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Three Essays on Macroeconomics with Incomplete Factor Markets

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Economics

by

Dmitry Plotnikov

2013

ABSTRACT OF THE DISSERTATION

Three Essays on Macroeconomics with Incomplete Factor Markets

by Dmitry Plotnikov

Doctor of Philosophy in Economics

University of California, Los Angeles, 2013

Professor Roger Farmer, Chair

This dissertation explores persistent unemployment dynamics in the U.S., alternative explanations for this phenomenon and potential policy implications. Chapter 1 develops and estimates a general equilibrium rational expectations model with search and multiple equilibria where aggregate shocks have a permanent effect on the unemployment rate. If agents' wealth decreases, the unemployment rate increases for a potentially indefinite period. This makes unemployment rate dynamics path dependent as in Blanchard and Summers (1987). I argue that this feature explains the persistence of the unemployment rate in the U.S. after the Great Recession and over the entire postwar period.

Chapter 2 conducts an empirical exercise to analyze which assumptions prevent a standard model from matching the persistence of the unemployment rate. I do this by using business cycle accounting procedure (Chari et. al. (2007)) on data in wage units (Farmer (2010)). I find that most movements in the unemployment rate are accounted for by the labor supply wedge. In other words, a standard model fits data badly because the assumption that households are on their labor supply is flawed. This finding is consistent with other papers in the literature. It also motivates assumptions that I make in my job market paper.

In Chapter 3, I with Roger Farmer focus on the persistent unemployment dynamics during the Great Depression. We explain the period between 1929 and 1950 within a single model which is driven by the stock market as a measure of consumer confidence. We document that the stock market measured by the S&P 500 and unemployment were moving closely between 1929 and 1939, but after 1939 the relationship between the two series seems to completely disappear. In particular, the stock market kept falling, but the employment rate recovered to the pre-recession level by 1942. Using our model we analytically study the effects of temporary bond-financed fiscal expansions that are similar to the actual data. We plug the actual data for the stock market and government expenditures from the Great Depression and WWII in the model and show that the model does a good job replicating consumption and unemployment dynamics during this period.

The dissertation of Dmitry Plotnikov is approved.

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Chapter 1

Hysteresis in Unemployment and Jobless Recoveries

1.1 Introduction

This paper addresses three questions. First, what caused the Great Recession? Second, why has the unemployment rate remained above 8% for more than 18 quarters since the official end of the recession? Third, how was this recession different from the other eleven post-war recessions?

To answer these questions I develop and estimate a general equilibrium rational expectations model with multiple equilibria, where non-fundamental demand shocks have a highly persistent effect on the unemployment rate. In my model, the unemployment rate exhibits hysteresis and is path-dependent in the sense of Blanchard and Summers (1986, 1987).[1] This result is in contrast to the widely accepted assumption that demand shocks do not have long-run effects on the unemployment rate (see Blanchard and Quah (1989); Long and Plosser (1983); Nelson and Plosser (1982) among others).

I find in my estimated model, that demand and supply shocks are both important in understand-

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[1]To my knowledge, very few papers argued in favor of this hypothesis. The major exception since 2000 is the paper by Ball (2009). This paper presents new empirical evidence from 20 countries that supports hysteresis in unemployment.

ing the dynamics of macroeconomic time series in the post-war period. I am also able to explain why the importance of persistent demand shocks has not been detected in earlier papers: they have a permanent effect on the unemployment rate and the real wage, but not on real output and its components.

The core of my model is a real version of the incomplete factor market model introduced in Farmer (2006). In Farmer's model unemployed households and potential employers engage in a random job search and matching process. The labor market is incomplete because there are no markets for inputs to the matching technology. Because factor markets are incomplete, the system that describes general equilibrium has one more unknown than the total number of equations. As a result, the model has a continuum of steady state equilibria.[2]

Instead of adding an extra equation for the wage (such as the Nash-bargaining equation), I assume that both firms and workers take the wage as given, as in a standard RBC model. I pick a particular equilibrium by adding a separate belief function that specifies how forward-looking households form self-fulfilling expectations about their wealth. This equation determines the aggregate demand for goods which, in turn, pins down output.

My model differs from Farmer (2010b, 2011a,b, 2012b) in two important ways. First, Farmer closes a model of this kind by specifying self-fulfilling beliefs about the stock market. In my model, there is no analog of the stock market. Instead, I adapt Friedman's (1957) work on adaptive expectations. In my model, households form expectations about their permanent income. As in Farmer (2002), adaptive expectations do not violate rationality of agents because of the multiplicity of equilibria.[3]

Second, in my model capital is reproducible. This assumption makes it possible to analyze the behavior of consumption and investment separately. Since these two series behave very differently

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[2]The multiplicity of steady state equilibria is the key difference between the model in this paper and the previous generation of endogenous business cycles models such as Farmer and Guo (1994) or Benhabib and Farmer (1994). These models exhibit dynamic indeterminacy but all dynamic paths converge to a single steady state. In contrast, the model I describe here has a continuum of steady states but a unique dynamic path that converges to each of them. In both types of models an independent expectations equation selects an equilibrium in every time period. For more details on comparison and evolution of the concept of indeterminacy see Farmer (2012a).

[3]Other papers that study when adaptive expectations can be rational include Evans and Honkapohja (1993, 2000).

in the data, this modification to Farmer's model is an important step towards an empirically relevant theory.

The equations of my model pin down the dynamic path of the economy given the transversality condition plus the initial belief about permanent income. But, the model still has a continuum of steady states because permanent income in every steady state coincides with GDP. The adaptive expectations equation uniquely determines the path of the economy, but the steady state that the economy eventually converges to, depends on the initial belief about permanent income.

My model features two sources of fluctuations - i.i.d. changes to perceived permanent income (demand) and standard persistent productivity (supply) shocks. I show that, even when driven by i.i.d. self-fulfilling belief shocks, the model can produce a high degree of persistence in the unemployment rate. This is in contrast to a standard RBC model where persistence in employment comes entirely from persistence in total factor productivity (TFP).

TFP shocks have a qualitatively similar, although more protracted, effect on the model economy than in a standard model. By protracted I mean that the economy experiences permanent effects following a productivity shock. By qualitatively similar, I mean that a positive productivity shock causes a large increase in real investment, a smaller increase in real output and a small increase in real consumption. TFP shocks act as a cyclical component in the model, and as I show in Section 1.5, they play an important role in explaining postwar dynamics.

I use a Bayesian estimation procedure to estimate the parameters of my model.[4] After I obtain estimates of all of the model parameters, I quantitatively describe the effect of each shock using impulse response functions. I show that together a TFP shock and a belief shock can reproduce the observed dynamics of the unemployment rate, output, consumption and investment for the entire post-war period, including the recovery from the Great Recession. By combining these two shocks in the right proportions, I am able to produce the characteristic business cycle dynamics of the first eight post-war recessions, as well as the jobless recoveries we have observed in the three recessions after 1990.

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[4]For a review of Bayesian methods see An and Schorfheide (2007). For applications see Fernandez-Villaverde and Rubio-Ramirez (2005a,b).

1.2 Model

This section builds a dynamic stochastic general equilibrium model. The distinguishing feature of the model is that households are not on their labor supply curve.[5]

My model deviates from existing models with multiple steady states in two dimensions. First, capital is reproducible. This lets me analyze the behavior of consumption and investment; two series that behave very differently in the data.

Second, because there is no analog of the stock market in my model, I do not close it with an exogenous sequence of asset prices as in Farmer (2012b). Instead, in Section 1.3, I adapt Friedman's (1957) work on the consumption function - I assume that households form adaptive expectations about their permanent income. As in Farmer (2002) because there is a multiplicity of equilibria, this assumption does not violate the rational expectations assumption.

A key advantage of closing the model with adaptive expectations is that it generates a feedback effect from the real economy to expectations of future income. Farmer (2012b) estimated a cointegrated VAR between the unemployment rate and the S&P 500 and found evidence of a significant negative short-run effect of increased unemployment on the stock market. This feedback channel is absent from previous incomplete factor models where the sequence of asset prices was assumed to be exogenous.

In my model, when GDP is high and the unemployment rate is low, agents revise up their perceived measure of permanent income. In response, they increase consumption demand, which in turn influences the real economy.

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[5]This assumption has both theoretical and empirical foundations. Theoretically, Farmer (2006) argues that the labor supply curve is missing because factor markets are incomplete. Kocherlakota (2012) refers to this feature as models of "incomplete labor markets". Empirically, Kocherlakota (2012) argues that labor supply equation is inconsistent with real wage, consumption and employment dynamics after the 2008 recession. In the companion paper to the current one, Plotnikov (2012) argues that the labor supply assumption is the most problematic of all assumptions made in a standard business cycle model. Justiniano *et al.* (2010) reach the same conclusion using a different dataset.

1.2.1 The household

Throughout this paper I use capital letters to denote nominal variables and lowercase letters to denote variables in physical units. There is a single representative household with a continuum of members. The household maximizes the expected discounted life-time utility of its members. All members of the household are perfectly insured against risks and thus they receive the same consumption value. Members derive utility from real consumption per household member and have no disutility from working.[6] I normalize the amount of time available to every member to one.

At every point in time t, a measure $l_t \in [0,1]$ of members is employed and the rest $u_t = 1 - l_t$ are unemployed. The assumption that there is no disutility from working implies that members spend all available time searching for a job. This, in turn, implies that all household members are in the labor force. As a result, all fluctuations in the equilibrium unemployment rate are due to agents dropping in and out of employment status and variation in the participation rate is absent in the model. Another implication of this assumption is that real consumption per household member corresponds to the real consumption per member of labor force in the data.

The one-period utility of the household is logarithmic:

$$u(c_t) = log(c_t).$$

Each employed member of the household earns nominal wage W_t per period so that the nominal labor income of the household is $W_t L_t$. The household accumulates physical capital k_t that it rents out to firms for the gross nominal rental rate R_t per period. This leads to the standard budget constraint in nominal terms:

$$C_t + I_t = R_t k_t + W_t l_t, \tag{1.1}$$

[6]Evidence from microeconometrics studies (see Blundell and MaCurdy (1999)) supports a labor supply elasticity that is close to zero.

where I_t is nominal investment and $C_t = p_t c_t$ is nominal consumption in period t per member of the labor force. The variable p_t represents the money price of the consumption good, also equal to the price of the investment good because consumption and investment are perfect substitutes. Capital depreciates at the rate δ per period and evolves according to the expression:

$$I_t = p_t(k_{t+1} - (1-\delta)k_t). \tag{1.2}$$

As in a standard RBC model the capital market is competitive: in equilibrium the gross real rental rate $r_t = \frac{R_t}{p_t}$ is such that the amount of capital supplied by the household is equal to the quantity of capital demanded by a representative firm. In contrast, the labor market does not clear every period. Household members engage in search activities and become employed according to the following equation:

$$l_t = \tilde{q}_t h_t. \tag{1.3}$$

Equation (1.3) states that if a measure $h_t \in [0,1]$ of agents searches for a job, $\tilde{q}_t h_t$ of them will find one, where $\tilde{q}_t$ is determined in equilibrium from the labor matching technology (described below) and is taken as given by the household.

The household discounts future utility with discount factor β. It takes wages and rental rates and as given and maximizes discounted lifetime utility $\sum_{s=t}^{\infty} \beta^{s-t} u(c_s)$ subject to equations (1.1), (1.2) and (1.3). The solution to the household's maximization problem can be summarized by two equations. The first one is the standard Euler equation expressed in nominal terms:

$$\left(\frac{p_t}{C_t}\right) = \beta E_t \left[\left(\frac{p_{t+1}}{C_{t+1}}\right)(1 - \delta + \frac{R_t}{p_t}) \right]. \tag{1.4}$$

Second, no disutility from working trivially implies that all household members will search for a job in equilibrium:

$$h_t = 1. \tag{1.5}$$

1.2.2 Firms

Consumption and investment goods are produced by representative firms using a CES technology with capital and labor as inputs:

$$\frac{Y_t}{p_t} = \left(a \cdot k_t^{\rho} + b \cdot s_t^{\rho} x_t^{\rho} \right)^{\frac{1}{\rho}}, \quad a + b = 1, \tag{1.6}$$

where Y_t is the nominal level of output, x_t is the amount of labor used in production of goods and s_t is a labor-augmenting TFP shock. The parameter ρ determines the elasticity of substitution between capital and labor:

$$\varepsilon_{k,l} = \frac{1}{1 - \rho}. \tag{1.7}$$

The parameter ρ is less than one. The value $\rho = 0$ corresponds to the Cobb-Douglas production function, $\rho = -\infty$ corresponds to a Leontief technology and $\rho = 1$ is a linear technology. There are two main reasons why this specification is preferred to the standard Cobb-Douglas case. First, there is evidence in the literature (see, for example, Klump *et al.* (2007)) that the elasticity between capital and labor is significantly below unity and close to 0.5. Second, a Cobb-Douglas production function implies a constant labor income share. As I show in the companion paper Plotnikov (2012), the labor income share is strongly procyclical in the data. A CES production function helps to explain this observation.

A representative firm solves the following problem every period:

$$\max_{x_t, l_t, k_t} \left(a \cdot k_t^{\rho} + b \cdot s_t^{\rho} x_t^{\rho} \right)^{\frac{1}{\rho}} - \frac{W_t}{p_t} l_t - \frac{R_t}{p_t} k_t, \tag{1.8}$$

$$s.t.$$

$$x_t + v_t = l_t, \tag{1.9}$$

$$q_t v_t = l_t. \tag{1.10}$$

Equation (1.9) states that workers, l_t, hired by the firm can be allocated to one of two tasks: they can produce goods, x_t, or work in the human resources department, v_t. Both types of workers earn the same real wage, $\frac{W_t}{p}$, which the firm takes as given along with the interest rate, $\frac{R_t}{p_t}$.

The hiring process works as follows. A firm can hire as many job applicants as it wants at the real wage $w_t = \frac{W_t}{p_t}$, however not all applicants are suitable to work at the firm. For this reason firm needs to screen potential employees using the human resources department, v_t. The variable q_t represents screening efficiency, which the firm takes as given.

Equation (1.10) states that the resulting number of employees at the firm, l_t, is equal to the number of people in the hiring/human resources department, v_t, augmented by the screening efficiency, q_t.[7] The screening efficiency of each worker, q_t, is determined in equilibrium by the aggregate matching technology. It depends on how many firms are looking to hire new workers at the same time. If many firms are searching, it is harder for each firm to find the necessary number of workers and q_t will be low. In contrast, if very few firms are searching, q_t will be high. In other words, equilibrium screening efficiency is a function of the aggregate unemployment rate.[8]

The firm's problem (1.8)–(1.10) can be reduced to the following:

$$\max_{l_t k_t} \left(a \cdot k_t^\rho + b \cdot s_t^\rho l_t^\rho \Theta_t^\rho \right)^{\frac{1}{\rho}} - \frac{W_t}{p_t} l_t - \frac{R_t}{p_t} k_t,$$

---

[7]Equation (1.10) implicitly makes a strong assumption that all workers are laid off in the end of each period. I intentionally make this assumption to show that the model can generate high persistence in the unemployment rate even without assuming that employment is a state variable. See beginning of the next subsection for further discussion.

[8]Equation (1.10) also implies that hiring costs are expressed in terms of labor units and not in terms of output as in standard labor search models. This assumption is not essential and is made for simplification.

where I define $\Theta_t = \left(1 - \frac{1}{q_t}\right)$ to be the externality that emerges from the labor search friction. Note that a high screening efficiency, q_t, implies a high value of Θ_t whereas a low value of q_t implies a low value of Θ_t.

The first order conditions for profit maximization of the firm are:

$$\frac{R_t}{p_t} = a\left(\frac{Y_t}{p_t k_t}\right)^{1-\rho}, \tag{1.11}$$

$$\frac{W_t}{p_t} = b s_t^\rho \Theta_t^\rho \left(\frac{Y_t}{p_t l_t}\right)^{1-\rho}. \tag{1.12}$$

These first order conditions have the standard intuition: the marginal product of capital (labor) is equal to the real rental rate (the real wage) respectively.[9] This implies that firms always make zero profit in equilibrium, independent of externality level Θ_t.[10]

1.2.3   Search in the labor market

The variables q_t, $\tilde{q}_t$ and Θ_t are determined in equilibrium and depend on aggregate activity levels. To distinguish aggregate from individual variables, I put bars over variables to denote the aggregate level of activity. For example, l_t represents the number of people employed by an average representative firm (the firm's choice variable) whereas $\bar{l}_t$ represents the aggregate level of employment (the individual firm does not have control over it). Because all firms and household members are

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[9]Notice that if $\rho = 0$ both equations reduce to the standard Cobb-Douglas case: income shares of both inputs are constant and equal to a for capital and b for labor.

[10]By definition, the income shares of capital and labor are:

$$(Capital\,share)_t = \frac{R_t k_t}{Y_t}$$
$$(Labor\,share)_t = \frac{W_t l_t}{Y_t}$$

Notice that these shares are not constant in the general CES case (except for the Cobb-Douglas case, $\rho = 0$) and depend on the current level of income and both inputs. Additionally, the labor income share is affected by the externality in the labor market, Θ_t and the labor productivity s_t. This feature of the CES technology can partially explain procyclicality in the labor income share in the data (see previous section). On the other hand, this mechanism is not central to the paper and does not substantially improve the performance of a standard model.

the same, in equilibrium these two concepts coincide, but it is important to distinguish between them.

I assume that labor is rehired every period. This implies that the number of matches every period, m_t, is equal to the aggregate number of people employed, $\bar{l}_t$.[11] I make this assumption for two reasons. First, it makes the dynamic system of equations of my model similar to a standard RBC model (see the next subsection for details). Second, assuming that all workers are rehired every period allows me to find a closed-form solution for Θ_t as a function of the aggregate employment level $\bar{l}_t$.[12]

The aggregate number of matches between firms and workers is determined according to the following Cobb-Douglas matching technology:

$$m_t = (\Gamma \bar{v}_t)^\theta \bar{h}_t^{1-\theta}, \qquad (1.13)$$

where Γ is a scale parameter and θ is the elasticity of the matching function with respect to the aggregate number of recruiters, $\bar{v}_t$. As in a standard labor search model,

$$q_t = \frac{m_t}{\bar{v}_t}, \quad \tilde{q}_t = \frac{m_t}{\bar{h}_t}. \qquad (1.14)$$

Equations(1.3), (1.5) and (1.10) along with definitions for q_t, $\tilde{q}_t$ (Equations (1.14)) imply the following expressions for q_t and $\tilde{q}_t$:

$$q_t = \frac{\Gamma}{\bar{l}_t^{\frac{1-\theta}{\theta}}}, \quad \tilde{q}_t = \bar{l}_t. \qquad (1.15)$$

One can also derive the following expression for the externality term Θ_t :

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[11] In contrast, the standard practice in the labor literature is to assume that employment is a state variable (see for example Rogerson *et al.* (2005)).

[12] Even when the employment level is a state variable, the standard model generates a very low persistence of the unemployment rate. In contrast, my model produces a highly persistent unemployment rate even without this assumption. In general, making employment a state variable will not worsen performance of the model. Farmer (2011a) builds a similar model where employment is a state variable and shows that none of the results depend on this simplification.

$$\Theta_t = \left(1 - \frac{1}{q_t}\right) = \left(1 - \frac{\bar{l}_t^{\frac{1-\theta}{\theta}}}{\Gamma}\right). \tag{1.16}$$

Notice that the externality term Θ_t is a decreasing function of the aggregate level of employment. Intuitively, since all firms search for workers in the same pool, it is harder to fill a vacancy if all firms exert higher search effort simultaneously.

This expression for Θ_t leads to the following aggregate production function for the economy:

$$\bar{y}_t = \left(a\bar{k}_t^\rho + bs_t^\rho \bar{l}_t^\rho \left(1 - \frac{\bar{l}_t^{\frac{1-\theta}{\theta}}}{\Gamma}\right)^\rho\right)^{\frac{1}{\rho}}. \tag{1.17}$$

In contrast to a standard Cobb-Douglas production technology, this production function has an inverted U-shape for a fixed $\bar{k}_t$ and reaches peak at l^*, where

$$l^* = (\theta\Gamma)^{\frac{\theta}{1-\theta}}. \tag{1.18}$$

The level of employment l^* corresponds to the socially optimum level of employment. A social planner that maximizes the discounted stream of household's utility functions subject to the matching and production technologies would choose this employment level in every time-period. Intuitively, l^* does not depend on the capital stock or on time t, because employment is an intratemporal decision variable for the social planner. Later, I use Equation (1.18) to calibrate the scale parameter Γ in the estimation procedure.

1.2.4 Equilibrium

To sum up, the equilibrium of the model is represented by the following set of equations:

$$\left(\frac{p_t}{C_t}\right) = \beta E_t \left[\left(\frac{p_{t+1}}{C_{t+1}}\right)\left(1 - \delta + a\left(\frac{Y_{t+1}}{p_{t+1}k_{t+1}}\right)^{1-\rho}\right)\right], \tag{1.19}$$

$$C_t + I_t = Y_t, \tag{1.20}$$

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$$I_t = p_t(k_{t+1} - (1-\delta)k_t), \tag{1.21}$$

$$\left(\frac{Y_t}{p_t}\right)^\rho = ak_t^\rho + bs_t^\rho l_t^\rho \left(1 - \frac{l_t^{\frac{1-\theta}{\theta}}}{\Gamma}\right)^\rho, \tag{1.22}$$

$$\frac{W_t}{p_t} = bs_t^\rho \left(1 - \frac{l_t^{\frac{1-\theta}{\theta}}}{\Gamma}\right)^\rho \left(\frac{Y_t}{p_t l_t}\right)^{1-\rho}, \tag{1.23}$$

where I have substituted expressions for the rental rate (1.11) into the Euler equation (1.4) and the expression for the externality term Θ_t (Equation (1.16)) into the production function (Equation (1.6)) and the first order condition for labor for a firm (Equation (1.12)). Equations (1.19)–(1.21) are the same as in any standard RBC model. Equations (1.22)–(1.23) include the externality term $\Theta_t = \left(1 - \frac{l_t^{\frac{1-\theta}{\theta}}}{\Gamma}\right)$ which is absent from the standard RBC model. Finally, my model does not have a labor supply equation.

