Debt Hangover in the Aftermath of the Great Recession*

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November 14, 2016

Abstract

Following the Great Recession, U.S. government debt levels ended up well over 100% of output. We develop a dynamic general equilibrium model to evaluate the role of various shocks during and after the Great Recession; shocks directly affecting the labor market are found to have the greatest impact on macroeconomic activity more broadly. We then evaluate the macroeconomic consequences of using a variety of fiscal policy instruments to implement a fiscal austerity program to return the debt-output ratio to its pre-Great Recession level. Our welfare analysis reveals that the capital income tax is the most preferred option while the labor income tax is the least preferred.

Keywords: Fiscal policies, tax reforms, government debt, government deficits.

JEL Classification: E24, E37, E62.

*We thank seminar participants at the University of Guelph and the Royal Economic Society Meeting (2016). We acknowledge financial support from the ANR-15-CE33-0001-Projet FIRE. Gomme acknowledges financial support from SSHRC 435-2016-1388.

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1 Introduction

The basic facts of the U.S. Great Recession are well known: macroeconomic activity dropped sharply, and the recovery has been protracted. While there is a general consensus that the underlying cause of the Great Recession was a financial crisis, there is less agreement as to the nature of the shocks that lead to the protracted recovery. A further consequence of the Great Recession that U.S. government debt now exceeds 100% of GDP. Such debt levels have very real consequences. Maintaining such a high level of debt necessarily requires some combination of government spending cuts and tax increases. Further, a high level of debt places the U.S. economy closer to its natural debt limit, leaving little wiggle room in the face of future economic downturns.

We develop a dynamic general equilibrium model of the U.S. with two goals. The first is to characterize the set of shocks driving U.S. macroeconomic activity through the Great Recession and subsequent recovery, the end of which we place at the end of 2014 when output returned close to trend, and the unemployment rate fell to pre-Great Recession levels. The second objective is to evaluate alternative fiscal policy instruments — government spending and taxes — to return the government debt-output ratio to its pre-Great Recession level.[1]

Key features of the model include the following. First, public consumption goods are valued by households making the tradeoff between government spending and taxes meaningful.[2] Second, labor markets incorporate Mortensen-Pissarides search frictions captured by a matching function, and so the model can address issues related to unemployment.

The following set of shocks are fed into the model simulations. First, a collection of fiscal shocks: government spending; tax rates on labor income, capital income, and consumption; and unemployment insurance payments. The unemployment insurance schedule is computed as the average unemployment insurance payment per unemployed person, and so succinctly

[1]Default, either explicit or implicit through inflation is ruled out. Returning the debt-output ratio to its pre-Great Recession value is motivated by the observation that the U.S. economy was performing well prior to the Great Recession.

[2]An alternative, government spending on public works projects, is left to future research.

captures the outcome of the various extensions to unemployment insurance benefits during and after the Great Recession; see Rothstein (2011) for the history of these benefits extensions. Second, a financial shock: motivated by Christiano, Eichenbaum, and Trabandt (2015), this shock is captured by a wedge in households' capital accumulation Euler equation. This shock is measured by the spread between the National Income and Product Accounts return to capital (see Gomme, Ravikumar, and Rupert, 2011) and the 20 year Treasure Inflation-Indexed Security. Third, a pair of labor market shocks: the probability of a job separation (taken directly from the data), and the cost of a job vacancy (inferred from the observed job-finding probability). Finally, a total factor productivity shock that is chosen so that the model's prediction for the path of output matches actual.

An important contribution of the paper is to evaluate the role played by the various shocks. To do so, the model is re-simulated with no variation in one or more shocks, with the contribution of a particular shock given by the difference between the new and original paths of macroeconomic variables. Contrary to perceived wisdom and the findings of Christiano, Eichenbaum, and Trabandt (2015), we find little role for the financial shock. This result suggests that reduced form wedge shocks of this ilk are inadequate substitute for a deeper modeling of the role of finance in the macroeconomy. We find that the Great Recession and recovery is largely a story of labor market shocks, with important contributions due to changes in the job separation probability, the vacancy posting cost, and unemployment insurance payments. The chief contribution of the fiscal shocks is to push the path for the debt-output over 100%, as seen in the data. In particular, the Great Recession and recovery are characterized by a temporary increase in government spending reflecting the effects of the American Recovery and Reinvestment Act 2009, declines in effective tax rates, and higher unemployment insurance payments.

