply elasticity. $\varphi > 0$.

χ : $\chi = 1(0)$ indicates whether liquidity-constrained consumers do (do not) pay lump-sum taxes.

$\chi^{(2)}$: $\chi^{(2)} = 1(0)$ indicates whether liquidity-constrained consumers do pay for their own unemployment insurance.

$\psi(\cdot)$: capital utilization costs.

ω : probability that a wholesale firm cannot update its price, $\in [0, 1)$.

F.4 Greek Upper Case

$\Delta_t^{(o)}$: utility difference employment versus unemployment in group o.

Π_t : gross inflation rate from $t-1$ to t.

Ψ_t : dividends per capita accruing to asset-holding family.

Ψ_t^C : dividends per capita accruing to asset-holding family from entire wholesale sector.

$\Psi_{j,t}^C$: dividends per capita accruing to asset-holding family from firm j in wholesale sector.

$\Psi_t^{(o)}$: dividends accruing to asset-holding family from a typical labor firm of type o.

F.5 Typewriter Style

$\mathtt{u}^{(o)}(\cdot)$: period utility of an individual consumer of type o.

$\mathtt{U}(\cdot)$: aggregate period utility function of the representative family for optimal allocation of consumption among members.

$\mathtt{W}_t^{(1)}$: aggregate utility (welfare) of the representative asset-holding family.