Because the system of equations (1.19)–(1.23) is written in nominal terms, I am free to choose a numeraire. Since I use data measured in wage units, it is convenient to pick the nominal wage to be a numeraire.

$$W_t = 1. \tag{1.24}$$

This normalization implies that p_t is the inverse of the real wage. Assuming a standard autoregressive process for TFP in logs gives an additional equation:

$$s_t = s_{t-1}^\lambda exp(\varepsilon_t^p), \qquad \varepsilon_t^p \sim N(0, \sigma_\varepsilon^2), \tag{1.25}$$

The parameter λ captures the persistence of labor productivity and ε_t^p represents the innovation to this process. The seven equations (1.19)–(1.25) jointly determine the eight-dimensional vector of unknowns:

$$X_t = \left[s_t, k_{t+1}, p_t, C_t, I_t, Y_t, l_t, W_t \right].$$

The model has one more unknown than the total number of equations because the market for search intensity of workers and vacancies posted by the firms is missing. This makes the model incomplete and, without an additional assumption to pin down the steady state, the system (1.19)–(1.25) has a continuum of steady state equilibria, each associated with a unique steady state employment level $l_{ss} \in (0,1]$. Only one of these equilibria is socially efficient (see Equation (1.18)).

To see which variables are determined by the seven equations (1.19)-(1.25) I evaluate the system at a steady state. Equation (1.25) gives the steady state productivity level $s_{ss} = 1$. The Euler equation (1.19) pins down the ratio of output to investment in wage units in every steady state,

$$\frac{Y_{ss}}{I_{ss}} = \frac{1}{\delta} \left(\frac{\frac{1}{\beta} - (1-\delta)}{a} \right)^{\frac{1}{1-\rho}},$$

and as a consequence of the national accounts identity (1.20) the ratio of consumption to output in wage units is determined by the expression,

$$\frac{C_{ss}}{Y_{ss}} = 1 - \delta \left(\frac{a}{\frac{1}{\beta} - (1-\delta)} \right)^{\frac{1}{1-\rho}}. \tag{1.26}$$

The existence of a multiplicity of steady state employment levels is not new in the labor search literature and is usually resolved by adding an extra equation to the system. This equation is *in-dependent* of the rest of the model and is often represented by a wage equation that determines how the surplus is split between a matched firm and a matched worker. The best known assumptions used in the literature are the Nash-bargaining equation (originally proposed in the original Diamond-Mortensen-Pissarides framework) and the sticky wage assumption (see, for example, Shimer (2012), Blanchard and Gali (2008), Hall (2005)). Recently Farmer (2011b) proposed that the model should be closed by specifying an exogenous sequence of asset prices.

1.3 Closing the model

In this paper I extend Farmer (2011b). I add a belief function as a new independent fundamental that resolves the indeterminacy of dynamic equilibrium paths. The way I do this is new. By using adaptive expectations, I am able to explain how demand and supply shocks feedback into beliefs and influence the future path of unemployment, output, consumption, investment and the real wage.

In my model, consumption depends on permanent income.[13] To incorporate this idea I adapt Friedman's (1957) work on the consumption function. There, Friedman argued that consumption is proportional to permanent income:

$$C_t = \phi Y_t^P, \tag{1.27}$$

and he assumed that expectations of permanent income are formed adaptively,

$$Y_t^P = (Y_{t-1}^P)^{\chi} Y_t^{1-\chi} exp(e_t^b) \quad \varepsilon_t^b \sim N(0, \sigma_b^2). \tag{1.28}$$

In Equation (1.28), Y_t^P is permanent income and χ measures the speed of adjustment of permanent income to new information. The term e_t^b represents an independent shock to beliefs. This shock can be interpreted as a non-fundamental demand disturbance ("animal spirits"). I show later that it has a permanent effect on both output in wage units and the unemployment rate. I refer to equations (1.27) and (1.28) as the permanent income hypothesis (PIH).

It is important to note that the belief function specified in Equations (1.27) and (1.28) does not violate the assumption of rational expectations. I*n the case when there is a continuum of equilibria, the expectations equation selects an equilibrium in every time period.*

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[13]Several recent papers pointed out the significance of wealth, in particular stock market and housing wealth, in the consumption decision. Ludvigson and Lettau (2004) pointed out that there is a low frequency relationship between consumption and asset wealth. Farmer (2012b) documented a similar relationship between consumption and S&P 500 index measured in wage units.

1.3.1 Steady State vs Dynamic Indeterminacy

To find when the adaptive expectations of permanent income are consistent with rational expectations, I evaluate Equations (1.27) and (1.28) at a steady state. Equation (1.28) implies that in every non-stochastic steady state, permanent income coincides with the economy's GDP, $Y_{ss}^P = Y_{ss}$. Because equation (1.27) has to hold in every steady state, it restricts the parameter ϕ to be the ratio of steady state consumption C_{ss} to the steady state level of income Y_{ss} as implied by equations (1.19)–(1.21).

Thus, as a consequence of the rational expectations assumption, ϕ has to be the following function of the other parameters (see equation (1.26)):[14]

$$\phi \equiv 1 - \delta \left(\frac{a}{\frac{1}{\beta} - (1 - \delta)} \right)^{\frac{1}{1-\rho}}. \tag{1.29}$$

Under condition (1.29), equations (1.27) and (1.28) are consistent with the system of equations (1.19)–(1.25). At the same time these two equations add no additional information about a steady state, and, as a consequence any unemployment rate can be a steady state equilibrium.

On the other hand, the belief function, in the form of the permanent income hypothesis, does resolve dynamic indeterminacy. By this I mean that Equations (1.27) and (1.28), together with the previously derived dynamic system of equations (1.19)–(1.21), pin down the model dynamics for a given set of initial conditions:

$$k_0 = \bar{k}_0, \tag{1.30}$$

$$s_0 = \bar{s}_0, \tag{1.31}$$

$$\lim_{T \to \infty} E_t \left(\beta^T \frac{k_T}{c_T} \right) = 0, \tag{1.32}$$

$$Y_0^P = \bar{Y}_0^P. \tag{1.33}$$

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[14] The necessity of this condition was first introduced by Muth (1961). There, the author showed that adaptive expectations about output are rational under specific restrictions on the speed of adjustment and on the output process, which, in his model, has to be ARIMA(0,1,1).

The first three boundary conditions are standard and are implied by the initial value of capital, the initial level of labor augmenting technology process and the transversality condition. The last condition is required because permanent income Y_t^P is a new state variable.

In every steady state, permanent income coincides with current income ($Y_{ss}^P = Y_{ss}$). At the same time, initial permanent income, Y_0^P, is required to pin down the model dynamics. This means that the model exhibits hysteresis as in Blanchard and Summers (1986, 1987), and initial beliefs about permanent income Y_0^P determine the steady state to which the model will converge. It also makes the model dynamics path-dependent.

1.4 Estimation

1.4.1 Overview

In this section I estimate the parameters of the model using Markov Chain Monte Carlo (MCMC). As an outcome of the procedure I obtain not only point estimates of all parameters of the model but also standard errors and the posterior distribution for each of the parameters.

I assume that I observe three series - the civilian unemployment rate, output in wage units and investment in wage units in quarterly data for the entire postwar period 1948:1 - 2011:4.[15] The model counterparts for these series are the variables $1 - l_t$, Y_t and I_t.

Bayesian estimation requires either that the number of shocks in the equations to be greater or equal to the number of observed series or that some of the variables are observed with measurement error. Because of this, I introduce a wedge ε_t^{LD} in Equation (1.23). Then first order condition for the firm after normalization (1.24) becomes

$$1 = b \cdot exp(\varepsilon_t^{LD}) p_t s_t^\rho \left(1 - \frac{l_t^{\frac{1-\theta}{\theta}}}{\Gamma} \right)^\rho \left(\frac{Y_t}{p_t l_t} \right)^{1-\rho} \tag{1.34}$$

There are two reasons why inserting a wedge in Equation (1.23) is a good idea. First, if $\rho = 0$,

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[15]The data was constructed as in Farmer (2010b). In the next section I present summary statistics and plot these series.

Equation (1.23) implies constant labor income share and that output in wage units is proportional to the employment rate. Because output in wage units and the employment rate are not exactly proportional in the data, the absense of this wedge creates a stochastic singularity. Second, in Plotnikov (2012) I found that the labor income share is highly countercyclical, although not very volatile. Since $\rho = 0$ implies constant labor income share, inserting a wedge in Equation (1.23) is a way to evaluate how much of labor income share cyclicality can be explained by a CES production technology. In the same paper I argued that Equation (1.23), when $\rho = 0$, is the second most problematic equation based on the outcome of the accounting procedure of the type described in Chari *et al.* (2007).

The solution to the model is standard except for one detail. Because there is no unique steady state, I can choose a steady state around which to log-linearize the model. I picked the obvious candidate – the steady state associated with long-run statistical mean of the civilian unemployment rate in the data – 5.7%.[16] This is the same steady state around which all DSGE models with unemployment are linearized. Thus the choice of this steady state eliminates potential differences due to the linear approximation between my model and any other DSGE model with unemployment.[17]

After the equations of the model have been linearized, I solve them using the methods developed in Sims (2001). This brought the system to the form

$$X_t = F \cdot X_{t-1} + G\varepsilon_t, \tag{1.35}$$

$$OBS_t = H \cdot X_t, \tag{1.36}$$

where $X_t = \left[\tilde{s}_t, \tilde{k}_{t+1}, \tilde{p}_t, \tilde{C}_t, \tilde{I}_t, \tilde{Y}_t, \tilde{l}_t, \tilde{Y}_t^p, E_t\tilde{C}_{t+1}, E_t\tilde{Y}_{t+1}\right]$ is a vector of state variables (a tilde over a variable denotes a log deviation from the steady state), $OBS_t = [Y_t^{obs}, I_t^{obs}, u_t^{obs}]$ is a vector of observables and $\varepsilon_t = [\varepsilon_t^p, \varepsilon_t^b, \varepsilon^{LD}]$ represents innovations to productivity and beliefs. The index t

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[16]The results of the model are not sensitive to this choice.

[17]Recall that, in contrast to standard models, this steady state does not correspond to the socially optimum steady state. The expression for the socially optimal steady state is given by Equation (1.18).

represents the time period and ranges from 1948:1 to 2011:4 – the maximum timespan available for the data series considered. The matrices F, G and H are nonlinear functions of the underlying parameters of the model.

Equation (1.35) contains the estimated linearized policy functions and the functions that describe how expectations about the future are formed based on the state vector X_{t-1}. Equation (1.36) links the observed series to their model counterparts.

I constructed the likelihood for every set of parameters by treating the first equation as if it were the true data generating process. Since OBS_t contains fewer variables than X_t , in order to construct the likelihood of a set of parameters, I used the Kalman filter to construct forecasts of all the underlying variables, X_t, given the observed variables $\{OBS_s\}_{s=0}^t$.[18] For this, I used the algorithms that are part of the open source MATLAB package DYNARE (See Adjemian *et al.* (2011)).

Then, I combined prior distributions of all parameters with the maximized likelihood function to obtain a posterior likelihood. I computed posterior distributions numerically using the random walk Metropolis-Hastings algorithm (MCMC). I made 100,000 draws and kept 50,000 of them to ensure independence from the starting point. Further details on the computational procedure can be found in An and Schorfheide (2007).

1.4.2 Priors

To estimate the parameters of the model using Bayesian maximum likelihood, I need to specify priors for all of the parameters of the model. The priors I used are summarized in Table 1.1.

I chose the prior mean of the parameter a in the CES production function to be close to the calibration value in the Cobb-Douglas case.[19] Instead of estimating the parameter ρ directly, I estimate the elasticity between capital and labor $\varepsilon_{k,l}$. Because of the one-to-one relationship

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[18]Since the matrix F always has a unit eigenvalue, I use the diffuse Kalman filter. Because the state space model (1.35) is non-stationary, the initial value for the filtering procedure matters. First introduced in Jong (1991) and later developed in Koopman (1997); Koopman and Durbin (2000), the diffuse Kalman filter addresses this problem.

[19]Recall, that if the production technology is CES, the capital share is not constant and depends on the current physical level of output and capital.

between the two (Equation (1.7)), any statistic characterizing a posterior distribution of ρ can be inferred from a posterior distribution of $\varepsilon_{k,l}$. Recent evidence in the literature (see for example Klump *et al.* (2007)) indicates that the elasticity between capital and labor can be significantly below unity and is close to 0.5. Taking this into account I set the prior for $\varepsilon_{k,l}$ to be as wide as possible with a mean of 0.5.

Parameter	Description	Distribution	Prior mean	Std. Dev.
a	$\approx$Capital share (= if $\rho = 0$)	beta	0.33	0.15
$\varepsilon_{k,l}$	Elasticity b/w capital and labor	beta	0.50	0.25
δ	Capital depreciation	beta	0.03	0.015
β	Discount factor	Fixed	0.99	–
u^*	Optimal unemployment rate	Fixed	0.045	–
λ	Labor productivity persistence	beta	0.90	0.05
χ	Expectations persistence	beta	0.90	0.05
θ	Elasticity of the matching function	beta	0.5	0.25
σ^p	St.dev. of ε^p	Inv. Gamma	0.02	0.01
σ^b	St.dev. of ε^b	Inv. Gamma	0.02	0.01

Table 1.1: Prior distributions of parameters of the model

The discount factor β is fixed at 0.99. This parameter is not identified in the data. The choice of 0.99 corresponds to the long-run annual interest rate of 4%. I picked the value for the scale parameter Γ in the matching function so that the optimal unemployment rate, u^*, is 4.5% as in Hall (2011). Intuitively, the socially optimal unemployment rate should be lower that the long-term average and somewhat close to it.[20]

For the rest of the parameters I chose somewhat wide priors. The prior mean for the persistence in the labor productivity process, λ, is 0.9. I picked the prior mean for the quarterly capital depreciation rate to be 0.03 which corresponds to an annual depreciation rate of 12%. The prior mean of the speed of adjustment of adaptive expectations is 0.8 - the same as the equilibrium persistence in Evans and Ramey (2006).

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[20]Because l^* depends on both Γ and θ, every time I evaluate the likelihood for a given set of parameters, I choose Γ so that Equation (1.18) is satisfied for the given value of θ and the fixed value of u^*. The results of the model do not depend on the value of Γ as long as $\bar{l} < l^*$. This inequality is not restrictive and follows from the inverted U shape of the production function as a function of labor, l_t for a fixed capital stock (see Equation (1.17)). The peak of this function corresponds to the value l^*. The point at which the model is linearized, $\bar{l}$, should be on the increasing part of this function to ensure that increasing the number of workers leads to an increase in production.

Estimates of the elasticity of the matching function, θ, range significantly in the literature - from 0.28 in Shimer (2005) to 0.54 in Mortensen and Nagypal (2007). Farmer (2012b) fixes θ at 0.5. Taking this into account I set the prior mean at 0.5 with a standard deviation of 0.25.

I picked the prior mean for the standard deviation of the productivity innovations to be 2% from the steady state – the standard calibration value for TFP process. I picked the same prior mean for the standard deviation of belief shocks, σ^b, and the labor demand shock, σ^{LD}. For all of the parameters I chose prior standard deviations that are as large as possible, given the means and the natural limits of the parameters.[21]

1.4.3   Posterior estimates

The outcome of the MCMC algorithm is presented in Table 1.2. For every parameter I report the prior mean, the posterior mean and the 90% posterior confidence interval centered around the posterior mode. All estimates are stable with respect to the choice of priors. Changing a prior mean or a standard deviation for one or several parameters does not change the posterior estimates.

The posterior means of all model parameters have reasonable values. Parameter a of the CES production function is estimated to be 0.4585. Recall that in a general CES case, $1 - a$ is not equal to the labor income share. To see that $a = 0.4585$ corresponds to a standard value of the labor income share, I calculate the labor share at the steady state that corresponds to the long-run statistical average of the unemployment rate, $\bar{u} = 5.7\%$. Solving for the steady state level of output $\bar{Y}$ that corresponds to $\bar{u}$ implies a standard value of the labor income share at this steady state of 0.65.[22]

The estimated elasticity between capital and labor $\varepsilon_{k,l}$ is equal to 0.92 and implies that the other parameter of the CES production function, ρ, equals -0.089 (see Table 1.2 and Equation (1.7)). Together the estimates for a and ρ imply that the U. S. economy can be well approximated

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[21]A rule of thumb that ensures bell-shaped prior distributions with no positive probability mass on either end of the support requires the distance between the prior mean and the closest natural limit to be less than two standard deviations.

[22]The labor share in this case can be calculated as $\frac{1-\bar{u}}{\bar{Y}}$, where $\bar{Y}$ is the level of output in wage units that corresponds to $\bar{u}$.

by a Cobb-Douglas function.[23] This finding contrasts with the recent evidence by Klump *et al.* (2007) who found that the elasticity between capital and labor is significantly less than unity in the U.S. aggregate data.

Parameter	Description	Posterior mean	$CI_{90\%}$
a	$\approx$Capital share (= if $\rho = 0$)	0.4585	[0.3929, 0.5212]
$\varepsilon_{k,l}$	Elasticity b/w capital and labor	0.9209	[0.8804, 0.9611]
δ	Capital depreciation	0.0082	[0.0079, 0.0086]
β	Discount factor	–	–
u^*	Optimal unemployment rate	–	–
λ	Labor productivity persistence	0.9175	[0.8784, 0.9531]
χ	Expectations persistence	0.9513	[0.9223, 0.9820]
θ	Elasticity of the matching function	0.6284	[0.3680, 0.8920]
σ^p	St.dev. of ε^p	0.0156	[0.0141, 0.0172]
σ^b	St.dev. of ε^b	0.0082	[0.0076, 0.0089]
σ^{LD}	St.dev. of ε^{LD}	0.0245	[0.0227, 0.0263]
$log L = 2101$	MCMC accept. rate 32.84%	100000 draws	50000 kept

Table 1.2: Posterior distributions of parameters of the model.

The capital depreciation rate is estimated to be approximately 3.3% per year. Even though depreciation rate values used in the literature are usually higher, my estimate coincides with Bureau of Economic Analysis estimates on the depreciation rate of physical capital (see Nadiri and Prucha (1997) for an overview).

These three parameters – a, ρ, δ – together with the discount factor β imply that households consume 84% of their permanent income (see Equation (1.26) for the formula). This number is in line with the original estimate of 90% in Friedman (1957).

The next two parameters in Table 1.2 are persistence in labor productivity process, λ and the speed of adjustment of adaptive expectations χ that have posterior means of 0.92 and 0.95. As expected, both parameters imply sufficient persistence in these two processes. At the same time both posterior means are far from unity. In contrast to the standard model where persistence in the simulated series comes from persistent shocks, my model does not require highly persistent shocks and belief shocks are, in fact, i.i.d. .

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[23]Recall that Cobb-Douglas case corresponds to $\varepsilon_{k,l} = 1$ and $\rho = 0$.

Finally, the elasticity of the matching function, θ, is not well identified in the data. This is expected given the wide range of estimates of this parameter in the literature. The reported confidence interval contains values from 0.4 to 0.9.

The lower half of Table 1.2 presents estimates of the standard deviation of the realized shocks. All posterior standard deviations are relatively small. The standard error of the technology shock is estimated to be 1.6% , even lower than its standard calibration value of 2%. The standard deviation of the belief shocks is even smaller – less than 1%.

The low standard deviation for belief shocks means that non-fundamental disturbances do not need high volatility to explain the data. The low standard deviation for labor productivity innovations suggests that belief shocks explain a share of the observed volatility in the data that is usually attributed to TFP shocks.

In Figure 1.1 I plot posterior densities for all the estimated parameters, together with the prior distributions. This figure shows that all of the parameters are identified. If a parameter were to be weakly or non-identified the difference between its prior and posterior densities would have been small. In contrast, all posterior densities, except for the one for θ, differ significantly from their respective priors, indicating that these parameters are identified. The posterior density for θ does not differ much from its prior distribution, which suggests that the data does not contain much information about this parameter.

1.5   Taking the model to the data

In this section I perform three exercises. First, I show that my model matches the stylized facts. Second, I explain the mechanism behind the model's performance and the contribution of each shock qualitatively. Finally, I present impulse response functions that clarify the effect of each shock on the economy.
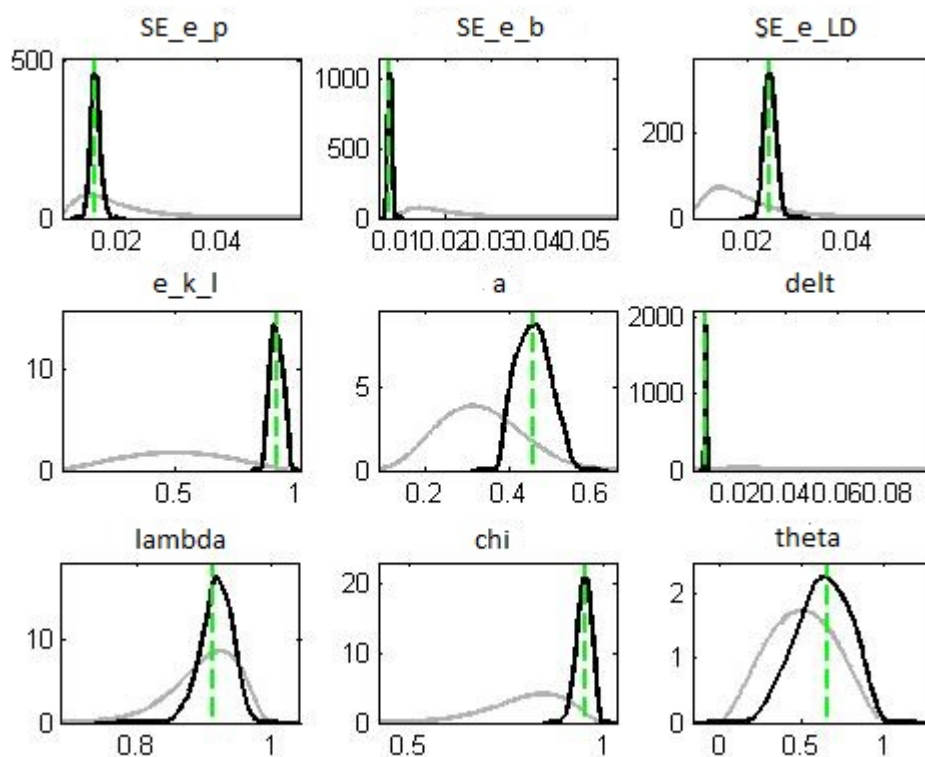
Figure 1.1: Posterior distributions. Grey line represents prior density. Dark line represents posterior density. Dashed line is estimated mode of the posterior density. SE stands for standard error.