These debt levels set the stage for the policy analysis. Starting in 2015, the government chooses one of its policy instruments (government spending, the labor income tax rate, the capital income tax rate, and the consumption tax rate) to satisfy a simple feedback rule that prescribes larger primary budget surpluses when the level of government debt is above target. We trace out our model's predictions under each of the four policy instruments. In the model, factor income taxes affect macroeconomic activity in the usual way, driving a wedge between factor supply and demand. Many of the results in our paper arise from the fact that shocks, apart from those directly affecting the labor market, have only very small effects on the job-finding probability. In turn, this insensitivity of the job-finding probability can be traced to the fact that job matches depend more heavily on vacancies than unemployment, and as a consequence firms' profits are not much affected by shocks affecting households' choices.

Nonetheless, there are substantial differences in the welfare implications of using alternative policy instruments. For our benchmark calibration, the preferred means of achieving the necessary fiscal austerity is via the capital income tax rate; the labor income tax rate is the least preferred, chiefly because of the very direct effects of lowering the after-tax wage; see Section 5.4 for details.

Diamond and Şahin (2014), Hobijn and Şahin (2013), among others, claim that the Beveridge curve, the empirical relationship between vacancies and unemployment, shifted during the Great Recession. To evaluate this possibility, we re-solve the model keeping the cost of a vacancy constant, choosing instead a path for match efficiency to fit the path for the job-finding probability. Doing so requires a severe decline in match efficiency, and a similar decline in the probability that a vacancy matches with a worker. By way of contrast, the benchmark model (the one that chooses a path for the cost of a vacancy) sees a rise in this worker-finding probability. Since this probability is inversely related to the average duration of a vacancy (how long it takes to fill a vacancy), the benchmark model implies a drop in the average duration of a vacancy while the match efficiency model sees a rise. The empirical evidence favors the benchmark model: Davis, Faberman, and Haltiwanger (2013) find that during the Great Recession, the average duration of a vacancy fell by nearly a half.[3]

Since the paper considers the effects of fiscal consolidation conditional on the current

[3]Data for Davis, Faberman, and Haltiwanger (2013) was downloaded from http://dhihiringindicators.com/.

economic situation resulting from the Great Recession, it bridges two strands of the literature: one concerning the causes and effects of the Great Recession, the other on fiscal consolidation. Within the first set, Christiano, Eichenbaum, and Trabandt (2015) shed light on the factors driving the dynamics of output, inflation and the labor market during the Great Recession using a medium-scale model with endogenous labor force participation. They argue that a combination of financial, total factor productivity and cost of working capital shocks can account for most of the dynamics of the U.S. economy during the Great Recession. We consider a smaller model, and abstract from financial frictions and the zero lower bound on nominal interest rates, but embed a richer set of fiscal policy variables, including public debt.

Elsby, Hobijn, Şahin, and Valletta (2011) and Elsby, Hobijn, and Şahin (2010) characterize the dynamics of the labor market since 2008 and show that flows from nonparticipation to unemployment are important for understanding recent changes in the duration distribution of unemployment. Our model of the labor market is more conventional in abstracting from flows in and out of the labor force, but is still able to capture the bulk of labor market dynamics quite accurately. Sala, Söderstrom, and Trigari (2012) use an estimated DSGE model with search and matching frictions and show that match efficiency (along with financial factors) explain most of the rise of the unemployment rate in the U.S. after 2008. Furlanetto and Groshenny (2013) present similar results. Our analysis highlights the fact that the cost of vacancies, rather than match efficiency, is crucial in accounting for the dynamics of labor markets during the Great Recession. In fact, when our model is solved with a constant vacancy cost, choosing instead a time path for match efficiency, the model predicts that the average duration of a vacancy rises during the Great Recession whereas the facts point to a fall; see Section 5.5.