1.5.1 Model performance

I perform the following exercise. I use my model to simulate $R = 10000$ Monte-Carlo samples of the same length as the length of the data sample ($T = 256$ observations) using randomly drawn productivity and belief shocks. I report the Monte-Carlo average and 90% Monte-Carlo confidence interval centered around the average of each statistic of interest (such as the standard deviation, persistence of consumption, investment, etc).[24]

Next, I compare each summary statistic of the data with its Monte-Carlo average.[25] The Monte-Carlo confidence interval represents the dispersion of a statistic across R Monte-Carlo samples.

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[24] The Monte-Carlo moments I report do not change once the number of simulated samples exceeds 5000. I take $R = 10000$ to eliminate even small changes.

[25] For example, I compare the standard deviation of investment to the Monte-Carlo average of the standard deviations of the simulated investment series.

X_t	$Std(X_t)$ Simulations MC Avg. $CI_{90\%}$	Data	$Corr(X_t, X_{t-1})$ Simulations MC Avg. $CI_{90\%}$	Data	Unit Root? Simulations MC Share of unit root	Data p-value of unit root
I_t	14.468 [10.883,18.017]	12.363	0.904 [0.858,0.950]	0.904	0.0022	0.0001
C_t	5.589 [2.319,8.849]	5.648	0.981 [0.963,0.999]	0.988	0.7358	0.3407
Y_t	6.007 [2.831, 9.173]	3.730	0.968 [0.942,0.997]	0.966	0.5167	0.0307
l_t	5.972 [2.784,9.149]	1.767	0.971 [0.942,0.997]	0.970	0.5518	0.0758

Table 1.3: Summary statistics of the simulated and the real data. All series are measured in log-deviations from their statistical means. MC=Monte-Carlo.

Fixing sample size and taking a sufficiently large R gives me a reasonable way to compare the similarity of the non-stationary series generated by the model with the non-stationary data.[26]

Table 1.3 presents the outcome of this exercise. I present statistics for four series: investment in wage units, consumption in wage units, output in wage units and the employment rate. All series are measured in log-deviations from their statistical means.[27]

In the first two columns I compare the standard deviation in log-deviations for the simulated series and the actual data. The model not only generates standard deviations similar to those in the data, but also Monte-Carlo means that are very close to the actual standard deviations (for all series except the employment rate). This result is non-trivial because the standard deviation of a non-stationary series is highly history dependent and the length of each sample is rather long.

As is in the data, simulated investment is the most volatile series among all four and the model captures this. The standard deviation of consumption in the data is lower than the standard deviation of investment and the Monte-Carlo mean matches it almost perfectly.

The model simulated GDP is more volatile – 6.007 – than the actual one – 3.730. Partially this is because GDP in the model consists only of consumption and investment whereas in the data

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[26] Because of nonstationarity I cannot take the limit $T \to \infty$ as many summary statistics do not converge. Moreover if some data series are non-stationary, statistics for these series will change over time. However as long as the sample size is fixed, statistics for the data and simulated series are comparable.

[27] Since the long run statistical mean of the employment rate is 0.943, a one percent log-deviation for the employment rate is approximately a 1% deviation in terms of the labor force.

GDP includes government expenditures. If I exclude government purchases from the measure of GDP in the actual data, the standard deviation of GDP increases from 3.730 to 5.204.[28]

Because the estimated CES technology is very close to Cobb-Douglas, the employment rate is highly correlated with output. This implies that the standard deviation of the simulated employment rate is similar to the standard deviation of GDP - 5.972. The actual deviation of the employment rate - 1.767 - is outside the reported 90% confidence interval, although it still within a 95% confidence interval (not reported in Table 1.3).

The next two columns of Table 1.3 compare the persistence of the simulated series and the persistence of the actual data. As before I report the Monte-Carlo average of persistence along with the 90% confidence interval. The model matches persistence of all series almost exactly.

The model again correctly replicates the different behavior of the four series: as in the data, the investment series is the least persistent of all, whereas the persistence of the other series is as high as in the data and close to unity. This is again non-trivial because only the productivity process in the model is persistent with a relatively low persistence of 0.9175 (see Table 1.2) whereas belief shocks are i.i.d. Nevertheless the model can match very different persistence behavior in all four series.

In the last two columns I present the outcome of the unit-root test for the data and the simulated series.[29] For the actual data I report the p-value where the null is that the process has a unit root. The share of processes for which existence of a unit root is not rejected at the 5% level is reported in the simulation column.

In the data, the unit root hypothesis is strongly rejected for investment, strongly not rejected for the consumption series and both output and unemployment series are borderline cases.[30] The model reflects this observation - simulated investment is stationary in more than 99% of all cases,

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[28]In Farmer and Plotnikov (2012b) we explore effects of fiscal policy in this environment.

[29]I used Dickey-Fuller test with no intercept and no trend since by construction means of all series are zero.

[30]There are two reasons to believe that output in wage units is in fact a random walk. First, consumption and investment together constitute 81% of U.S. GDP. Since consumption is a random walk and investment is stationary GDP is likely to be a random walk as well. Second, since labor share in the U.S. data is close to being constant, this implies that the employment rate is roughly proportional to the output in wage units. Since existence of unit root in the unemployment rate is not rejected, it suggests that output in wage units has to have a unit root as well.

simulated consumption is a random walk in 73% of all simulations and both output and the employment rate are random walks slightly more than half of the time. These results are consistent with the p-values for the actual data. The higher the probability that the actual series is a random walk, the higher the share of simulated series that are random walks.

Based on the evidence I present in Table 1.3 I conclude that the model replicates key characteristics of the data. In the next subsection I address the mechanism behind this success.

1.5.2   The mechanism of the model

In this subsection I discuss the qualitative properties of the model-generated series. As before I pick parameters of the model to be equal to the posterior mean of the Bayesian estimation procedure (see Table 1.2).

The left column of Figure 1.2 presents typical dynamics of the model with randomly drawn technology and belief shocks. The right column of Figure 1.2 plots actual consumption and investment in wage units. On the bottom panel of the figure I plot the analog of output in the data - the sum of consumption and investment.[31] As in the previous subsection, all series are measured in log-deviations from their statistical means.

The left column of Figure 1.2 shows that the model qualitatively captures the data behavior: simulated consumption in wage units is smooth, persistent and drives medium term changes in output; whereas the investment series appears stationary and is much less persistent.

What is the mechanism behind the high serial correlation in the simulated data? Algebraically, the estimated policy rule always has an eigenvalue that is equal to unity.[32] This makes all the simulated series nonstationary. Economically, the simulated output and consumption series are persistent because the economy does not fluctuate around the unique steady state (as in a standard model), but constantly shifts from one steady state to another. This implies that the model economy exhibits hysteresis – the entire history of shocks determines the steady state to which the economy

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[31]Consumption and investment constitute 81% of the U.S. GDP.

[32]This is because equations (1.27) and (1.28) are proportional to the rest of the equations in every steady state.
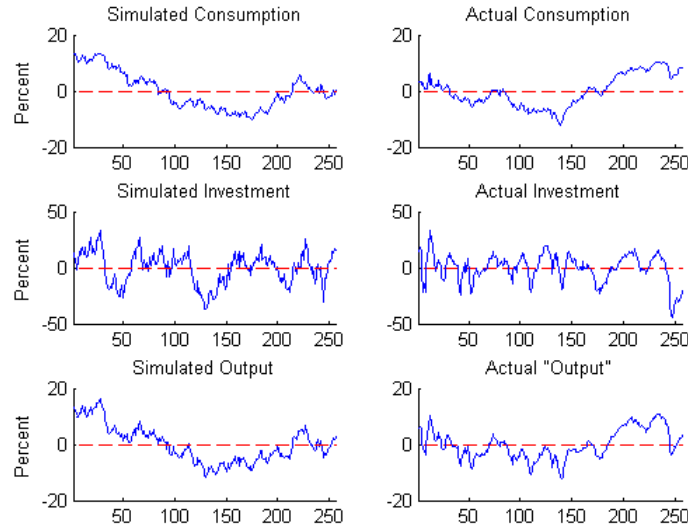
Figure 1.2: Simulated series (left column) and the actual data counterparts (right column). Output in quotation marks is defined as sum of consumption and investment. Scale of axis is the same for simulated and actual data.

converges.

If all the simulated series are random walks, why is investment stationary (see Figure 1.2 center left and Table 1.3 last column)? In fact it is non-stationary, but the "degree of nonstationarity" is significantly lower for investment than for consumption and output in wage units. To see what I mean by this, consider the simulated series generated by the same innovations to beliefs and no productivity innovations, $\varepsilon_t^p = 0$. These series are plotted in Figure 1.3 in the right column. The left column in Figure 1.3 is the same as the left column on Figure 1.2.

As expected, all the series in Figure 1.3, including investment, are highly persistent and satisfy the inequality (see Equations (1.26) and (1.29))

$$\frac{C_t}{Y_t} \approx \phi \gg 1 - \phi \approx \frac{I_t}{Y_t}. \tag{1.37}$$

Equations (1.26) and (1.29) imply that all the series in Figure 1.3 on the right are identical. This means that belief shocks are responsible for persistence in the data, but cannot replicate the high volatility of the investment series.

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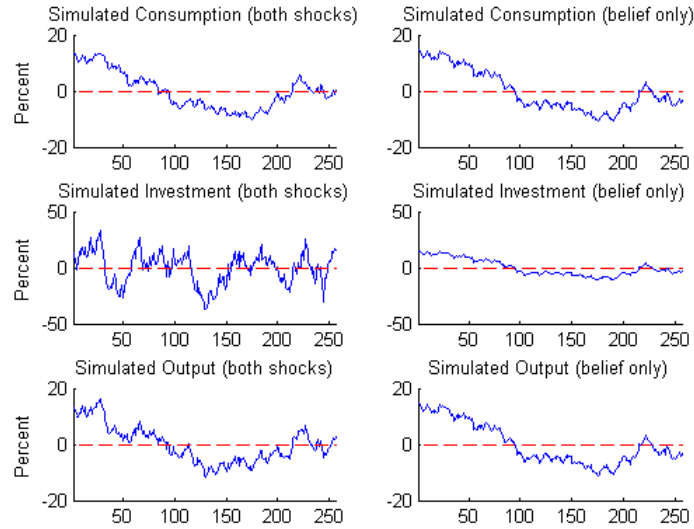
Figure 1.3: Simulated series with both shocks (left column) and simulated series with belief only (right column). The left column is the same as the left column of Figure 1.2. Scale of y-axis is the same for both columns.

Because on average the share of consumption is approximately 5 times the share of investment in U.S. GDP, if one were to construct the investment series generated by the belief shocks in levels, it would appear almost constant. In other words, belief shocks imply very small changes in the investment series, but large changes in consumption and output.

What if beliefs shocks are shut down and only productivity shocks are used to generate data? The right column of Figure 1.4 presents the simulated series produced with the same productivity innovations as in the left column of Figure 1.4 (which is the same as the left column in Figure 1.2) and no belief shocks.

It follows from the right column of Figure 1.4 that TFP shocks have their largest effect on the investment series (the standard intuition from the real business cycle models applies) but almost no effect on consumption. This is because the adaptive expectations assumption (equation (1.28)) smooths the consumption series. As a result, all fluctuations in the investment series are transferred almost one to one to the output series.

If one were to construct the consumption and investment series implied by the right column of Figure 1.4, consumption would be almost flat, whereas investment would be similar to the one

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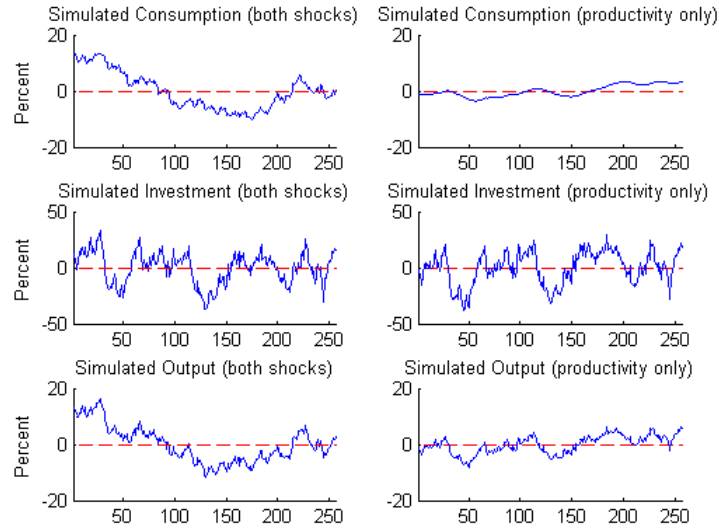
Figure 1.4: Simulated series with both shocks (left column) and simulated series with productivity shocks only (right column). The left column is the same as the left column of Figure 1.2. Scale of y-axis is the same for both columns.

implied by the left column of Figure 1.4. This follows from the same logic as before: on average the share of consumption is approximately 5 times the share of investment in U.S. GDP. Because the fluctuations in consumption in levels, implied by productivity shocks alone (Figure 1.4, top right), are very small relative to the ones produced by both shocks (Figure 1.4, top left) these fluctuations result in an almost constant level of consumption.

Now consider how shocks to productivity and beliefs interact to produce the series in the left panel of Figure 1.2. Because belief shocks change the investment steady state only slightly, fluctuations in this series are dominated by productivity fluctuations. This results in an investment series that is statistically stationary. On the other hand, the consumption series is dominated by belief shocks and is very smooth. Combining the behavior of the consumption and investment series results in volatile and persistent output, where high persistence comes from consumption and volatility comes from the investment series - exactly as in the data.

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1.5.3 Impulse response functions

In this subsection I quantitatively describe the model's implications for the series both in wage units and in the real terms using impulse response functions (IRFs).
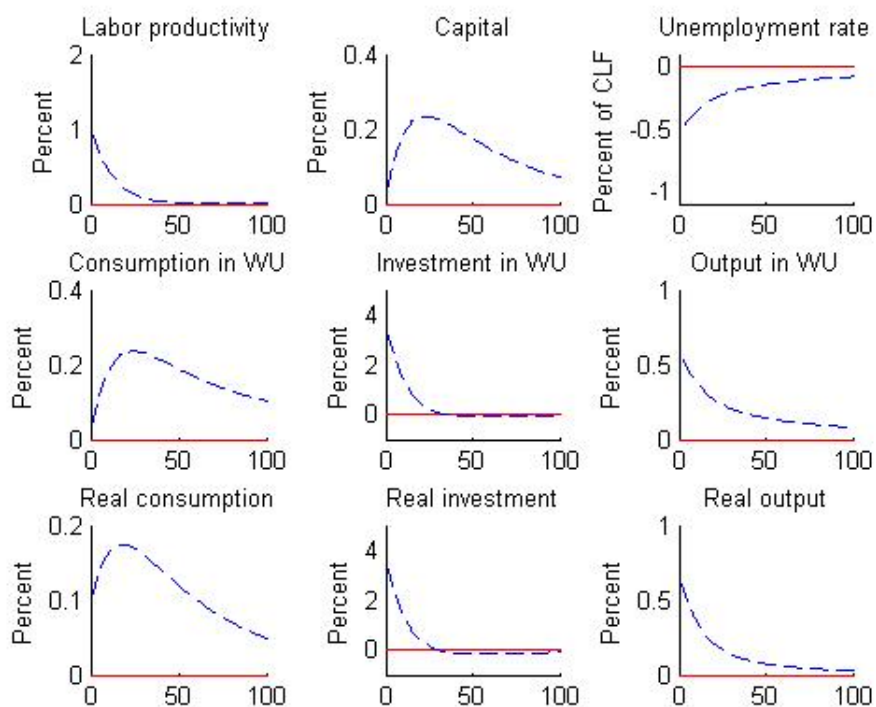
Figure 1.5: Impulse response functions to 1% labor productivity shock. The panels in the center row present the effects of this shock on the variables in wage units and the bottom row presents the effects of the shock on the variables in consumption units. X-axis correspond to time in quarters of a year. Zero line corresponds to the steady state associated with the long-run statistical mean of the unemployment rate. Effect on the unemployment rate is measured in percents of the labor force.

Figure 1.5 presents IRFs to a positive 1% TFP shock. This magnitude corresponds to approximately 60% of the standard deviation of productivity innovations. Because the productivity process is autocorrelated with persistence $\lambda = 0.9175$, the effects of the initial shock disappear completely after approximately 45 quarters (see Figure 1.5, top left).

The effects of the TFP shock are standard with extra propagation and permanent effects on the unemployment rate and consumption. The panels in the center row of Figure 1.5 present the effects

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of this shock on the variables in wage units and the bottom row presents the effects of the shock on the variables in consumption units. As in a standard RBC model, investment is the most volatile component of GDP (see the central column of Figure 1.5). Investment in both wage units and consumption units increases by more than 3.5% as a result of the shock. In contrast, both measures of consumption are very smooth and change by less than 0.25% (the left column of Figure 1.5). As a result, most of the fluctuations in output are due to changes in the investment series. Given that the investment series constitutes around 1/6 of U.S. GDP, the resulting effect on output is approximately 0.6% on impact decreasing exponentially thereafter. Because the unemployment rate is highly correlated with output in the model, the effect of the shock on the unemployment rate is the mirror image of the effect of the shock on output in wage units.

Even though TFP level is indistinguishable from its steady state value 50 quarters after the initial impact, many variables are still significantly affected by the shock even after 50 quarters. In particular, only 2/3 of the initial impact on the unemployment rate disappears after 50 quarters. 80% of the impact is absorbed after 75 periods and 10% is never absorbed and is permanent (the top right panel of Figure 1.5)[33]. This is in sharp contrast to standard models with unemployment where a persistent response of variables to shocks comes mostly from persistence in the TFP process.

The response of consumption to a TFP shock is less than 0.25% and there is almost no permanent effect on the investment series. The permanent effect on output in wage units is completely caused by a small but significant change in the real wage (compare the central and the bottom panels in the right column of Figure 1.5).

This means that the real wage exhibits endogenous "rigidity" even though there are no artificial barriers that prevent wages from moving. This is because wages are determined by aggregate demand which for the most part is determined by consumption. Consumption smoothness implies smooth wages. Although the intuition behind the persistent effects of TFP shocks is similar to models with rigid wages, the difference is that real rigidity appears endogenously in my model.[34]

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[33]In contrast to the rest of the IRFs reported, I report the effect on the unemployment rate in percent of the labor force, not as a percent of the steady state value.

[34]This is in contrast to the literature where rigid wages are imposed as an assumption. See for example Shimer (2012); Hall (2005).

31
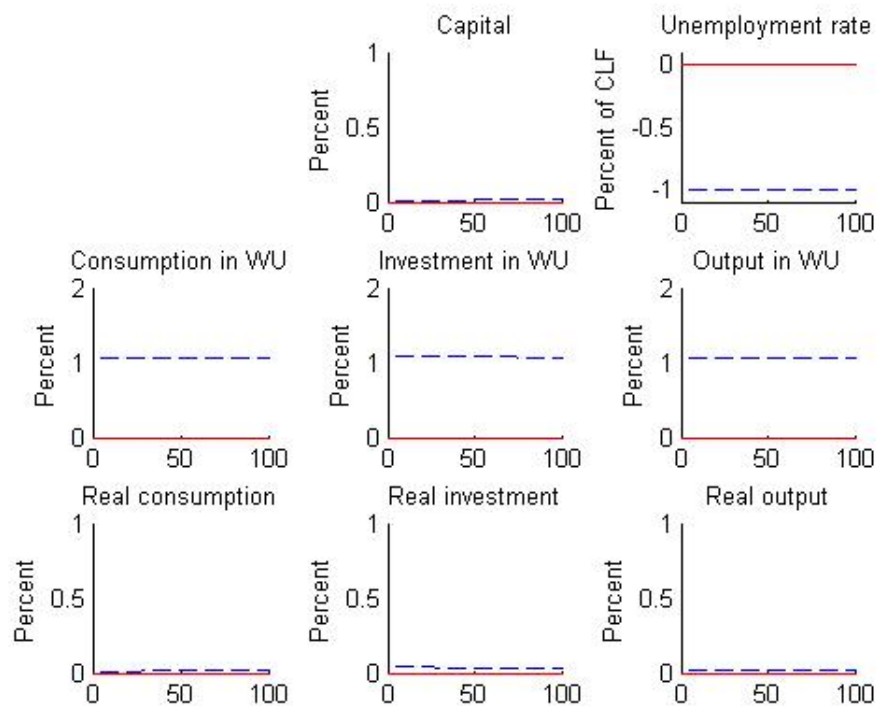
Figure 1.6: Impulse response functions to 1% positive belief shock. X-axis correspond to time in quarters of a year. The panels in the center row present the effects of this shock on the variables in wage units and the bottom row presents the effects of the shock on the variables in consumption units. Zero line corresponds to the steady state associated with the long-run statistical mean of the unemployment rate. Effect on the unemployment rate is measured in percents of the labor force.

Figure 1.6 presents impulse response functions for a one-time positive 1% belief shock. This magnitude corresponds to 122% of its estimated standard deviation (see Table 1.2). Figure 1.6 shows that all series in wage units increase proportionally and the increase is permanent (see the middle panels). A positive belief shock moves the economy to a different steady state with a lower unemployment rate while keeping the ratio of consumption to output constant (see Equation 1.37).

In a response to a belief shock, there is almost no effect on the real variables (see the bottom panels of Figure 1.6). This means that the increase in variables in wage units is due to the 1% drop in the real wage. The unemployment rate drops by 1% and this decrease is permanent. Thus the unemployment rate exhibits hysteresis. These dynamics explain the phenomenon that has been dubbed "jobless recoveries" – a high persistent unemployment rate and real growth at the

same time. To see this, consider a negative belief shock. In response to a shock of this kind, unemployment will rise proportionally and stay high for a potentially infinite period of time. At the same time there will be no decrease in real output, consumption or investment. If a positive productivity shock follows such a belief shock, the economy will converge back to a new steady state with the new higher unemployment rate.

The dynamics of my model, presented in Figures 1.5 and 1.6, are consistent with the reduced-form findings in Cochrane (1994). As in Cochrane (1994) "shocks to output, holding consumption constant are almost entirely transitory". This statement holds for data measured in both consumption goods and wage units for both productivity and belief shocks.[35] This implies that my model captures the fact that consumption a good estimate of "trend" output.[36]

In my model a negative belief shock causes an increase in real wages. This is exactly what happened – between 2006 and 2011, real hourly earnings have increased by around 3% while hours worked and the employment rate dropped significantly (see Kocherlakota (2012)).

1.6 Conclusion

In this paper I constructed and estimated a general equilibrium rational expectations model that displays hysteresis in unemployment as in Blanchard and Summers (1987). My model has the potential to explain the prolonged increase in the unemployment rate that we observed in the U.S. after the Great Recession as a socially inefficient equilibrium outcome. Additionally, the model can reproduce stylistic business cycle dynamics in output, consumption, investment and real wages over the entire postwar period. In particular, in contrast to nearly all labor search models, in my

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[35]To see how Cochrane's statement follows from Figures 1.5 and 1.6, consider, first, the effect of a TFP shock on consumption and output (Figure 1.5). Permanent change in output in wage units as a result of 1% TFP shock (the center right panel of Figure 1.5) is almost the same as in consumption in wage units (the center left panel of Figure 1.5) − 0.1%. This means that conditional on the change in consumption, the effect on output is transitory. Similar reasoning holds for the data in consumption good units (see bottom panels of Figure 1.5). Second, consumption and output react exactly in the same way as a response to a belief shock and the effect on both variables is permanent (Figure 1.6). If consumption is held constant, there is no change in output as a result of a belief shock. Thus Cochrane's statement holds regardless whether the economy is hit by a TFP or a belief shock or a combination of the two.

[36]Cochrane (1994) documents this fact in his paper as well. Farmer (2010b) makes this observation for consumption and output measured in wage units.

model real wages are countercyclical as in the data.

My model advances on two other branches of the literature. First, it expands second generation endogenous business cycle models to include the behavior of investment, consumption and real wages together with output and unemployment.[37] Second, it provides deeper micro-foundations for why real wages are rigid with respect to a TFP shock. In contrast to the existing rigid wages literature (see Hall (2005); Shimer (2005)), I obtain this property of the real wage without directly imposing an assumption of nominal or real rigidity.

My model is driven by two shocks: a TFP shock that explains fluctuations at business cycle frequencies and a belief shock that explains permanent shifts in the unemployment rate. Productivity shocks have similar transitory effects as in a standard model. But they also have long-lasting effects on the unemployment rate, produced by an endogenous propagation mechanism. Together, demand and supply shocks generate jobless recoveries, and a high persistent unemployment rate can coexist with positive real growth.

The model does not contradict the view that productivity shocks are a major source of economic fluctuations as in Nelson and Plosser (1982) and Long and Plosser (1983). Rather the model enriches this view by combining it with the idea that the unemployment rate displays the property of hysteresis.

I find that neither demand nor supply shocks alone can explain the observed dynamics of employment and GDP in the postwar data. With no demand disturbances one is likely to come across an "unemployment volatility puzzle" because the unemployment rate is a lot more volatile than the data generated by the model. With no TFP shocks the model cannot explain the observed volatility of investment.

What is a belief shock? Farmer (2012b) argues that the stock market crash of 2008 was similar in nature to what Keynes (1936) referred to as "animal spirits". Stock market wealth and housing wealth both fell sharply in 2008. This drop in wealth, caused by self-fulfilling shock to beliefs about permanent income, can potentially explain the Great Recession.

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[37]See Farmer (2012a) for a recent review of endogeneous business cycle literature

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Chapter 2

What Prevents a Real Business Cycle Model From Matching the U.S. Data? Decomposing the Labor Wedge

2.1   Introduction

The Great Recession of 2008 was declared over by the NBER in June of 2009, but the economy still has not returned to pre-recession levels of output and employment. The U.S. unemployment rate has remained above 8% for more than 11 quarters. Real U.S. GDP dropped more than 2% during the crisis and in contrast to previous postwar recessions did not jump back to the pre-recession trend. The two main questions of this paper are the following. First, if the dynamics that we observe today are part of the business cycle, can they be reconciled within a standard framework together with the rest of the postwar data? Second, if not, what are the required features of a successful model to explain observed fluctuations that are absent in the standard model?

Based on the behavior of the unemployment rate after 2008 and its similarity to the Great Depression several researchers have begun to consider models with multiple equilibria (See Kaplan and Menzio (2012), Heathcote and Perri (2012), Farmer (2012b), Kashiwagi (2012), Cowen

(2012), Guerrazzi (2010) and Basu (2009) among others.) For example, Farmer (2012b) argues in favor of models with multiple steady state equilibria. He claims that the reason why unemployment has not returned to its pre-recession level of 5% is because the economy switched to a new, inefficient steady state equilibrium with a higher unemployment rate and the lower level of output. He also argues that that the standard real business cycle (RBC) model is unable to match these unemployment and GDP dynamics for the same reasons that the Great Depression is hard to reconcile within such framework. Since a standard RBC model has a unique steady state equilibrium, for plausible parameter values it implies that the economy quickly returns to its steady state.

Even though there is agreement in the literature (see, for example Cole and Ohanian (2004)) that an RBC model cannot explain the persistence of the unemployment rate during the Great Depression, it has not been tested on the recent data. First, the increase in the unemployment is much smaller (from 5% to above 8% for the current recession and from 2% to 25% for the Great Depression). Second, in the current recession productivity decreased significantly, a feature that is potentially consistent with conventional explanations.

In this paper I conduct an empirical exercise to analyze which assumptions, if any, prevent a standard model from matching the persistence of the unemployment rate for the current recession and the entire postwar period. I proceed as follows. I remove the trend from aggregate time series data by deflating nominal GDP by a series of money wages. I call this detrended series "GDP in wage units". I show that GDP in wage units is twice as volatile as real GDP detrended by a more conventional approach such as the HP filter. The reason is that the HP filter removes medium term fluctuations that are an important component of business cycles. Note that preserving medium term comovements in the data is directly related to the questions I answer in the paper: I am interested if the standard model can explain high level of unemployment (low levels of GDP) for a long time period, not its deviations from the HP trend.

I establish that GDP in wage units is highly correlated with unemployment. Since unemployment is a measure of underutilization of resources, the medium term movements in GDP that are removed by the filter are, arguably, an important determinant of welfare fluctuations over the busi-

ness cycle.

Next, I carry out a business cycle accounting exercise (as in Chari *et al.* (2007)) on the data filtered in this new way. First, I describe the benchmark RBC model (see Section 3) and introduce wedges in the model's equations that do not hold exactly in the data. Second, I estimate this model using Bayesian techniques and obtain smoothed values for all of the wedges (see Section 4 for details).

By constructing the wage series I am able to decompose the labor wedge into the labor supply and the labor demand wedges. This means I evaluate the model's predictions about labor supply and labor demand independently of each other. This contrasts with the conventional approach in the real business cycle literature in which wages are eliminated from the equilibrium model equations.

Using the methodology of Chari *et al.* (2007) (later CKM), I reverse a key finding of the real business cycle literature which asserts that 70% or more of economic fluctuations can be explained by TFP shocks. In contrast, in the transformed data, most movements in GDP are accounted for "the labor supply wedge". In other words, the real business cycle model fits the data badly because the assumption that households are on their labor supply equation is flawed. This failure is masked by the data that has been filtered with a conventional approach because the HP filter removes a significant part of the business cycle fluctuations.

My results empirically justify abandoning the assumption that the household is on its labor supply curve as suggested in the literature on incomplete labor markets (see Farmer (2010b); Farmer and Plotnikov (2012a); Kocherlakota (2012); Kashiwagi (2012); Miao *et al.* (2012)) They also support introduction of multiple equilibria as a way of dealing with the inability of a standard model to fit medium-term fluctuations.

2.2 Wage Units

This section outlines the detrending procedure I use in this paper.[1] A key advantage of this structural procedure is that it preserves medium and long-term fluctuations across different macroeconomic series.This contrasts with a more conventional, but mechanical, band-pass filter (Baxter and King (1999)), which extracts different trends from different series.

The intuition behind the detrending procedure is simple. To remove inflation and the trend in total factor productivity (TFP) from nominal macroeconomic variables, one can divide the variable of interest by nominal wage.[2] Following Farmer (2010b) I define the nominal wage to be:[3]

$$W_t = \frac{(compensation\,to\,employees)_t}{(number\,of\,full\text{-}time\,equivalent\,employees)_t} \tag{2.1}$$

Compensation to employees is a better measure of the wage than gross earnings alone because it includes all monetary benefits (not just salary) paid to employees. Using the constructed series of wages, W_t, GDP in wage units is defined as

$$Z_t = \frac{Y_t}{W_t} \cdot \frac{1}{N_t} \tag{2.2}$$

where Y_t is nominal U.S. GDP and N_t is the civilian labor force in period t.[4] While the ratio of total GDP to the nominal wage $\frac{Y_t}{W_t}$ should now be free of inflation and productivity trends, it still grows because the number of working people increases with time. For this reason I further divide this ratio by a measure of civilian labor force N_t.[5] The term Z_t represents GDP deflated by wage

[1]This procedure was developed by Farmer (2010b). See this paper for further details

[2]By contrast, deflating by price alone removes only inflation and requires further detrending, e.g. using the HP-filter.

[3]Both series are available from BEA website on the annual basis from 1929 to 2011. I linearly interpolated resulting wage series to obtain quarterly data. Since the original series is very smooth, the error associated with interpolation should not be large.

[4]This definition of GDP in wage units is robust with respect to different measures of the labor force: total vs. civilian. The difference between the two measures of the labor force during the entire postwar period does not exceed 2%.This difference does not affect the resulting series for GDP in wage units.

[5]While it might be intuitive to divide by population to express GDP in per capita terms, I divide by the labor force (N_t). The model ignores fluctuations in employment due to people entering and leaving the labor force. In contrast, the standard RBC literature ignores the other key reason for fluctuations in employment: individuals in the labor force receiving and leaving jobs. See section 5 for more details.

and expressed in per-capita terms.

The output in wage units, Z_t, can be interpreted in the following way. First, let b_t be the share of labor income in the total nominal output Y_t, and let L_t denote the number of full-time equivalent employees (FTE) used in production of the output. Then, by the definition of the share of labor income,

$$b_t Y_t = W_t L_t \tag{2.3}$$

The RHS of Equation (2.3) is the compensation of FTE in dollars. The LHS of this equation is total nominal GDP multiplied by the (potentially time-varying) share of the labor income. Dividing both sides of Equation (2.3) by the civilian labor force N_t and the constructed series of nominal wages W_t (Equation (2.1)) implies that

$$\frac{Y_t}{W_t} \cdot \frac{1}{N_t} = \frac{1}{b_t} \cdot \frac{L_t}{N_t} \tag{2.4}$$

The LHS of the Equation (2.4) is equal to Z_t, GDP in wage units, as defined in Equation (2.2). The ratio $\frac{L_t}{N_t}$ on the RHS of Equation (2.4) is the employment rate in the economy. Define the unemployment rate as

$$u_t = \frac{N_t - L_t}{N_t} = 1 - \frac{L_t}{N_t} \tag{2.5}$$

Combining this definition with Equation (2.4) leads to the following expression:

$$Z_t = \frac{1}{b_t}(1 - u_t) \tag{2.6}$$

Equation (2.6) implies that GDP in wage units is equal to the product of the inverse of the labor share and the employment rate. If the labor income share were constant, GDP in wage units would have been proportional to the employment rate. In the data, the constructed series of GDP in wage units Z_t and the civilian employment rate reported by BLS (defined as one minus the unemployment

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rate) for the quarterly postwar data are highly correlated, but not exactly proportional. Statistically, the correlation between these series is -0.88. Figure 2.1 presents these series graphically. The constructed series of GDP in wage units is on the right axis and the unemployment rate is on the inverted left axis.

Why are the series on Figure 2.1 different? The RHS of Equation (2.6) suggests two possible reasons. First, the unemployment rate reported by BLS is different from the unemployment rate defined in Equation (2.5). Because BLS does not distinguish between part-time and full-time workers and counts both of them as employed, the unemployment rate defined in Equation (2.5) is larger than the unemployment rate reported by BLS..[6] In the paper I use the series reported by BLS because it is more conventional and widely used in the literature.[7] Second, the share of labor income in the total output b_t is not constant and in fact counter-cyclical over time (Rios-Rull and Santaeulalia-Llopis (2010); Choi and Rios-Rull (2009)). In particular, the divergence of two series after 2009 can be potentially attributed to a fall in the labor share.[8]
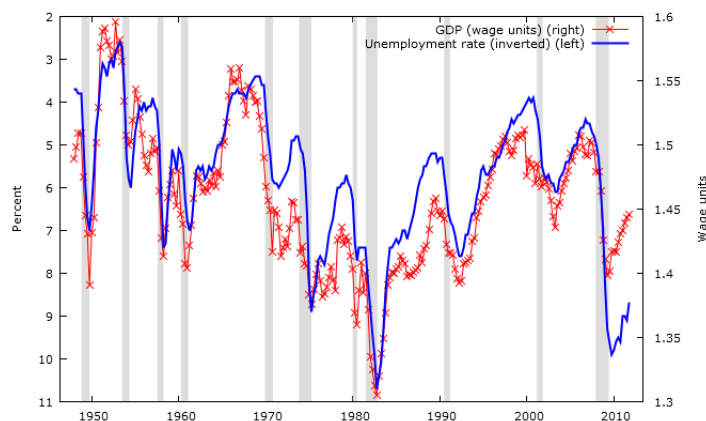
Figure 2.1: Civilian unemployment rate (percent, left scale, inverted) and GDP in wage units (right scale). Quarterly data 1948:1 - 2011:4. Shaded areas are NBER recession dates.

Next I detrend different components of GDP in a similar way. Using data from the NIPA tables,

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[6]For example, consider a part-time employee working 50% of the full-time employment. In the number of FTE, L_t, this employee is counted as $\frac{1}{2}$, whereas BLS counts him as 1 in the number of people employed. Nevertheless, correlation between these two series is very high - 0.93.

[7]Correlation between these two series is close to one - 0.93.

[8]The decrease in the labor share of total income was pointed out by several researchers in the literature. See, for example, Gomme and Rupert (2004); Jacobson and Occhino (2012)

I define nominal investment I_t to be equal to the sum of nominal private and government investment. Then, using the national accounts identity for nominal GDP, I define nominal consumption to be

$$C_t = Y_t - I_t \tag{2.7}$$

In other words, C_t contains nominal private consumption, government consumption and net exports. Similarly to the definition of GDP in wage units, I define investment in wage units , I_t^w, and consumption in wage units, C_t^w to be

$$I_t^w = \frac{I_t}{W_t} \cdot \frac{1}{N_t} \qquad C_t^w = \frac{C_t}{W_t} \cdot \frac{1}{N_t} \tag{2.8}$$

Equation (2.8) states that C_t^w and I_t^w represent consumption and investment deflated by the nominal wage and expressed in per-capita terms. These series have two important properties. First, it follows from Equations (2.2), (2.7) and (2.8) that the national accounts identity still holds for series in wage units:

$$Z_t = C_t^w + I_t^w \tag{2.9}$$

Most importantly, since all of the series were detrended using the same nominal wage series, W_t and the civilian labor force N_t, medium- and long-term comovements among GDP, consumption investment and unemployment are preserved. In contrast, the standard mechanical HP-filtering procedure eliminates medium- and long-term comovements because it removes potentially different trends from these series.

2.3   A Prototype Economy

In this section I describe a RBC model that I later use in the accounting procedure. I choose functional forms that are similar to the ones used in CKM as the "prototype economy" except that

I interpret hours worked by individuals as the employment rate. I picked this version of the model to make my quantitative results comparable to the ones obtained in CKM. See section 5 for the standard alternative specification.

There is one infinitely-lived household that maximizes expected discounted life-time utility of its members. At any given moment of time t share $l_t \in (0,1)$ members of the household are employed and share $1 - l_t$ are not. The household head derives utility from real consumption c_t per household member and the share of its members who do not work $1 - l_t$. This setup implicitly assumes that the labor force in the economy – the number of members of the household – is normalized to unity and l_t corresponds to the employment rate. For the same reasons, c_t corresponds to the real consumption per member of the labor force. The one-period utility function of the household's head is

$$u(c_t, l_t) = log(c_t) + \psi \cdot log(1 - l_t)$$

Each working member of the household earns real wage w_t per period so that the labor income of the household is $w_t l_t$. The household can also accumulate capital k_t that it rents out to firms for the real rental rate r_t per period. This leads to the standard budget constraint:

$$c_t + i_t = r_t k_t + w_t l_t \tag{2.10}$$

where i_t is the investment in period t per member of the labor force. Capital depreciates with the rate δ per period and evolves according to the following expression:

$$k_{t+1} = i_t + (1 - \delta)k_t \tag{2.11}$$

The household discounts future utility with discount factor β. It takes wages and rental rates as given and maximizes $E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} u(c_s, l_s) \right]$ subject to equations 2.10 and 2.27. The solution to the household's maximization problem can be summarized by the following Euler and labor supply

equations:

$$\frac{1}{c_t} = \beta E_t \left[\frac{1}{c_{t+1}} (1 - \delta + r_{t+1}) \right] \tag{2.12}$$

$$\psi c_t \frac{1}{1 - l_t} = w_t \tag{2.13}$$

Consumption and investment goods are perfect substitutes in production and produced by firms using the technology:

$$y_t = A_t k_t^\alpha l_t^{1-\alpha} \tag{2.14}$$

where $1 - \alpha$ is labor's share of income and y_t is the real output per member of the labor force. The term A_t represents the aggregate level of technology. Firms maximize profit by renting capital and hiring labor in perfectly competitive markets. They take wages and rental rates as given. The first order conditions for the maximization problem of the firm are standard:

$$r_t = \frac{\alpha y_t}{k_t} \tag{2.15}$$

$$w_t = \frac{(1 - \alpha) y_t}{l_t} \tag{2.16}$$

The general equilibrium of the model is described by the system of equations (2.10)–(2.16). Combining Equations (2.10), (2.12) and (2.15) leads to the standard national accounts identity

$$c_t + i_t = y_t \tag{2.17}$$

and the Euler equation

$$\frac{1}{c_t} = \beta E_t \left[\frac{1}{c_{t+1}} \left(1 - \delta + \frac{\alpha y_{t+1}}{k_{t+1}} \right) \right]. \tag{2.18}$$

The final set of equations to be used in the accounting procedure in the next section is summarized by 6 equations: the capital accumulation equation (2.27), the labor supply equation (2.13), the production function (2.22), the labor demand equation (2.16),the national accounts identity (2.17) and the forward-looking Euler equation (2.18). Together these equations determine the vector of variables

$$x_t = [c_t, y_t, i_t, k_{t+1}, w_t, l_t] \tag{2.19}$$

2.4 Accounting procedure: evaluating the RBC model

2.4.1 Overview

The objective of the accounting procedure is to evaluate how well the RBC model describes fluctuations in the data. The procedure I use is identical to the accounting procedure introduced in CKM for the postwar quarterly data with three important differences. First, the data I use preserves medium and long-term comovements between GDP and its components and the unemployment rate; the CKM paper uses HP-filtered data. Using series in wage units facilitates decomposition of the labor wedge into the labor demand and the labor supply wedges. Second, I use the unemployment rate data as a measure of employment in the economy; Chari *et al.* (2007) use the conventional data on hours worked.[9] Third, the dataset I use contains the Great Recession of 2008; the dataset used by Chari *et al.* (2007) ends in 2003.

The intuition behind the accounting procedure is the following. To evaluate a particular equation of the model, I back out the implied residual (or wedge) series that is needed for the equation to hold exactly given the observed series of data. If the equation describes the data well, the residual series should look like white noise with low dispersion. In contrast, a high dispersion and autocorrelation in the residual series indicate problematic equations.

The backed out wedge series for each equation can additionally be interpreted as the required

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[9]In Section 5 I discuss how results change if hours worked series is used as a measure of employment.

realizations of single or multiple shocks hitting the equation to match the observed series. Using this interpretation, a high dispersion in a wedge series corresponds to highly, and potentially implausibly, volatile shocks needed to explain fluctuations in the data.

Finally, by recovering all of the wedge series one can assess the contribution of each wedge in explaining data fluctuations. To do this one can simply simulate the economy (using estimated policy rules) with all but one realized wedge held constant. A large difference between these simulated series and the corresponding data counterparts indicates low contribution of this particular wedge to the model's ability to explain the data. In contrast, if the simulated series closely follow the data, it implies a high contribution of the selected wedge. Similar experiments can be conducted for any subset of wedges. This exercise identifies the equations that have to be altered (i.e., where shocks need to be introduced) to produce better fit of the model.

2.4.2 The accounting procedure using the prototype economy

Following Chari *et al.* (2007) I introduce three wedges ε^{invest}, ε^{LS} and ε^{eff} (investment, labor supply and efficiency) into three equations of the prototype model (the Euler equation (2.12), the labor supply (2.13) and the production function (2.22) respectively).[10] The CKM paper shows how these wedges can be interpreted as an investment tax, a labor income tax and an innovation in the technology process .

In addition to these three wedges, I use the constructed series of nominal wages W_t to evaluate the fit of the labor supply equation (2.13) and the labor demand equation (2.16) separately by adding an extra labor demand wedge ε^{LD} to Equation (2.16).[11] Intuitively, this wedge captures countercyclicality in labor's share of income (Rios-Rull and Santaeulalia-Llopis (2010)). It is possible to introduce this wedge because I observe the unemployment rate, nominal GDP and investment deflated by the nominal wage and expressed per member of the labor force. Model

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[10]Because I am able to decompose government purchases into government consumption and government investment and, additionally, consider net exports to be a part of the consumption series C_t, I do not have government wedge which is present in the original CKM paper. Excluding net exports from the consumption series and considering it to be an extra wedge does not affect the results of this paper.