On the fiscal consolidation side, Mendoza, Tesar, and Zhang (2014) run debt sustainability experiments in the Euro Area while Auray, Eyquem, and Gomme (2016) run debt-output ratio reduction experiments, again in Euro Area countries. Erceg and Linde (2011) run comparable experiments with a particular focus on the role of the zero lower bound on nominal interest rates, nominal rigidities and an interaction between fiscal and monetary policy. Corsetti, Kuester, Meier, and Müller (2010) show that expectations matter for the size of the effects of fiscal consolidations. Our paper is more focused on the joint analysis of fiscal consolidations and labor market dynamics. Closer to our paper is Nukic (2014) who quantifies the output and employment losses induced by fiscal consolidations in a framework that embeds search and matching frictions in the labor market. However Nukic does not consider the capital income tax as an instrument, nor does he consider useful public spending as entering the utility function of households. Further, unlike Nukic, we confront our model's predictions for the dynamics of the U.S. economy over the entire Great Recession and subsequent recovery as a validity check on the model. We solve our model non-linearly which is particularly important since at the start of the period of fiscal austerity, the economy is not in a steady state which matters in evaluating welfare.

The remainder of the paper is organized as follows. Section 2 looks at U.S. data during and after the Great Recession. The model is presented in Section 3 and calibrated in Section 4. Model results, policy analysis and robustness results are contained in Section 5. Section 6 concludes.

2 The Great Recession

Figure 1 presents a number of facts concerning the behavior of macroeconomic variables during the Great Recession. The quarterly data in Figures 1(a) to 1(d) are detrended by band pass filtering, removing frequencies over 100 quarters – that is, the long run trend.[4] Output, depicted in Figure 1(a), fell precipitously from around 3% above trend, to more than 3% below trend over the course of two years. This fall in output was very long lived, and it is only late in 2014 that output returns close to trend. While the NBER business cycle dating committee set the end of the Great Recession in mid-2009, the data shows that the recovery took much longer – lasting, arguably, until some time in 2014.

[4] While attention is focused on the period starting in 2007, all available data is used in band pass filtering.