[11]This in contrast to the standard RBC literature that eliminates real wages from the system (2.10)–(2.16) altogether.

counterparts for these series are series $1 - l_t$, $\frac{y_t}{w_t}$ and $\frac{i_t}{w_t}$ respectively.[12]

The introduction of wedges transforms the system of equations that describe the general equilibrium of the prototype model to the following equivalent system:

$$\frac{1}{c_t}exp(\varepsilon_t^{invest}) = E_t\left[\beta\frac{1}{c_{t+1}}\left((1-\delta)exp(\varepsilon_{t+1}^{invest}) + \frac{\alpha y_{t+1}}{k_{t+1}}\right)\right] \tag{2.20}$$

$$w_t = \psi \cdot exp(\varepsilon_t^{LS}) \cdot c_t\frac{1}{1-l_t} \tag{2.21}$$

$$y_t = A_t k_t^\alpha l_t^{1-\alpha} \tag{2.22}$$

$$A_t = exp(z_t) \tag{2.23}$$

$$z_t = \rho z_{t-1} + \varepsilon_t^{eff} \tag{2.24}$$

$$w_t = exp(\varepsilon_t^{LD}) \cdot \frac{(1-\alpha)y_t}{l_t} \tag{2.25}$$

$$y_t = c_t + i_t \tag{2.26}$$

$$k_{t+1} = i_t + (1-\delta)k_t \tag{2.27}$$

To back out the realized wedges necessary to match the data, I follow the procedure described in Chari *et al.* (2007). First, I estimate a set of parameters of the prototype model using Bayesian maximum likelihood. I log-linearize the system (2.20)-(2.27) around the deterministic steady state. Then I solve it using methods developed in Sims (2001). This brings the system to the form

$$X_t = F \cdot X_{t-1} + G\varepsilon_t \tag{2.28}$$

$$Y_t = H \cdot X_t \tag{2.29}$$

where $X_t = [\tilde{x}_t, z_t, E_t c_{\tilde{t}+1}, E_t y_{\tilde{t}+1}]$ is a vector of state variables (x_t is defined in (2.19) and a tilde

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[12]Another reason to introduce a wedge in the labor demand equation (2.16) is to avoid statistical singularity problem. If the aggregate production function is Cobb-Douglas, as I assume in the benchmark model, Equation (2.16) implies that GDP in wage units has to be proportional to the employment rate. Since in the data these series are not proportional (see Figure 2.1), the estimation procedure requires a wedge in the labor demand equation (2.16).

over a variable denotes a log deviation from the steady state), $Y_t = [(\frac{y_t}{w_t})^{obs}, (\frac{i_t}{w_t})^{obs}, (1-l_t)^{obs}]$ is a vector of observables and $\varepsilon_t = [\varepsilon_t^{invest}, \varepsilon_t^{LS}, \varepsilon_t^{eff}, \varepsilon_t^{LD}]$ represents shocks to the wedges. The index t represents the actual time period and ranges from 1948:1 to 2011:4 - the maximum timespan available for the data series considered. Matrices F, G and H are nonlinear functions of underlying parameters of the model.

Equation (2.28) contains estimated linearized policy functions and the functions that describe how expectations about the future are formed based on the state vector X_{t-1}. Equation (2.29) links the observed series to their model counterparts.

I construct the likelihood for every set of the parameters by treating the first equation as if it were the true data generating process. Since Y_t contains fewer variables than X_t, in order to construct the likelihood for every set of the parameters, I use the Kalman filter algorithm to construct forecasts of all underlying variables X_t given observed variables $\{Y_s\}_{s=0}^t$.

Then, I combine prior distributions of all parameters with the maximized likelihood function to obtain a posterior likelihood. I compute posterior distributions numerically using the random walk Metropolis-Hastings (MCMC) algorithm. I make 100'000 draws and keep 50'000 of them to ensure independence from the starting point. Further details on the computational procedure can be found in An and Schorfheide (2007).

The second step of the accounting procedure is to use the Kalman filter to obtain smoothed (or realized) wedges. For this, I use the algorithms that are a part of the open source MATLAB package DYNARE (See Adjemian *et al.* (2011)).

Given the estimated series of realized wages and estimated policy functions, I conduct experiments as in Chari *et al.* (2007) to evaluate the contribution of each wedge to fit the data. For example, to evaluate contribution of the TFP fluctuations, I consider the *efficiency economy* where all wedges are constant except the efficiency wedge. To calculate the model predictions for this economy, I feed innovations $\varepsilon_t = [0, 0, \varepsilon_t^{eff}, 0]$ (where ε_t^{eff} are realized TFP shocks) into the estimated policy function (2.28).

The next section describes the numerical results I archived using this accounting procedure.

2.4.3 Priors

To obtain posterior estimates of all of the parameters of the model using MCMC algorithm I need to specify priors for all of the parameters of the model. The priors I use are summarized in Table 2.1. For capital share α, capital depreciation rate δ and technology persistence ρ I chose prior means to be close to commonly used calibration values. The discount factor β is fixed at 0.99.[13] The choice of 0.99 corresponds to the long-run annual interest rate of 4%. I picked the prior mean for the leisure parameter from the labor supply condition (Equation (2.21)) evaluated at the steady state assuming a 5% long-run unemployment rate.

Parameter	Description	Distribution	Prior mean	Std.Dev
α	Capital share	beta	0.33	0.15
δ	Capital depreciation	beta	0.03	0.015
ρ	Tech. persistence	beta	0.90	0.05
β	Discount factor	Fixed	0.99	–
ψ	Leisure parameter	Gamma	0.04	0.02
σ_{eff}	St.dev. of ε^{eff}	Inv. Gamma	0.02	0.01
σ_{invest}	St.dev. of ε^{invest}	Inv. Gamma	0.02	0.01
σ_{LS}	St.dev. of ε^{LS}	Inv. Gamma	0.10	0.05
σ_{LD}	St.dev. of ε^{LD}	Inv. Gamma	0.02	0.01

Table 2.1: Prior distributions of parameters of the model

The prior mean for the standard deviation of the efficiency wedge was picked to be a 2% deviation from the steady state – the standard calibration value for the technology process. I picked similar prior means for standard deviations of other wages except for the labor wedge. I chose larger value for the labor wedge because I expected it to have higher variance than the other wedges based on the results of CKM paper. I chose prior standard deviations to be as large as possible given the natural limits of the parameters.[14]

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[13]This parameter is not identified in the data.

[14]In order to have bell-shaped prior distributions with no positive probability mass on either end of the support, the distance between the prior mean and the closest natural limit should not exceed two standard deviations.

2.4.4 Parameter estimates

The results of the Bayesian estimation procedure are presented in Table 2.2. For every parameter I report the prior mean, the posterior mean and the 90% posterior confidence interval centered around the posterior mode. All of the model parameters have reasonable values. Labor's share of total income is estimated to be 65% which corresponds to a value often used in the calibration literature. Capital depreciation is estimated to be approximately 4.5% per year. The long run unemployment rate is estimated to be 5.7% which is also a standard value used in the literature.

Description	Prior mean	Posterior mean	$CI_{90\%}$
Capital share	0.33	0.3529	[0.3514; 0.3546]
Capital depreciation	0.03	0.0137	[0.0126; 0.0147]
Tech. persistence	0.90	0.9774	[0.9588; 0.9958]
Discount factor	0.99	-	-
Leisure parameter	0.04	0.0493	[0.0478; 0.0509]
St.dev. of ε^{eff}	0.02	0.0093	[0.0074; 0.0111]
St.dev. of ε^{invest}	0.02	0.0051	[0.0045; 0.0055]
St.dev. of ε^{LS}	0.10	0.3091	[0.2846; 0.3341]
St.dev. of ε^{LD}	0.02	0.0265	[0.0245; 0.0283]
MCMC acc. rate 36%	100000 draws	50000 kept	$log(L) = 1945$

Table 2.2: Estimates of all of the parameters on the quarterly data from 1948:1 to 2011:4.

The lower half of Table 2.2 presents estimates of the standard deviation of the realized wedges. Among all of them, the posterior standard deviation of the labor supply wedge, estimated to be 0.31, stands out. The magnitude of this number relative to the other estimated standard deviations suggests that it explains a lot of the fluctuations at least in one of the observed series. I show later that this intuition is indeed correct.

The posterior standard deviations of the other wedges are much smaller in magnitude. The standard error of the technology wedge is estimated to be 1%, close to its standard calibration value of 2%. Estimated standard deviations for innovations of the investment and labor demand wedges are below 1%. These numbers suggest that the investment wedge does not explain much variation in the data and the variation in labor's share of income (Equation (2.25)) is relatively small.

In Figure 2.2 I plot posterior densities for all of the estimated parameters, together with their prior distributions. This figure shows that all of the parameters are identified. If a parameter were to be weakly or non-identified the difference between its prior and posterior densities would have been small. In contrast, all posterior densities differ significantly from their respective priors indicating strong identification.

The estimates displayed in Table 2.2 are robust to the choice of prior means. I experimented with different combinations of prior distributions to check robustness of the estimates and obtained insignificantly different results. The maximization routine and MCMC algorithm either produce estimates almost identical to the ones in Table 2.2 or the routine does not converge at all. For example, varying the prior mean of the standard deviation of the labor wedge over $(0,1)$ interval (keeping other prior distributions the same) does not affect any of the estimates in Table 2.2.
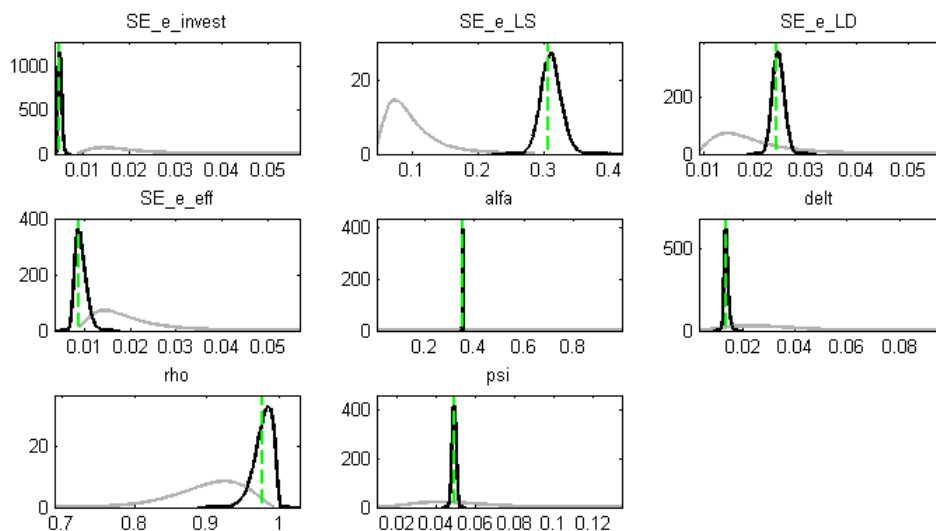
Figure 2.2: Posterior distributions. Grey lines represent prior densities. Dark lines represent posterior densities. Dashed lines are estimated modes of the posterior densities. SE stands for standard error.

2.4.5 Realized wedges

Figure 2.3 presents the realized wedge series graphically. Table 2.3 summarizes the descriptive statistics of these series. The first half of the table includes individual statistics of each wedge: ratio of the variance to log output, and correlation to log output at different lags. The second half of the table presents cross-correlations between wedges at different lags.

Recall that if the prototype model is a good description of the economy, then all four series on Figure 2.3 should look similar to white noise. In contrast, only the investment wedge series (Figure 2.3, top right) looks like white noise. Moreover, as the second line of Table 2.3 shows, white noise is not a bad approximation for this series: investment innovations constitute a very small fraction of the output and are almost uncorrelated with it. This finding indicates that the Euler equation (Equation (2.20)) holds well in the data. This finding is consistent with CKM paper.

Figure 2.3: Realized wedge series as an outcome of the estimation procedure for the entire postwar period. Grey areas indicate NBER recessions.

The top left panel of Figure 2.3 presents realized innovations to total factor productivity. By assumption, this series is the main driving force of economic fluctuations in a real business cycle model. However, as the first line in Table 2.3 shows, the TFP shocks do not explain data in wage

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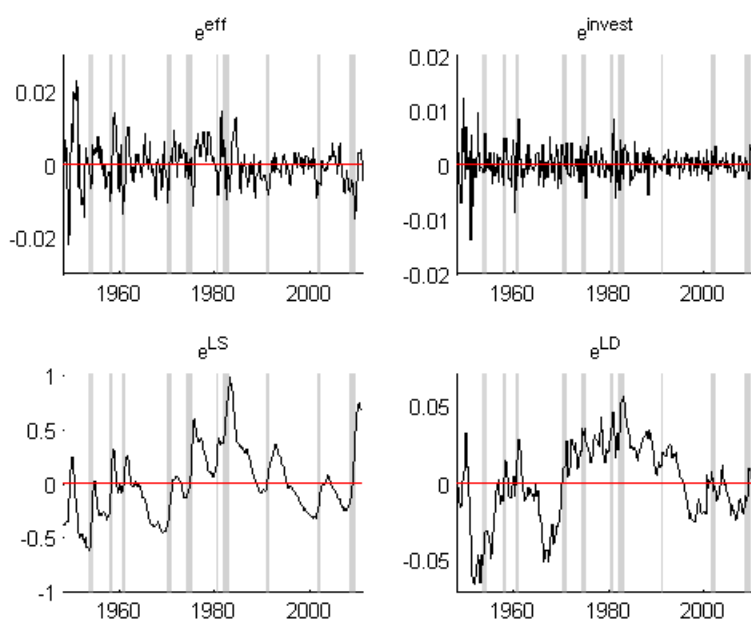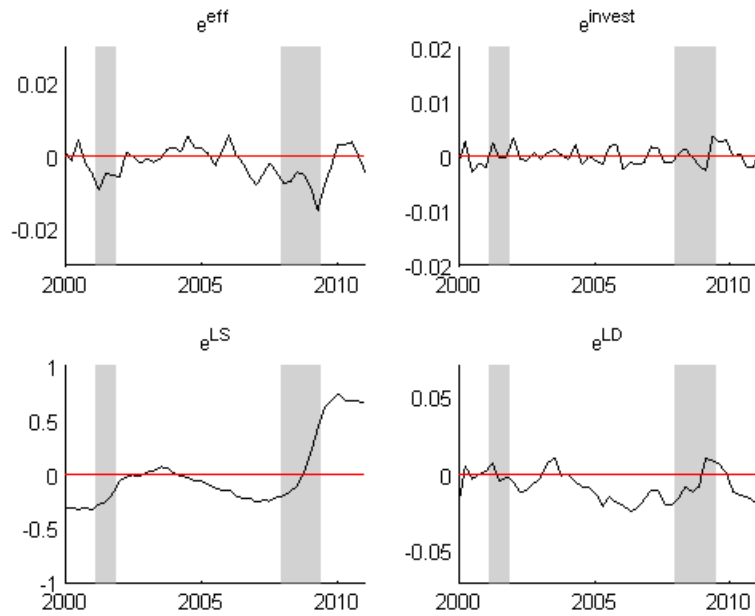Figure 2.4: Realized wedge series as an outcome of the estimation procedure for the period 2000:1-2011:4. Grey areas indicate NBER recessions.

units. This is perhaps not surprising since the TFP shocks are eliminated from GDP when GDP is deflated by the money wage. However, in a standard RBC model one would *still* expect to see a sharp correlation between TFP and GDP in wage units that operates through an intertemporal substitution mechanism. The low correlation between GDP and the realized TFP shocks indicates that this channel is absent from the data.

Figure 2.3 also suggests that TFP shocks cannot explain unemployment dynamics. To see this more clearly using the Great Recession as an example, I present the same realized wedge series for the period 2000:1-2011:4 on Figure 2.4.[15] The model associates this recession with a large drop in productivity (Figure 2.4, top left). At the same time the labor supply wedge increases (Figure 2.4, bottom left) indicating that even such a prolonged sequence of negative TFP shocks is not enough to produce the rise in the unemployment rate observed since 2008. Later, I confirm this hypothesis by simulating an economy that is hit only by the realized TFP innovations with all other wedges

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[15]Notice that the scale on y-axis is different for each wedge series and is normalized according the wedge's variance to better see the dynamics.

A. Summary Statistics

Wedge	Variance relative to log output	Correlation with log output at lag k=				
		-2	-1	0	1	2
Efficiency	0.15	-0.2893	-0.2258	-0.0741	0.0080	0.0704
Investment	0.07	0.0253	-0.0548	-0.1469	-0.0807	-0.0630
Labor Supply	8.15	-0.8801	-0.9137	-0.9136	-0.8721	-0.8087
Labor Demand	0.64	-0.8248	-0.8854	-0.9414	-0.9203	-0.8848

5% critical value (two-tailed) for correlation coefficients is 0.1225

B. Cross Correlations

Wedges (X,Y)	Cross Correlation of X with Y at lag k=				
	-2	-1	0	1	2
Efficiency, Investment	0.2425	0.4758	-0.5250	-0.2658	-0.2369
Efficiency, LS	0.3128	0.2536	0.1562	0.0448	-0.0495
Efficiency, LD	0.2339	0.1787	0.0217	-0.0262	-0.0552
Investment, LS	-0.0279	0.0470	0.0887	0.1072	0.0932
Investment, LD	-0.0247	0.0482	0.1537	0.0483	0.0304
LS, LD	0.7540	0.7524	0.7244	0.6833	0.6353

5% critical value (two-tailed) for correlation coefficients is 0.1225

Table 2.3: Properties of the wedges 1948:1-2011:4

kept constant.

Do the implied TFP innovations look realistic? To answer this question I compare implied annualized changes in the logarithm of TFP in the model and in the data. The model counterpart of these series is

$$400 \cdot (ln(T\hat{F}P_t^{model}) - ln(T\hat{F}P_{t-1}^{model})) = 400 \cdot (z_t - z_{t-1}) \tag{2.30}$$

where series z_t are calculated using implied productivity innovations as

$$z_t = \hat{\rho} z_{t-1} + e_t^{eff}$$

Note that z_t in the model is stationary. In contrast, the TFP series in the data are growing:

$$TFP_t^{data} \equiv \left[\prod_{s=1}^{t} (1+g_s) \right] \times e^{\tilde{z}_t}$$

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where g_t is the trend component and $\tilde{z}_t$ is the cyclical component. This leads to the following expression for the annualized changes in the logarithm of TFP:

$$400 \cdot (ln(T\hat{F}P_t^{data}) - ln(T\hat{F}P_{t-1}^{data})) = 400 \cdot ln(1 + g_t) + 400 \cdot (\tilde{z}_t - \tilde{z}_{t-1}) \qquad (2.31)$$

Ideally, one would like to compare the series z_t and $\tilde{z}_t$. However, the observed series (LHS of equation (2.31)) is contaminated with a trend component $ln(1 + g_t)$ that is potentially different from period to period.

To address this, I plot the demeaned data for annualized change in the logarithm of TFP (Equation (2.31)) and its model counterpart (Equation (2.30)) in Figure 2.5. I use TFP data published on the website of the Federal Reserve Bank of San Francisco.[16] These two series should coincide if the trend component g_t was constant during the whole time period. Since trend component in TFP, g_t, varies over time, the data series are more volatile than the TFP series implied by the model. Nevertheless the series follow each other closely and exhibit the same pattern for the Great Recession: they both drop below the trend before the recession starts and stay below the trend until the end of the Recession. Figure 2.5 shows that the model picks up TFP fluctuations that are very close to the empirical estimates, not something else.

The other two wedge series - labor supply and labor demand - do not look like white noise at all. In fact, the labor supply wedge (the bottom left of Figure 2.3) is highly correlated with the unemployment rate. The labor demand wedge (the bottom right of Figure 2.3) is highly correlated with the output. Both of these observations suggest that these two wedges explain a significant fraction of the variation in the unemployment rate and the output respectively.

The last line in the second half of Table 2.3 shows why it is important to distinguish between the labor supply and the labor demand wedges. Since the correlation coefficient between these two series is very strong and negative the sum of these two series (which corresponds to what Chari *et al.* (2007) call the labor wedge) will be less volatile and potentially exhibit less autocorrelation, canceling out effects of each wedge.

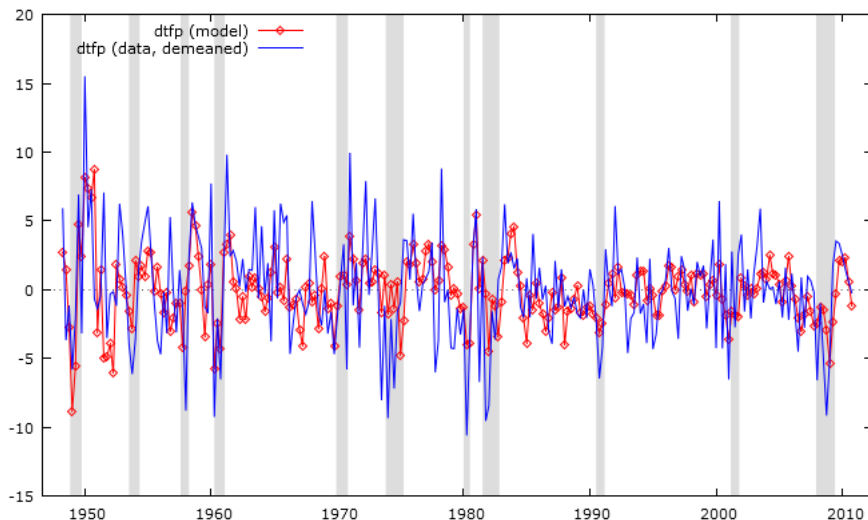[16]http://www.frbsf.org/csip/tfp.php

Figure 2.5: Annualized percent change in TFP: data vs. model. For definitions see equations (2.30) and (2.31).

2.4.6 The contribution of each wedge to the data fluctuations

In this section I assess the contribution of each wedge to the data fluctuations. I consider what Chari *et al.* (2007) call one- , two- and three-wedge economies to evaluate the contribution of each wedge. For example, to evaluate the contribution of TFP fluctuations, I consider the *efficiency only economy* where all wedges are constant except the efficiency wedge. To calculate the model predictions for this economy, I feed innovations $\varepsilon_t = [0, 0, \varepsilon_t^{eff}, 0]$ (where ε_t^{eff} are the realized TFP shocks) into the estimated policy function (2.28). Recall that if I feed realized innovations of all of the wedges into the estimated policy rules I get back the observed data. Thus, feeding only a subset of four wedges allows me to estimate a share of the variance explained by this subset of wedges.

All one-wedge economies are presented on Figures 2.6 – 2.9. Each of the figures compares the actual data (investment, output and the unemployment rate) with the series generated by the model when only a single realized wedge series is fed into the policy functions.

As Figure 2.6 shows, the investment wedge does not explain any of the series. This is consistent with the intuition I provided in the previous subsection. Recall that the investment wedge is the wedge in the Euler equation. Since it is the only forward-looking equation in the model, Figure 2.6 implies that the model captures intertemporal decisions of the agents well.
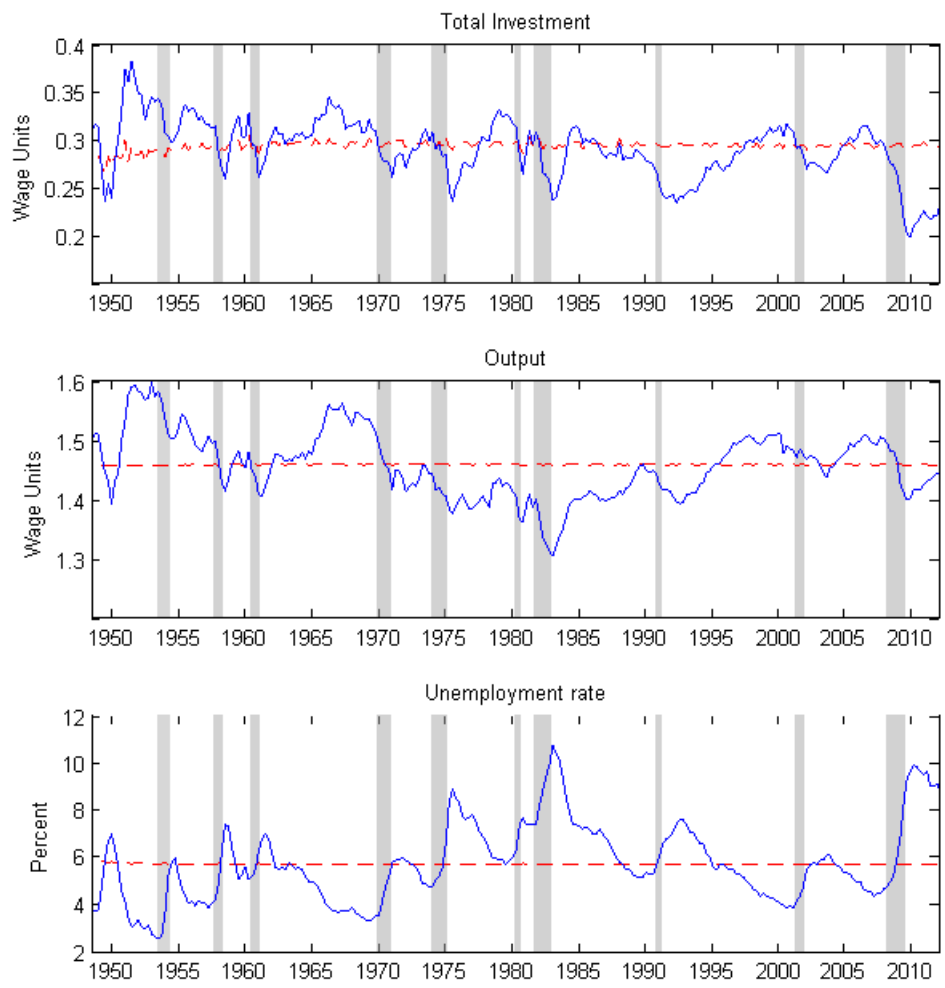
62

Figure 2.6: Investment wedge only economy. Dashed lines represent the series implied by the model. Solid lines represent the actual series.
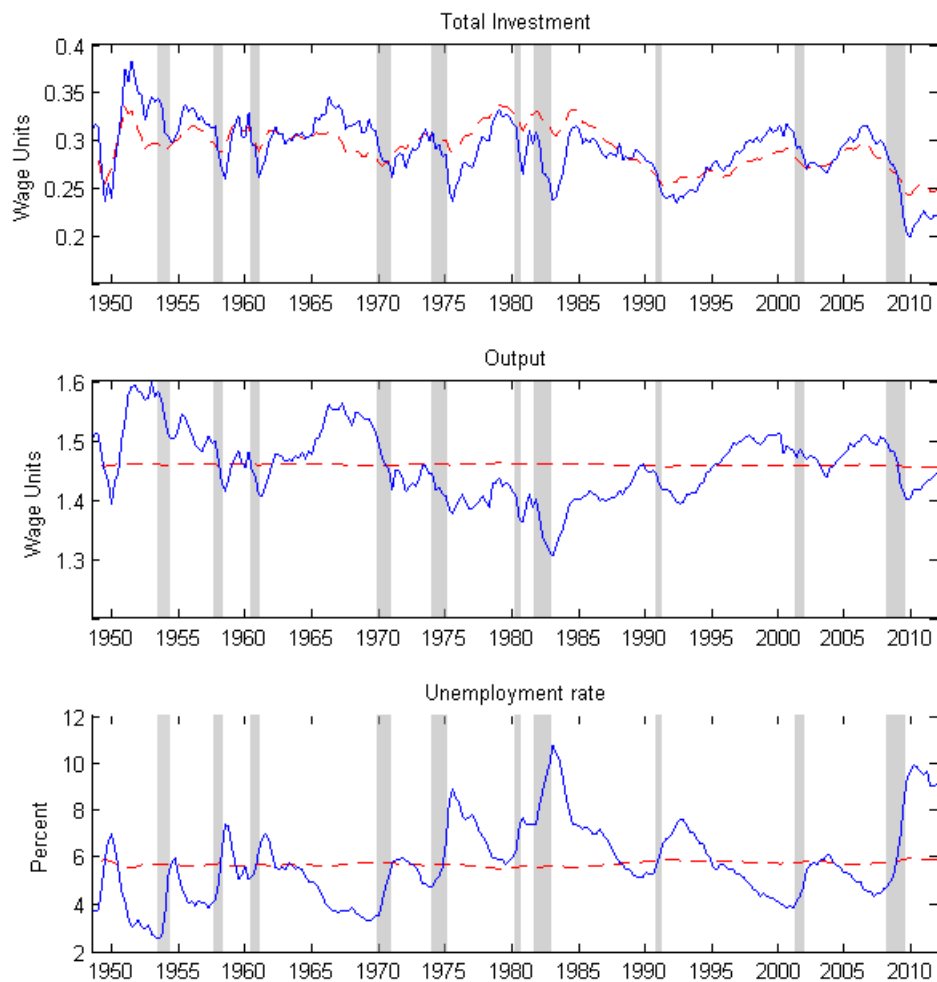
Figure 2.7: Efficiency wedge only economy. Dashed lines represent the series implied by the model. Solid lines represent the actual series.

Figure 2.7 presents the efficiency wedge only economy. This figure shows that the TFP fluctuations explain only part of the variation in the investment series, but they do not explain any fluctuations in either GDP or the unemployment rate. This is a striking result, because it reverses a key finding of the business cycle literature that 70% of all economic fluctuations can be attributed to changes in productivity. In the model, the ratio of real output to the real wage is almost flat, because the real wage reacts almost one-to-one to changes in productivity. In contrast, real investment is more elastic than the real wage with respect to an increase in productivity. Thus, the effect of a one-time increase in productivity is large for investment measured in wage units whereas for output it is negligible. This explains why TFP shocks explain a significant share of variation in the investment series while the explained share of output in wage units is close to zero (see Figure 2.7).

Figure 2.8 implies that the labor demand wedge explains a substantial share of output, but does not explain any variation in the unemployment rate or the investment series. This reflects the fact that the labor demand wedge is highly correlated with output (see the first half of Table 2.3). Recall, that this high correlation follows from the fact that the labor income share is countercyclical. In contrast, the Cobb-Douglas production function imposes a constant labor share. I assumed a constant labor share in the prototype economy to make my results comparable with those obtained by Chari *et al.* (2007). A possible solution to the autocorrelated residual in the labor demand equation is to assume a CES production function. This would make the labor income share a function of output and the current employment level.[17]

Finally, Figure 2.9 implies that the labor supply wedge explains almost all of the variation in the unemployment rate and significant shares of the variation in the output and the investment series. As in Chari *et al.* (2007) I find that the labor wedge explains a significant portion of variation in investment. In contrast to Chari *et al.* (2007) I find that it is the labor supply wedge that explains an overwhelming share of variation in the unemployment rate relative to the share of variation explained by the TFP fluctuations and the labor demand wedge.

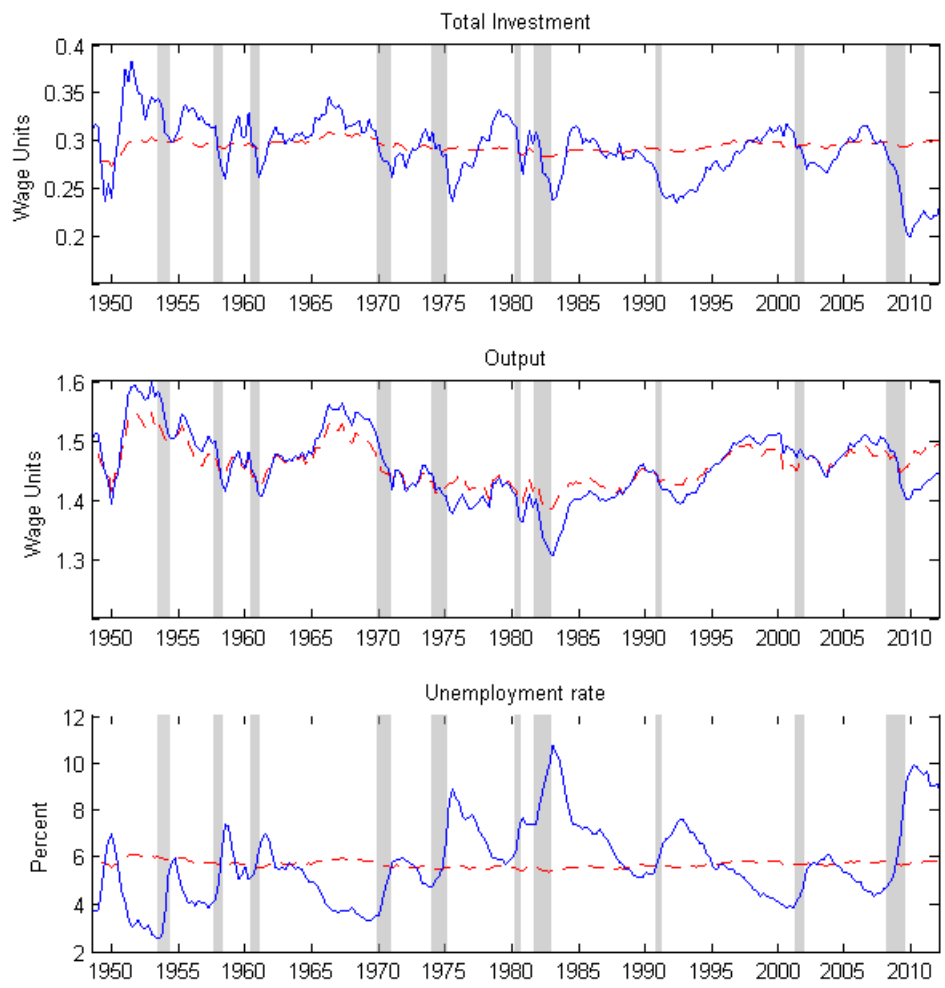[17]Choi and Rios-Rull (2009) propose this solution.

Figure 2.8: Labor demand wedge only economy. Dashed lines represent the series implied by the model. Solid lines represent the actual series.
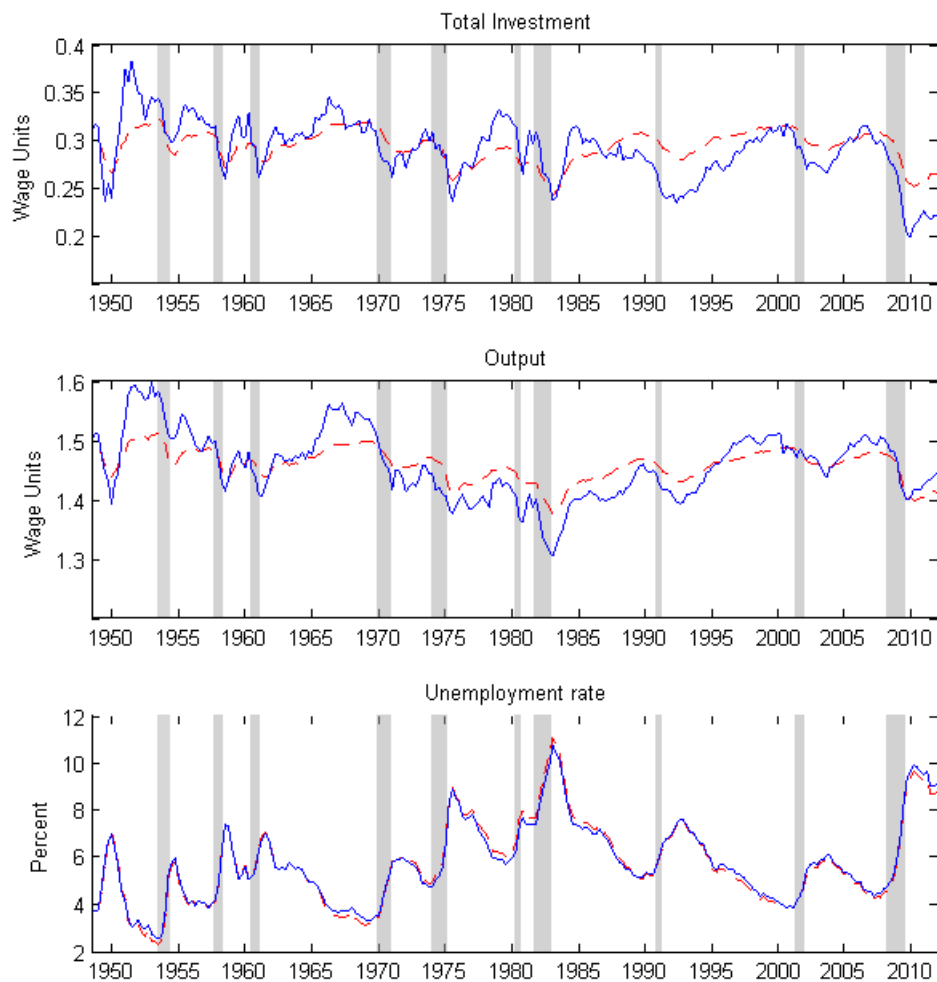
Figure 2.9: Labor supply wedge only economy. Dashed lines represent the series implied by the model. Solid lines represent the actual series..

	Percent of variation explained in log		
Wedges included*	Output	Unemployment rate	Investment
Efficiency*	0.20	1.32	49.45
Labor demand (LD)*	36.77	1.65	4.91
Labor supply (LS)*	23.67	114.23	30.32
Efficiency and LD*	36.58	2.12	50.94
LS and LD*	100.04	98.36	45.56

*Investment wedge always included

Table 2.4: Share of variation in output and unemployment explained by different wedges, defined as $\frac{var(log(x_t^{model}))}{var(log(x_t^{obs}))} \cdot 100\%$

Table 2.4 summarizes fractions of explained variance for economies with different subsets of wedges included. I include the investment wedge in all of the economies because it explains a negligible fraction of each series. It follows from the first three rows of Table 2.4 that the efficiency wedge explains approximately 50% of the variation in the investment series, the labor demand wedge explains 37% of variation in the output and 5% of variation in the investment series. The rest of the variation in the data is explained by the labor supply wedge. Note that all wedges except the labor supply wedge together explain a negligible share of the variation in the unemployment rate.

2.5   Discussion of the results

I discuss two questions in this section. Why does the standard RBC model fail to match the data measured in wage units? And why does it make sense to look not just at hours worked when studying business cycle fluctuations but rather at the unemployment rate?

The failure to match the data is not surprising, since the RBC model was constructed to match much less volatile data (deviations from the HP-trend.) To put HP-detrended GDP in perspective, Figure 2.10 presents three series: the demeaned logarithm of GDP in wage units, the HP cyclical component and the residual from a linear trend. The y-axis plots logarithmic deviations from trend (linear and HP-trends for series 2 and 3) and the mean (for GDP in wage units). This figure shows that the HP-cyclical component is the least volatile of the three series. Its standard deviation is 2
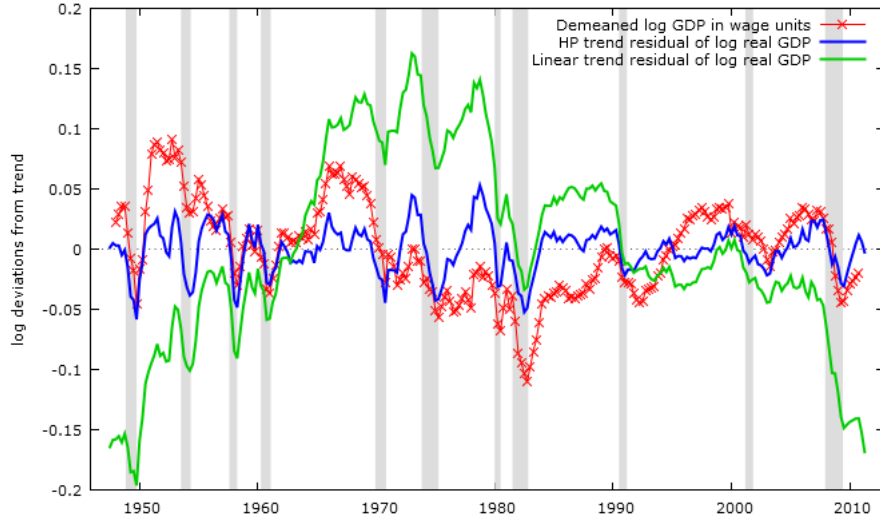
Figure 2.10: U.S. GDP detrended in three different ways.

times less than that of GDP in wage units and 4 times less than that of the linear trend residual.

While this is useful to study the HP cyclical component when economic fluctuations are relatively small, it eliminates a significant fraction of potentially interesting business cycle variation can explain persistence in the unemployment rate.

How is variation in the employment rate related to the variation in hours worked? How would using hours worked change the results of the accounting procedure? In the RBC literature hours worked per person are defined in the following way:

$$HoursWorked_t = \frac{h_t \cdot L_t}{P_t}$$

where h_t are the average number of hours worked per week, L_t is the number of people employed and P_t is noninstitutional population aged 16 to 64. Dividing both the numerator and denominator of the expression above by a measure of civilian labor force N_t one can decompose it into three terms.

$$HoursWorked_t = h_t \cdot \frac{L_t}{N_t} \cdot \frac{N_t}{P_t} = h_t \cdot (1 - u_t) \cdot \frac{N_t}{P_t} \tag{2.32}$$

where I define the unemployment rate as $u_t = 1 - \frac{L_t}{N_t}$. The third component in this expression,

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(a) Average hours per week   (b) Labor force participation rate (percent)
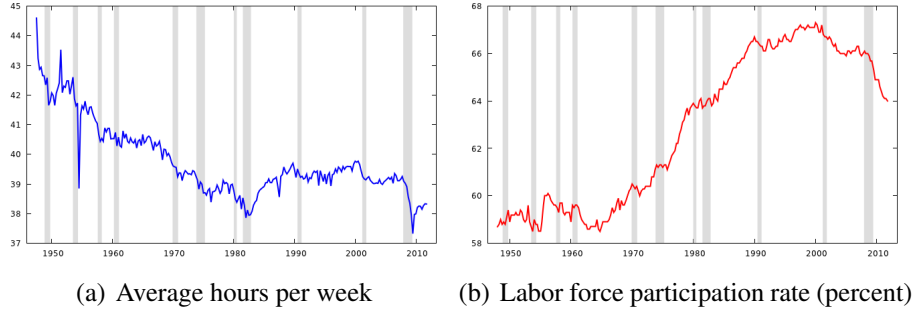
Figure 2.11: Components of the standard measure of hours worked.

$\frac{N_t}{P_t}$, is the labor force participation rate. I report the first and third components in Figure 2.11. Average hours per week, h_t, are depicted on the left.[18] These series do not exhibit much movement at business cycle frequencies with the possible exception of the Great Recession when hours dropped substantially. Similarly, the labor force participation rate, $\frac{N_t}{P_t}$ (see Figure 2.11, right) is acyclical.

Thus, almost all of the variation in the standard measure of hours worked at business cycle frequencies has to come from the employment rate, $1 - u_t$. Figure 2.12 supports this argument. It plots series of normalized hours worked (defined as in (2.32)) against the employment rate.[19] The series in Figure 2.12 are highly correlated, although hours worked are a noisier measure of employment. This is especially true for the period before 1976 for which the data sources used to derive the hours worked series are different and potentially less reliable.[20]

Given all the evidence above, if one were still to use hours worked as a measure of employment instead of the employment rate, why would not it improve performance of the model? The fact that the means of the two series are different is irrelevant, because it will only affect the estimate of ψ in the labor supply equation (2.21). The standard deviations of these series are very close: 0.016 for the employment rate vs 0.013 for the hours worked. This means that explaining hours worked series is not going to be easier for the model. Moreover, using hours worked instead of the employment rate will adversely affect the labor demand wedge, because an analog of Equation (2.6) does not exist for GDP in wage units and hours worked.

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[18]These series come from Cociuba *et al.* (2012).

[19]The series on hours worked come from the same paper: Cociuba *et al.* (2012).

[20]The Chow test confirms a structural break in the relationship between normalized hours series and the unemployment rate in 1976 at the 1% confidence level.
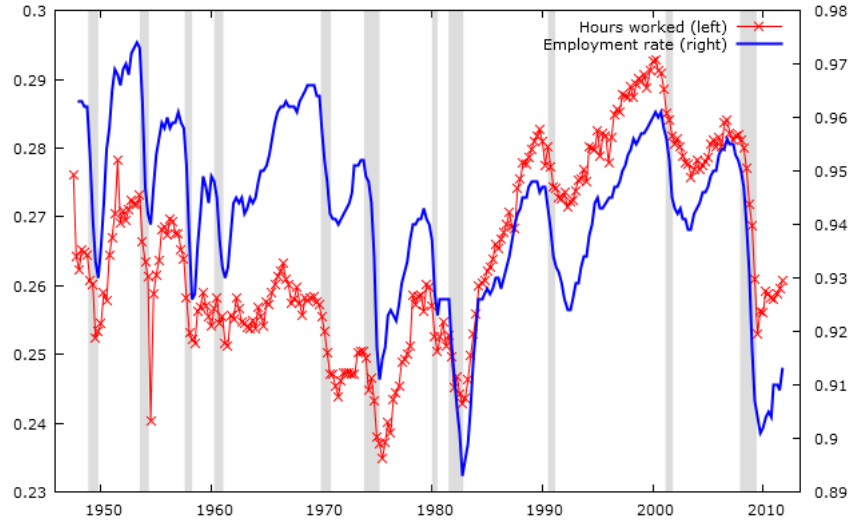
Figure 2.12: Normalized series of hours worked (left scale) and the employment rate (right scale)

To evaluate these arguments formally, I repeat the estimation procedure with the same priors for all parameters, using hours worked as a measure of employment instead of the employment rate. I obtain unrealistic and unstable posterior estimates of all of the parameters of the model. Logarithm of the likelihood function is almost two times as less than the benchmark estimation (1945 versus 1083). Additionally, the standard deviation of the labor demand wedge is more than 40 times larger than in the benchmark case.

To summarize, most of the variation in hours worked comes from the variation in the unemployment rate. Using hours worked as a measure of employment does not improve performance of the model.

2.6 Conclusion

This paper evaluates performance of the standard real business cycle model using aggregate U.S. data in wage units. The main advantage of using wage units instead of a conventional approach (such as the HP filter or a band-pass filter) is that this approach preserves medium-term fluctuations across macroeconomic series. As I show in the paper, these common medium-term fluctuations are an important component of the business cycle and should not be ignored.

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I find that the standard model has trouble explaining the data in wage units. In particular, I show that, first, productivity innovations explain only 50% of fluctuations in the investment series and virtually none of the fluctuations in GDP and unemployment. This contradicts the well-known stylized fact that productivity innovations can explain more than 70% of business cycle fluctuations. The failure of the RBC model to explain the data follows from the fact that GDP measured in wage units is twice as volatile as GDP filtered using the conventional approach. In other words, filtering data using the HP filter masks the problem by removing a major fraction of data volatility. This finding is consistent with the studies that looked at "medium-term business cycles" – the outcome of a band-pass filter.[21]

Second, I find that the smoothed labor demand wedge (which is equivalent to the labor income share) is strongly countercyclical. This as an argument in favor of an aggregate production function with a varying labor share (such as a CES production function) and against a Cobb-Douglas specification. This finding is consistent with Rios-Rull and Santaeulalia-Llopis (2010); Choi and Rios-Rull (2009).

Finally, data in wage units facilitates disaggregation of the labor wedge into the labor demand and the labor supply wedges. I show that the main problem is with the labor supply wedge, which accounts for 99% of the variation in the unemployment rate. Intuitively, the real business cycle model fits the data badly because the assumption that households are on their labor supply equation is flawed. This finding supports the assumptions made in the incomplete labor market literature (see Kocherlakota (2012); Farmer (2010b); Farmer and Plotnikov (2012a); Farmer (2011b)). This finding is also consistent with Justiniano *et al.* (2010) who find that labor supply shocks are important at low frequencies.

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[21]See Comin and Gertler (2006))

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Chapter 3

Does Fiscal Policy Matter? Blinder and Solow Revisited

3.1 Introduction

Economists are still debating the causes of the Great Depression seventy years later.[1] For thirty years after the publication of *The General Theory of Employment Interest and Money* (1936) the dominant theory attributed the Depression to a lack of aggregate demand. Most contemporary interpretations of Keynes are based on the idea that unemployment occurs because prices and wages adjust slowly in response to monetary shocks (Clarida *et al.*, 1999; Galí, 2008; Woodford, 2003). In a series of books and papers, Farmer (2008a,b, 2011b, 2010b,c,d) develops an alternative interpretation of Keynesian economics that does not rely on sticky prices. In (2010b) he raises the possibility, in a representative agent model with Keynesian unemployment, that a permanent increase in government expenditure will be ineffective at restoring full employment.

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[1]Monetary explanations of the Great Depression include the work of Friedman and Schwartz (1963) who blame the Fed for failing to prevent a collapse of the money supply and Bernanke (1983) who points to the effects of banking panics. Real explanations include the work of Temin (1978) who cites an autonomous drop in consumption, Ohanian (2009) who blames Herbert Hoover's labor policies and Cole and Ohanian (2004) who argue, using a neo-classical model, that the industrial policy of President Roosevelt's New Deal made an ordinary recession much worse. Mc-Grattan and Ohanian (2011, Forthcoming) have used the same model to study the role of fiscal policy in aiding the recovery. Our paper is most closely related to Harrison and Weder (2006) who use a model with an indeterminate steady state to explain the Great Depression. In contrast, our model is one with a continuum of steady states.

Farmer's (2010d) paper compared two steady state policies within the context of the *incomplete markets model*. In that model, confidence is an independent driving variable that determines the amount that households are willing to pay for assets. Farmer studied what would happen if an exogenous drop in confidence were to shift the economy from an equilibrium with full employment to a new equilibrium with high unemployment. By assumption, confidence would remain low for all future periods. He showed, in the context of that model, that a class of stationary balanced budget fiscal policies cannot restore full employment.

In this paper we revisit that result by studying temporary increases in government purchases. Our work is motivated by US experience during WWII when government purchases increased from 16% of GDP to 52% and government debt climbed from 40% of GDP to 120% in the space of three years.

In the paper we prove two propositions. First, we generalize the crowding out result of Farmer (2010b, Proposition 6.3, page 103) to non-stationary sequences of government expenditures. Second, we study a stylized class of policies in which there is a temporary boost to government expenditure of fixed duration. This class mimics the experience of the US during WWII. We prove, for this class of policies, that unemployment falls temporarily during the period of fiscal expansion. At the end of the boost it falls back to the level that would have occurred in the absence of the expansion.

We show that our model can quantitatively explain the movements in the unemployment rate and consumption during WWII by feeding into the model the actual paths of stock market wealth and government expenditures that occurred during this period. In the conclusion, we discuss the implications of our results for current economic policy.

3.2   Keynesian Economics and Crowding Out

In Farmer and Plotnikov (2012a) we show graphical evidence that stock market wealth was highly correlated with unemployment during the 1930s and again during the last decade. According

to Keynes, the drop in the value of the markets *caused* the Great Depression. But even if we were to accept this explanation, one would still be left with the puzzle of what generated the remarkable recovery that occurred with the onset of WWII. From 1938 to 1950 the stock market and unemployment were unrelated whilst unemployment fell from 20% in June 1938 to 1.2% in February 1944. An obvious candidate to explain the recovery is the huge increase in the size of government that occurred as the economy geared up for and entered WWII.

In textbook Keynesian analysis, fiscal policy works because consumption depends on income. But research on the consumption function after WWII (Dusenberry, 1949; Friedman, 1957) found that consumption is better explained by wealth. Milton Friedman developed the *permanent income theory* in which he explained how long-lived agents would plan to smooth out their consumption over time. His theory predicts that households will expect an increase in government borrowing to lead to future tax increases.

The permanent income theory predicts that increased government purchases will *crowd out* private consumption expenditure. Crowding out reduces the stimulative effect of increased government purchases and, in the extreme case, every dollar spent by government may cause households to consume one dollar less. In this extreme case fiscal policy will have no effect on output or employment and Farmer (2010b) showed that this is exactly what happens in the incomplete markets model if a fiscal expansion is permanent.

This paper asks a simple question in the same model: Can a reduction of unemployment be explained by a temporary increase in government purchases similar to the expansion that occurred in the US during WWII?

3.3   The Incomplete Markets Model

We assume that utility is logarithmic and that households have access to one period nominal bonds. Since there is no aggregate uncertainty, markets are complete. The assumption that utility is logarithmic implies that the following Euler equation holds in nominal terms,

$$\frac{1}{C_t} = \frac{\beta}{C_{t+1}}(1+i_t), \tag{3.1}$$

where C_t is the dollar value of consumption expenditure and i_t is the nominal interest rate.

Households' assets are the liabilities of a competitive financial sector which holds capital and government bonds. We assume that capital is non-reproducible and that it is valued at the price $p_{k,t}$. Capital is rented to the firms for the rental rent rr_t. The no arbitrage condition between investing in government bonds and investing in capital implies

$$1+i_t = \frac{p_{k,t+1} + rr_{t+1}}{p_{k,t}}. \tag{3.2}$$

The price of capital is not equal to the price of the consumption good because capital and consumption are different goods. We assume that there is one unit of non-reproducible capital.

We define Z_t to be the money value of GDP. From the national income accounting identity this is equal to the sum of nominal consumption C_t and nominal government expenditure G_t,

$$Z_t = C_t + G_t. \tag{3.3}$$

The structure of the labor market is explained in Farmer (2010b). Briefly, we assume two technologies; one for producing goods and one for matching workers with jobs. Firms take wages and prices as given and they allocate workers between production and recruiting to maximize profit. Farmer shows that this leads to a reduced form technology

$$y_t = Q_t^{1-\alpha} L_t^{1-\alpha} K_t^{\alpha} \tag{3.4}$$

where Q_t is an externality that depends on the number of workers being hired in the aggregate economy and y_t is the real value of output measured in physical units.[2]

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[2]This assumption generalizes to an economy with many different consumption goods and multiple capital goods. See Farmer (2010b).

This economy has the same two first order conditions as a standard neoclassical economy. These are represented by equations (3.5) and (3.6),

$$(1 - \alpha) Z_t = w_t L_t, \tag{3.5}$$

$$\alpha Z_t = rr_t, \tag{3.6}$$

where $Z_t = p_t y_t$ is nominal GDP as defined above.

3.4 Wages and the Labor Market

The model we have developed looks a lot like a one good representative agent model with a fixed labor supply. It behaves very differently. We assume that every household sends a measure 1 of workers to look for a job every period and that L_t of them find a job. To keep the labor market dynamics simple, we assume that the entire work force is fired every period and the process starts again next period.

Since this is a general equilibrium model without money, we are free to pick the numeraire. As in Farmer (2011b) we choose the money wage to be the numeraire by setting

$$w_t = 1. \tag{3.7}$$

To map our model economy into the data we will normalize nominal variables by a measure of the money wage. The money wage grows because of inflation and because of productivity improvements. By deflating GDP, consumption and government purchases by the money wage we are able to generate data series that are stationary.

3.5 What the Government Does

Households each supply one unit of labor and pay a labor income tax $\tau_t L_t$. Since labor is inelastically supplied, this tax is non distortionary. We abstract from capital taxes and sales taxes. We assume that government purchases G_t dollars worth of goods in period t and that the service flow provided by these goods is separable from private consumption in utility. Government chooses sequences $\{\tau_t, G_t, B_t\}$ that satisfy the intertemporal budget constraint

$$\sum_{s=t}^{\infty} \left(\frac{1}{1+i_s}\right)^{s-t} G_s + B_t(1+i_{t-1}) = \sum_{s=t}^{\infty} \left(\frac{1}{1+i_s}\right)^{s-t} (1-\alpha)\tau_s Z_s. \tag{3.8}$$

Here, B_t is nominal government debt, G_t is nominal government expenditure and τ_t is the tax rate on labor income.

3.6 Closing the Model with Beliefs

Most models of search are closed by assuming that firms and workers bargain to determine the wage. Following Farmer (2010b), we assume instead that workers and firms take the wage and the price as given. This leads to a labor market with one less equation than unknown. To close the model we assume that households form a sequence of self-fulfilling beliefs about the value of assets. We operationalize this assumption by taking the sequence $\{p_{k,s}\}_{s=t}^{\infty}$ to be chosen exogenously.[3] We call this sequence the *state of expectations*.

For any given state of expectations, our model contains the following four equations,

$$\frac{1}{Z_t - G_t} = \frac{\beta}{Z_{t+1} - G_{t+1}}(1+i_t), \tag{3.9}$$

$$1 + i_t = \frac{p_{k,t+1} + \alpha Z_{t+1}}{p_{k,t}}, \tag{3.10}$$

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[3] Farmer (2010a) shows how to operationalize the idea of animal spirits by defining a *belief function*. He estimates a three equation incomplete markets model and shows that it fits the US data better than a three equation new-Keynesian model.

$$L_t = (1 - \alpha) Z_t, \tag{3.11}$$

$$\sum_{s=t}^{\infty} \left(\frac{1}{1+i_s} \right)^{s-t} G_s + B_t (1 + i_{t-1}) = \sum_{s=t}^{\infty} \left(\frac{1}{1+i_s} \right)^{s-t} (1 - \alpha) \tau_s Z_s, \tag{3.12}$$

together with the initial condition,

$$B_t = \bar{B}_t. \tag{3.13}$$

A *fiscal policy* is a set of sequences $\{B_{s+1}, G_s, \tau_s\}_{s=t}^{\infty}$. If there exists a solution to equations (3.9)–(3.13) that remains bounded for all t we say that the fiscal policy is *feasible*. A perfect foresight equilibrium given the state of expectations $\{p_{k,s}\}_{s=t}^{\infty}$ is a feasible fiscal policy and a bounded set of sequences $\{Z_t, i_t, L_t\}$ that satisfy equations (3.9)–(3.13).

3.7 Steady State Solution

Farmer (2010b) showed that a stationary equilibrium of the model for a given state of expectations $\{p_{k,s}\}_{s=t}^{\infty}$ and a stationary sequence of government expenditures $G_s = G$ for $s = t \cdots \infty$ implies

$$C_s + G_s = Z_s = \frac{1-\beta}{\beta \alpha} p_k, \text{ for all } s. \tag{3.14}$$

Two interesting facts follow from Equation (3.14). First, one additional dollar of government expenditure decreases private consumption by one dollar. This follows because the RHS of Equation (3.14) does not depend on government expenditure, G_s. Second, the stationary equilibrium value of GDP depends on the state of expectations, p_k. Farmer (2010b) shows that p_k can taken any value in a bounded set and it follows from this fact that there is a continuum of stationary equilibria, each supported by a different stationary value of p_k and each associated with a different stationary unemployment rate.

Now consider the following experiment. Let the state of expectations fall from $p_{k,1}$ to $p_{k,2}$ where

$$p_{k,2} < p_{k,1}. \tag{3.15}$$

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In the new stationary equilibrium, GDP will be lower and the unemployment rate will be higher. If

expectations about the future prices of the assets in the economy never recover, the economy will

be in a new equilibrium with a higher unemployment rate for ever. But how does the economy

behave if $p_{k,t}$ and G_t are not constant sequences? Will the above result about crowding out hold?

We turn to that question next.

3.8 Main Results

This section presents the main results of the paper. First, we show that increased government

spending lowers consumption. Second, we show that a temporary increase in government pur-

chases can increase employment in the short-run.

The following proposition compares two economies: one with and one without government in-

tervention. We hold the state of expectations fixed. The proposition states that there is a *crowding*

out effect: private consumption will be lower in the economy with government spending.[4]

Proposition 1 *Consider two economies with the same state of expectations* $\{p_{k,s}\}_{s=t}^{\infty}$ *but with*

different feasible non-negative expenditure sequences $\{G_s\}_{s=0}^{\infty}$ *and* $\{\tilde{G}_s\}_{s=0}^{\infty}$. *Let* $\{\tilde{G}_s\}_{s=0}^{\infty}$ *be equal*

to zero for all s. Let there be a date T such that $G_s = 0$ *for all* $s > T$ *and* $G_s > 0$ *for all* $s \leq T$. *Then*

there is crowding out in the following sense. If $\{C_s\}_{s=t}^{\infty}$ *is the sequence of private consumption in*

the first economy and if $\{\tilde{C}_s\}_{s=t}^{\infty}$ *is the sequence of private consumption in the second economy*

then $\tilde{C}_s > C_s$ *for all* $s < T$.

Proof. *See Appendix A.* ∎

A statement about the exact effect of a government expansion on unemployment is more diffi-

cult to prove. Ideally one would want to have a condition for each sequence of government expen-

ditures that would tell us, depending on parameter values and the state of expectations, whether

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[4]It is easy to extend this result to the case where expenditure is positive in the second economy but lower than in
the first economy in every period. The extension of the proof is straightforward and is omitted.
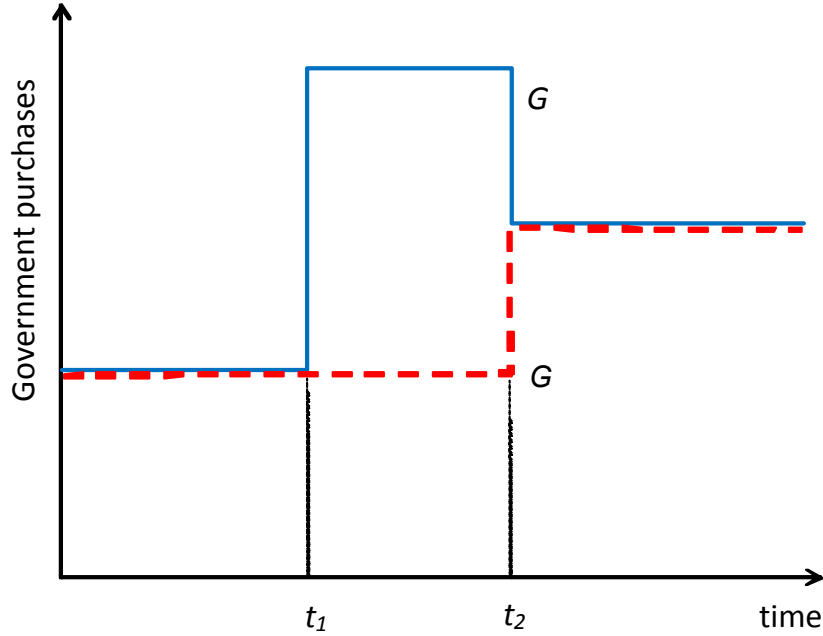
Figure 3.1: Government Purchases in the Treatment and Control Economies

such a policy will decrease or increase employment in the current and the following periods. We have not been able to prove a statement with this degree of generality.

Instead, we focus on a specific class of non-stationary fiscal policies, inspired by the experience of actual fiscal policy before and after WWII. Government purchases were approximately 16% of GDP before WWII. During the war they peaked at 52% and at the end of WWII they increased permanently to a new higher level of 23% of GDP.

We characterize this policy by studying the class of fiscal expansions depicted in Figure 3.1. We compare two economies with the same state of expectations but different fiscal policies. In the *control* economy there is a predetermined sequence of government expenditures $\tilde{G}_s$. In the *treatment* economy government expenditure increases by a fixed factor, $\Delta > 1$ at time $s = t_1$[5] and remains at $\Delta \cdot \tilde{G}_t$ for $t_2 - t_1$ periods. After period t_2, expenditure reverts to the sequence $\tilde{G}_s$. Figure 3.1 depicts a special case of this class where $\{\tilde{G}_t\}$ is constant for $s < t_2$ and increases to a new higher level after date t_2.

Given these policies we prove that the change in fiscal policy reduces unemployment during the

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[5]This experiment makes sense if $\tilde{G}_s > 0$ which we assume from now on.

expansion period at the cost of higher unemployment before the expansion. If the policy is unan-ticipated, it reduces unemployment during the expansion period with no cost. This corresponds to the case $t_1 = 0$.

Proposition 2 *Consider two economies with the same state of expectations $\{p_{k,s}\}_{s=t}^{\infty}$ but with different feasible non-negative expenditure sequences $\{G_s\}_{s=0}^{\infty}$ and $\{\tilde{G}_s\}_{s=0}^{\infty}$ in "treatment" and "control" economies. Let these sequences satisfy the properties,*

$$
G_s = \begin{cases}
\tilde{G}_s & \text{if } s < t_1, \\
\Delta \times \tilde{G}_s & \text{if } t_1 \leq s \leq t_2, \text{ where } \Delta > 1 \text{ is a constant} \\
\tilde{G}_s & \text{if } t_2 < s.
\end{cases}
$$

These assumptions imply that the treatment economy undergoes a fiscal expansion during the time interval $\{t_1...t_2\}$. Let $\{U_s \equiv 1 - L_s\}$ and $\{\tilde{U}_s \equiv 1 - \tilde{L}_s\}$ be the unemployment rates in each economy. There exists an integer $T \geq 1$, where $t_2 \equiv t_1 + T$, such that,

1. *Part 1 $U_s = \tilde{U}_s$ for $s > t_2$,*

2. *Part 2 $U_s > \tilde{U}_s$ for $s < t_1$,*

3. *Part 3 $U_s < \tilde{U}_s$ for $t_1 \leq s \leq t_2$.*

Proof. *See Appendix B.* ∎

Part 3 of Proposition 2 implies that a temporary fiscal policy expansion will reduce unem-ployment and it provides a basis for understanding why the boost in government purchases that occurred in 1941-1945 resulted in the end of the Depression. This proposition implies that a boost to fiscal spending will be effective at increasing employment for a finite time.

Our next proposition discusses the effect of changing the length of the expansion period on the effectiveness of fiscal policy. One might think that government would want to increase the length of the fiscal expansion in order to exploit the benefit of an increase in government expenditure on the unemployment rate. Proposition 3 implies that a permanent increase in government expenditure

at time $s = t_1$ will have *no* effect on the unemployment rate. Moreover, the positive effect on the unemployment rate at the beginning of the expansion becomes smaller at an exponential rate as the anticipated length of the expansion increases.

Because we are interested in the asymptotic behavior of GDP, we need to specify what happens to government expenditure in the limit. We will focus our analysis on the case when the share of government expenditure to GDP is constant as $t_2 \to \infty$. We distinguish two cases. As $t_2 \to \infty$:

$$\lim_{s \to \infty} \beta \left(1 + \alpha \frac{G_s}{p_{k,s}} \right) \equiv \beta (1 + \alpha x) < 1,$$
$$\lim_{s \to \infty} \beta \left(1 + \alpha \Delta \frac{G_s}{p_{k,s}} \right) \equiv \beta (1 + \alpha \Delta x) \geq 1,$$

(Condition A)

Or

$$\lim_{s \to \infty} \beta \left(1 + \alpha \frac{G_s}{p_{k,s}} \right) \equiv \beta (1 + \alpha x) < 1,$$
$$\lim_{s \to \infty} \beta \left(1 + \alpha \Delta \frac{G_s}{p_{k,s}} \right) \equiv \beta (1 + \alpha \Delta x) < 1.$$

(Condition B)

The first inequality that is common to Condition A and Condition B is necessary for the expenditure plan $\{\tilde{G}_s\}$ to be feasible given that households hold expectations $\{p_{k,s}\}$. The second inequality of Condition A will be satisfied if the increase in government purchases, represented by Δ, is large enough. In this case Proposition 3 implies that a boost to fiscal spending will only be effective at increasing employment for a limited time.

The second inequality of Condition B implies that the fiscal expansion is relatively small. Proposition 3 states that in this case an expansion in government spending, that is known to end at a some future date, will lower unemployment for an arbitrarily long period of time. But the longer the policy is expected to last, the less effective it will be when it is first implemented. Moreover, effectiveness at date t_1, decreases exponentially as $t_2 \to \infty$.

Proposition 3 *Consider two economies with the same state of expectations $\{p_{k,s}\}_{s=t}^{\infty}$ but with different feasible non-negative expenditure sequences $\{G_s\}_{s=0}^{\infty}$ and $\{\tilde{G}_s\}_{s=0}^{\infty}$ in "treatment" and "control" economies. Let these sequences satisfy the properties,*

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$$G_s = \begin{cases} \tilde{G}_s & \text{if } s > t_2 \\ \Delta \times \tilde{G}_s & \text{if } t_1 \leq s \leq t_2, \ \Delta > 1 \\ \tilde{G}_s & \text{if } s < t_1 \end{cases}$$

Let $\{U_s\}$ and $\{\tilde{U}_s\}$ be the unemployment rates in each economy and let $\Delta > 1$ and $x > 0$ be constants. Then

1. *$U_s = \tilde{U}_s$ for $s > t_2$*

2. *$U_s > \tilde{U}_s$ for $s < t_1$*

    (a) *If Condition A holds then there exists an integer $T \geq 1$ such that*

        i. *If $|t_2 - t_1| \leq T$ then $U_s < \tilde{U}_s$ for $t_1 \leq s \leq t_2$*

        ii. *If $|t_2 - t_1| > T$ then $U_s > \tilde{U}_s$ for $t_1 \leq s < t_2 - T$ and $U_s < \tilde{U}_s$ for $t_2 - T \leq s \leq t_2$*

    (b) *If Condition B holds then $U_s < \tilde{U}_s$ for $t_1 \leq s \leq t_2$, but for all fixed $\bar{s} \in [t_1, t_2)$ $U_{\bar{s}} \to \tilde{U}_{\bar{s}}$ as $t_2 \to \infty$ monotonically at an exponential rate.*

Proof. *See Appendix C.* ∎

Note that as a special case, Proposition 3 states that if Condition B holds and if $t_2 = \infty$, then $U_s = \tilde{U}_s$ for all $s \geq t_1$. In other words, the fiscal expansion has no effect on the unemployment rate.

3.9   An Application to the Data

Our theory predicts that movements in the unemployment rate are caused by movements in aggregate demand. To address the plausibility of our explanation, we took the observed movements in wealth and government purchases from the data and we used them to infer the implied movements in consumption from our model.

We used government purchases from the NIPA accounts and the S&P 500 and we deflated both series by a measure of the nominal wage. The wage series was also constructed from NIPA data
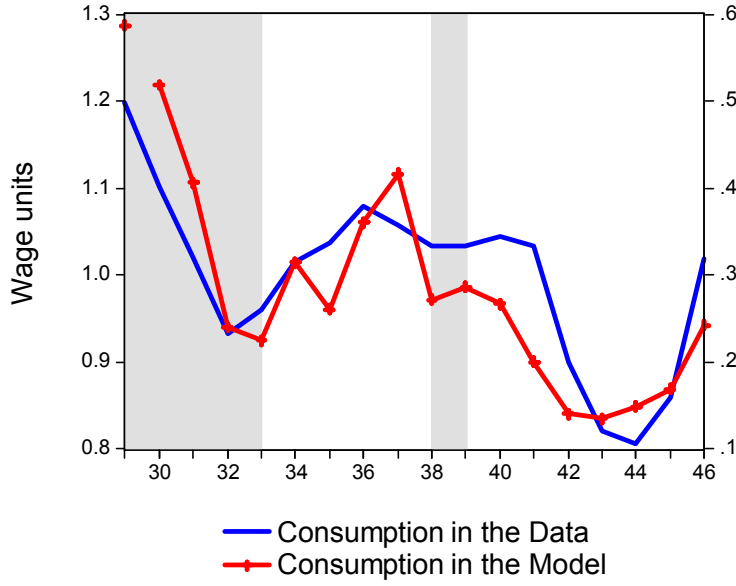
Figure 3.2: Consumption in the Data and in the Model

using the methodology described in Farmer (2010b). Using these series we fixed C_T where $T = 1947$ and we calculated the implied consumption series by setting $\alpha = 0.33$, $\beta = 0.96$ and using the actual values of the series on government expenditure and the stock market $\{G_s, p_{k,s}\}_{s=1929}^{1947}$, by solving Equations (3.9)–(3.13). The result of this experiment is graphed in Figure 3.2.

Since the S&P is an index number, the units of our real wealth variable are only defined up to a scalar multiple where the weight attached to each data point reflects money prices at the inception date of the index. We normalized the value of the index by scaling the S&P series by 579, a value that implies that the economy was in a steady state in 1929. This scaling factor, μ, is defined by the steady state relationship

$$\mu = \frac{C_{1929} + G_{1929}}{p_{k,1929}} \frac{\beta \alpha}{(1 - \beta)}. \tag{3.16}$$

The model predicts that consumption is related to wealth. Since the S&P is only a partial measure of all tangible assets, our model is unlikely to capture all of the movements in employment and consumption in the data. We would hope, however, the model is capable of capturing the movements in the consumption series implied by changes in government expenditure and in stock
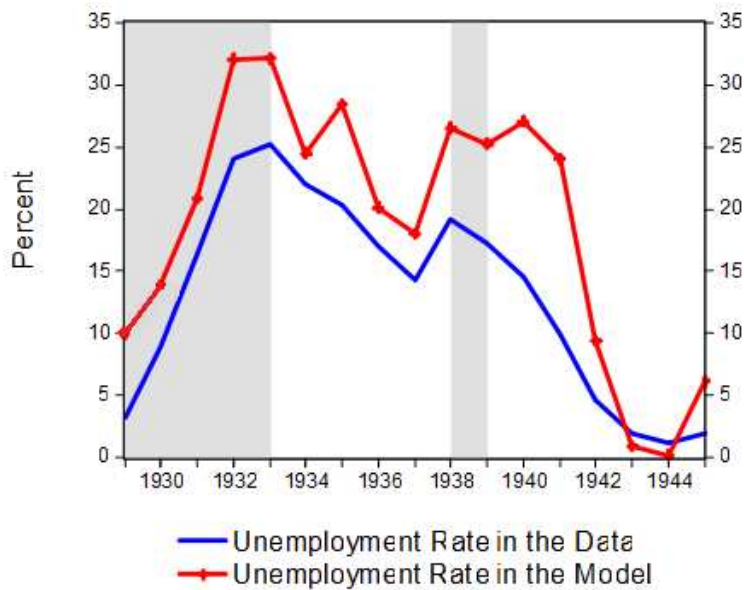
Figure 3.3: Unemployment in the Data and in the Model

market wealth. The fact the actual and model series for consumption move relatively closely gives us some encouragement that the theory is on the right track.

In Figure 3.3 we plot the unemployment rate in the data and the unemployment rate implied by our model using Equation (3.11) where Z_t is the sum of the actual government expenditure series and the consumption series implied by our model.

We have more confidence in the *movements* of this series than in its *level* which is sensitive to a normalization constant that defines the supply of labor. Notice that our model is able to capture the reduction in the unemployment rate as the U.S. economy gears up for WWII which occurs as a result of the huge increase in government purchases that began in 1941.

Since our model assumes that capital is fixed, we are unable to discuss the effects of government purchases on investment. Barro 2008 has argued that these effects were substantial and that consumption moved very little in response to a fiscal expansion during WWII. Our own analysis (see Farmer and Plotnikov (2012a)) finds a measurable impact of government purchases on consumption when series are measured in wage units. Part of the discrepancy with Barro's findings are caused by this difference in the deflator. We chose the model with fixed capital because it allows us
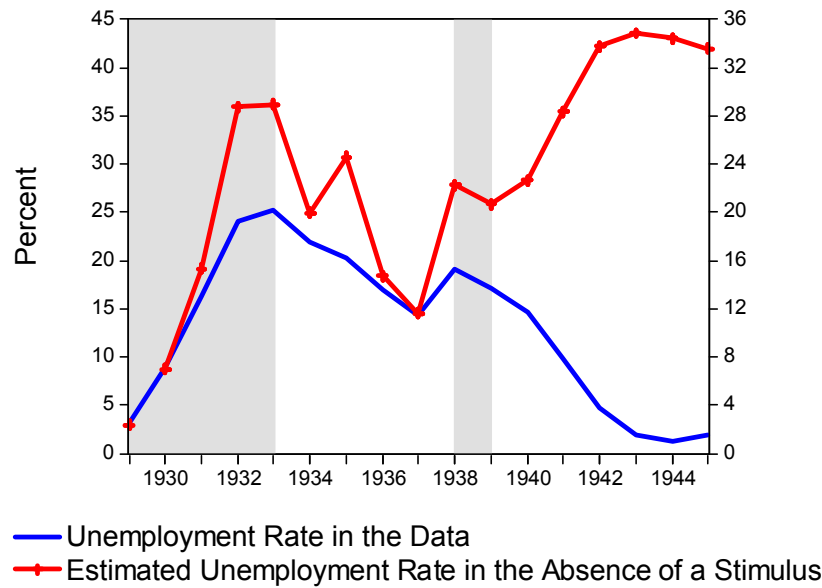
Figure 3.4: Predicted Unemployment without a Fiscal Stimulus

to discuss, in a relatively simple model, what happens to unemployment in response to a change in the relative price of capital. In the one-good real business cycle model this relative price is always one and that is not a good framework for thinking about stock market movements.[6]

We can also use our model to ask a second question. What would have happened to the unemployment rate in the early 1940s if the government had not increased expenditures from 16% to 52% of the economy and if the stock market had followed the same path that we observed during this period? To answer this question we took the same series for $p_{k,t}$, but we fed in a different series for government expenditures for the years $1941 - 1945$ by assuming that government spending during these years remained at the 1940 level. Since we are treating the state of expectations as an independent variable, that is a legitimate question within the context of the model. Figure 3.4 presents results of this experiment. The actual unemployment rate is plotted on the left axis and the model unemployment rate on the right.

The model predicts that without a large fiscal stimulus, and conditional on the actual path of

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[6]We are currently working on an extension of these results to models that allow for investment by incorporating a cost of adjustment and more realistic labor market dynamics.

the stock market, the unemployment rate would have increased dramatically in the early 1940s. These findings are consistent with propositions 1 and 2 which show that a *temporary* increase in government expenditure is predicted to crowd out consumption and reduce unemployment.

3.10 Conclusion

To summarize, the paper studies the effect of an expansionary fiscal policy on output and employment in the economy using Farmer's (2010b) incomplete markets framework. We find that expansionary fiscal policy increases economic activity and reduces unemployment in the short-run at the cost of reduced consumption. If the stimulus is foreseen, there will be an additional cost of reduced employment in the years leading up to the increase in government purchases.

Given its simplicity, the model does a good job of fitting actual data for the period of the Great Depression and the early years of WWII. It is encouraging that the dynamic version of the model can explain why a fiscal stimulus increased employment in the 1940s since the steady state version of the same model implies 100% crowding out of consumption and no effect on the unemployment rate.

But the fact that a temporary fiscal stimulus can be shown to increase employment does not mean that it is the right policy to cure a depression. The crowding out of consumption that occurs in the model implies a substantial welfare loss associated with increased government expenditure unless the government purchases goods that have a significant social value. That clearly *was* the case in WWII since the US was fighting for its survival. Most of the newly employed people were directed to the war effort either directly by enlisting in the army or indirectly by producing munitions.

The case for fiscal stimulus in the current crisis is less clear. If the economy is not self-correcting as Keynes believed, a large fiscal expenditure may not be the best way to restore full employment. In the model we have outlined in this paper, it is critical to increase the value of confidence in the value of private wealth in order to permanently restore jobs.

Appendix A: Proof of Proposition 1

To prove Proposition 1 we first prove:

Lemma 1: *If there exists a date s for which $\tilde{C}_s > C_{s+1}$ then $\tilde{C}_s > C_s$.*

Proof. Combining equations (3.1), (3.2) and (3.6), it follows that $\{\tilde{C}_s\}_{s=t}^{\infty}$ satisfies the equation

$$\frac{1}{\beta}\frac{p_{k,s}}{\tilde{C}_s} = \alpha + \frac{p_{k,s+1}}{\tilde{C}_{s+1}}, \tag{A1}$$

and $\{C_s\}_{s=t}^{\infty}$ satisfies

$$\frac{1}{\beta}\frac{p_{k,s}}{C_s} = \alpha + \frac{p_{k,s+1}}{C_{s+1}} + \alpha\frac{G_{s+1}}{C_{s+1}}. \tag{A2}$$

Dividing (A2) by (A1) and defining

$$f(x) = \frac{1}{\beta}\frac{p_{k,t}}{x} - \alpha, \tag{A3}$$

we have

$$\frac{f(C_s)}{f(\tilde{C}_s)} = \frac{\tilde{C}_{s+1}}{C_{s+1}}\left[1 + \alpha\frac{G_{s+1}}{p_{k,s+1}}\right]. \tag{A4}$$

Since $f(x)$ is decreasing in x, it follows that if

$$\frac{\tilde{C}_{s+1}}{C_{s+1}}\left[1 + \alpha\frac{G_{s+1}}{p_{k,s+1}}\right] > 1, \tag{A5}$$

then $\tilde{C}_s > C_{s+1}$. QED ∎

Proof. [Proof of Proposition 1] Note that $\tilde{C}_{T+1} = C_{T+1}$ and $\{G_s = 0\}_{s=T+1}^{\infty}$ since the economies are identical from date $T+1$ onwards, it follows from (A1) and (A2) that $\tilde{C}_T = C_T$. Since $G_s/p_{k,s} > 0$ for $s \le T$,

$$\frac{\tilde{C}_T}{C_T}\left[1 + \alpha\frac{G_T}{p_{k,T}}\right] > 1. \tag{A6}$$

But then, it follows from Lemma 1 that $\tilde{C}_s > C_s$ for $s < T$. QED ∎

Appendix B: Proof of Proposition 2

Proof. It follows from Equation (3.11) and the definitions of U_t and $\tilde{U}_t$ that

$$U_s < \tilde{U}_s \iff Z_s > \tilde{Z}_s. \tag{B1}$$

Thus, instead of proving a statement about a relationship between unemployment rates, we can prove an equivalent statement about GDP.

Combining (3.1) and (3.3) gives the following expressions that must hold in each economy

$$\frac{1}{\beta} \frac{p_{k,s}}{C_s} = \frac{p_{k,s+1}}{C_{s+1}} + \alpha \frac{G_{s+1} + C_{s+1}}{C_{s+1}}, \tag{B2}$$

$$\frac{1}{\beta} \frac{p_{k,s}}{\tilde{C}_s} = \frac{p_{k,s+1}}{\tilde{C}_{s+1}} + \alpha \frac{\tilde{G}_{s+1} + \tilde{C}_{s+1}}{\tilde{C}_{s+1}}. \tag{B3}$$

Proof of Part 1: By assumption, the sequence of government expenditures is the same in both economies for $s > t_2$. It follows that

$$C_s = \tilde{C}_s \quad \forall s > t_2 \tag{B4}$$

Combining Equation (B4) with the national accounting identity for $s > t_2$ we obtain that $Z_s = \tilde{Z}_s \quad \forall s > t_2$. This proves Part 1.

Proof of Part 2

Note that, by assumption, there is a fiscal expansion in the treatment economy during the period $[t_1, t_2]$. It follows from Proposition 1, that

$$C_s < \tilde{C}_s \quad \forall s < t_2 \tag{B5}$$

But $G_s = \tilde{G}_s$ if $s < t_1$. It follows from the national income accounting identity that $Z_s < \tilde{Z}_s, \quad \forall s < t_1$. This proves Part 2.

Proof of Part 3.

We must show that if $|t_2 - t_1| \leq T$ where T is a fixed number then

$$C_s + G_s > \tilde{C}_s + \tilde{G}_s \quad \forall t_1 \leq s \leq t_2. \tag{B6}$$

Suppose first that $T = |t_2 - t_1| = 1$. Since $C_T = \tilde{C}_T$, and $G_T > \tilde{G}_T$, it follows immediately that $Z_T > \tilde{Z}_T$ and hence a one period increase in government expenditure increases GDP. To establish that T may be greater than 1, consider the following change of variables. Divide both sides of Equation (B6) by $\tilde{G}_s$ and define $\tilde{y}_s$ and y_s,

$$\tilde{y}_s \equiv \frac{\tilde{G}_s}{\tilde{C}_s}, \quad y_s \equiv \frac{G_s}{C_s}. \tag{B7}$$

Since we assume that, for $t_1 \leq s \leq t_2$,

$$\frac{G_s}{\tilde{G}_s} \equiv \Delta > 1, \tag{B8}$$

some simple algebra establishes that inequality (B6) is equivalent to the statement

$$\Delta > \frac{\frac{1}{\tilde{y}_s} + 1}{\frac{1}{y_s} + 1} \equiv \frac{1 + \tilde{y}_s}{g(s) + \tilde{y}_s} \equiv f(s), \tag{B9}$$

for all $t_1 \leq s \leq t_2$ where $g(s) \equiv \frac{\tilde{y}_s}{y_s}$. To establish (B9), we will show (1) that $\tilde{y}_s$ and y_s each satisfy a non-autonomous quasi-linear difference equation (2) that $\tilde{y}_s = y_s$ for $s > t_2$ (3) $g(t_2 + 1) = 1$ and (4) $g(s) < g(s+1)$ for $t_1 < s < t_2$. Together, these statements imply that $f(t_2 + 1) = 1 < \Delta$ and that $f(s)$ is increasing as we move backwards in time from t_2. Since (B9) is equivalent to (B6), for all s for which $f(s) < \Delta$, a fiscal expansion increases GDP and reduces unemployment. We now turn to the properties of $f(s)$ by showing that (1)–(4) hold.

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(1) Define two exogenous variables $\tilde{x}_s$ and x_s

$$\tilde{x}_s \equiv \frac{\tilde{G}_s}{p_{k,s}}, \quad x_s \equiv \frac{G_s}{p_{k,s}}, \tag{B10}$$

and let

$$\lambda_s \equiv \beta \left(\frac{x_s}{x_{s+1}} + \alpha x_s \right), \quad \theta_s \equiv \alpha\beta x_s, \tag{B11}$$

and

$$\tilde{\lambda}_s \equiv \beta \left(\frac{\tilde{x}_s}{\tilde{x}_{s+1}} + \alpha\tilde{x}_s \right), \quad \tilde{\theta}_s \equiv \alpha\beta\tilde{x}_s. \tag{B12}$$

Using these definitions, it follows from equations (B2) and (B3) that $\{y_s\}$ and $\{\tilde{y}_s\}$ are character-ized by the following simple recursions:

$$y_s = \lambda_s y_{s+1} + \theta_s, \tag{B13}$$

and

$$\tilde{y}_s = \tilde{\lambda}_s \tilde{y}_{s+1} + \tilde{\theta}_s. \tag{B14}$$

This establishes (1).

(2) Notice that from date $t_2 + 1$ onwards both economies are identical and hence

$$\tilde{y}_{t_2+1} = y_{t_2+1}. \tag{B15}$$

This establishes (2).

(3) Since $\tilde{y}_{t_2+1} = y_{t_2+1}$ it follows from the definition of $g(s)$ that $g(t_2+1) = 1$. This establishes (3).

(4) Notice that for $t_1 \leq s \leq t_2$

$$\theta_s = \Delta\tilde{\theta}_s > \tilde{\theta}_s, \quad \text{and} \quad \tilde{\lambda}_s > \lambda_s. \tag{B16}$$

For $s = t_2$

$$\lambda_s = \Delta\tilde{\lambda}_s > \tilde{\lambda}_s, \tag{B17}$$

while for $t_1 \leq s < t_2$,

$$\lambda_{t_2} = \beta\left(1 + \alpha\Delta x_{t_2}\right) > \beta\left(1 + \alpha x_{t_2}\right) = \tilde{\lambda}_{t_2}. \tag{B18}$$

Moving backwards in time from t_2, it follows from (B13)–(B18) that for $t_1 \leq s \leq t_2$,

$$\frac{y_s}{y_{s+1}} > \frac{\tilde{y}_s}{\tilde{y}_{s+1}}, \tag{B19}$$

and hence

$$g(s) = \frac{\tilde{y}_s}{y_s} < \frac{\tilde{y}_{s+1}}{y_{s+1}} = g(s+1). \tag{B20}$$

This establishes (4).

We have established that $f(t_2) = 1 < \Delta$ and that $f(s)$ is increasing as s moves back in time from t_2. It follows that there exists a $T \geq 1$ such that $f(s)|s \in \{t_2 - T, \ldots t_2\} < \Delta$. QED. ∎

Appendix C: Proof of Proposition 3

Proof. Using the notation from the proof of Proposition 2, there are two possible cases: either at some $s = t_2 - T$, $f(s) > \Delta$ or $f(s) \to \Delta$ as $s \to -\infty$. The first case correspond to Condition A and the second corresponds to Condition B. It follows from Condition A that for sufficiently small s,

$$\lambda_s \equiv \beta\left(\frac{\tilde{x}_s}{\tilde{x}_{s+1}} + \alpha\Delta\tilde{x}_s\right) \geq 1, \tag{C1}$$

and

$$\tilde{\lambda}_s \equiv \beta\left(\frac{\tilde{x}_s}{\tilde{x}_{s+1}} + \alpha\tilde{x}_s\right) < 1. \tag{C2}$$

These inequalities imply that the gap between $\tilde{y}_s$ and y_s will grow as s decreases from t_2 and hence there must be a T such that at $s = t_2 - T$, $f(s) > \Delta$. At this point the fiscal expansion will

lower output and increase unemployment. This establishes that T is finite if Condition A holds.

Now suppose that Condition B holds. Recall (B9), which we restate below

$$\Delta > \frac{\frac{1}{\tilde{y}_s} + 1}{\frac{1}{y_s} + 1} \equiv \frac{1 + \tilde{y}_s}{g(s) + \tilde{y}_s} \equiv f(s). \tag{C3}$$

We established in the proof of Proposition 2 that y_s and $\tilde{y}_s$ satisfy the recursions

$$y_s = \lambda_s y_{s+1} + \theta_s,$$

and

$$\tilde{y}_s = \tilde{\lambda}_s \tilde{y}_{s+1} + \tilde{\theta}_s,$$

and since we restrict ourselves to the case where $x_s \to x$ as $s \to -\infty$,[7] it follows from Condition B that $\lambda_s, \tilde{\lambda}_s, \theta_s$ and $\tilde{\theta}_s$ are constants in the limit and that λ_s and $\tilde{\lambda}_s$ are both positive and less than one. Hence as $s \to -\infty$

$$y_s \to y = \frac{\theta}{1 - \lambda}, \tag{C4}$$

and

$$\tilde{y}_s = \tilde{y} = \frac{\tilde{\theta}}{1 - \tilde{\lambda}}. \tag{C5}$$

From the definitions of $\lambda_s, \tilde{\lambda}_s, \theta_s$ and $\tilde{\theta}_s$ and the definition of $f(s)$ one can establish that as $s \to -\infty$

$$f(s) \to \frac{\frac{1-\beta}{\alpha\beta\bar{x}}}{\frac{1-\beta}{\alpha\beta\Delta\cdot\bar{x}}} = \Delta. \tag{C6}$$

Since establishing that $f(s) = \Delta$ is equivalent to showing that (B6) holds as an equality we have shown that a fiscal expansion that is expected to persist for an arbitrarily long period will have an arbitrarily small effect on GDP and employment. QED ∎

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[7]This is identical to the statement that government purchases constitute a constant share of GDP since in the long-run GDP itself is proportional to $p_{k,s}$.

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