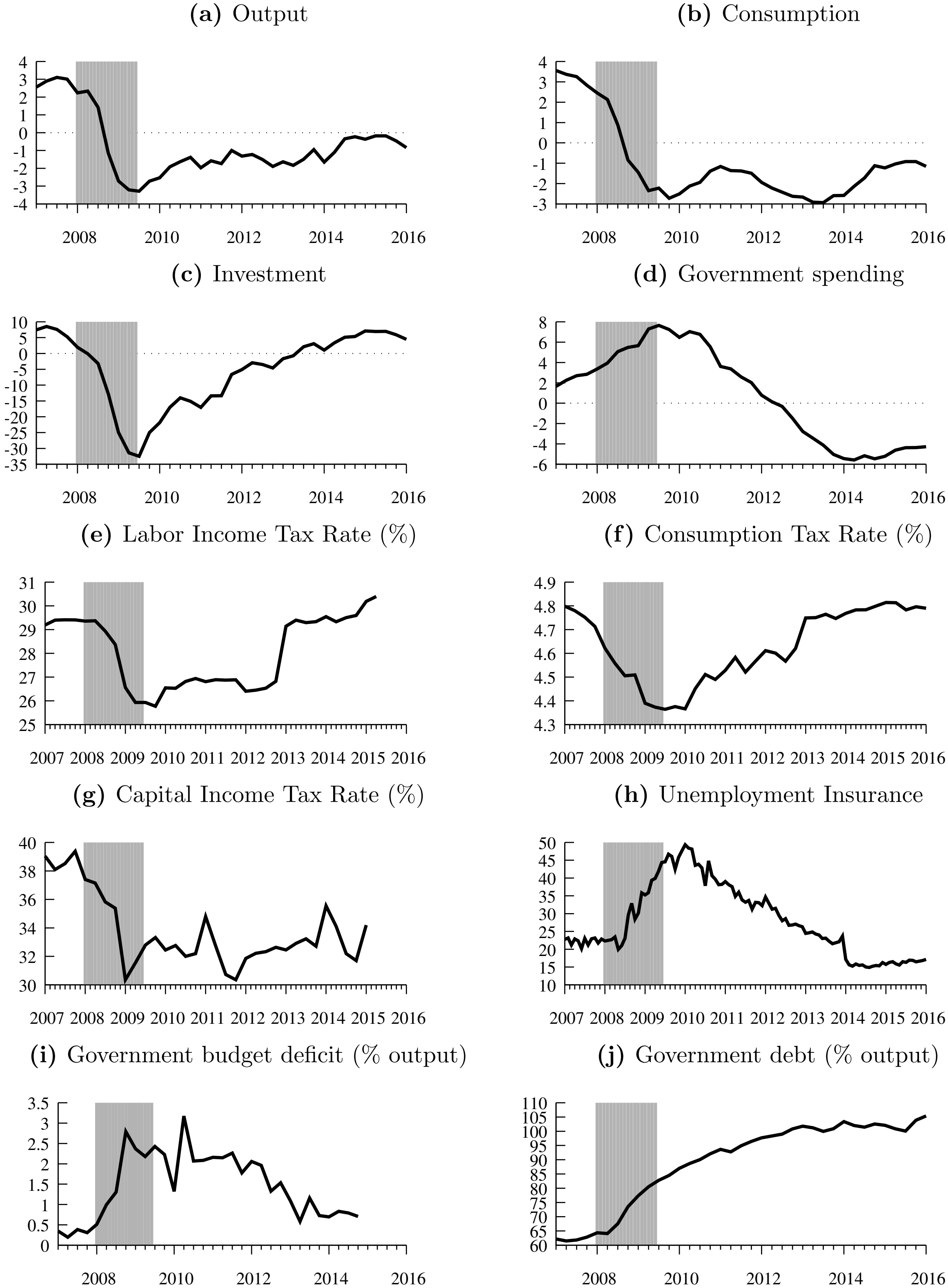
The falls in consumption and investment, in Figures 1(b) and 1(c), are likewise large – particularly for investment which, by the end of the Great Recession, was more than 30% below trend. While consumption has yet to recover to trend, by late 2013 investment had risen above trend.

Figures 1(d) to 1(j) tell the story of the fiscal side of the economy. Government spending rose from 2.8% above trend just prior to the Great Recession to 7.6% at the trough, reflecting the effects of the American Recovery and Reinvestment Act 2009. Indeed, government spending remained more than 5% above trend through 2010, after which there was a fairly sharp drop. By mid-2012, government spending had fallen below trend, and was more than 5% below trend through all of 2014. At the same time, government revenues fell not only due to lower macroeconomic activity, but because of a decline in effective tax rates.[5] The effective tax on labor income fell by more than 3 percentage points; that on capital income by as much as 7 points; and the consumption tax by a more modest 0.3 percentage points. Unemployment insurance payments (here measured as average benefits per unemployed person) rose owing to various extensions to benefits during and after the Great Recession; see Rothstein (2011) for a time line of these benefit extensions. As a result of all of these factors, budget deficits rose from 0.3% of GDP just prior to the Great Recession, to 3.2% in early 2010, after which this ratio has fallen somewhat. As a consequence of those larger deficits, the government debt-output ratio rose from 62% prior to the Great Recession to 105% in early 2016.

While it is widely accepted that the proximate cause of the Great Recession was the financial crisis, the depth and persistence of the Great Recession is largely a story of the labor market. Figure 2(c) shows that the unemployment rate rose from somewhat less than 5% just prior to the Great Recession, to a peak of 10% in late 2009, nearly a full year after the trough. While the unemployment rate has fairly steadily fallen since then, it has remained stubbornly high. These movements in the unemployment rate can usefully be traced to changes in the job-finding (f_t) and separation probabilities (s_t). Abstracting from movements in and out of

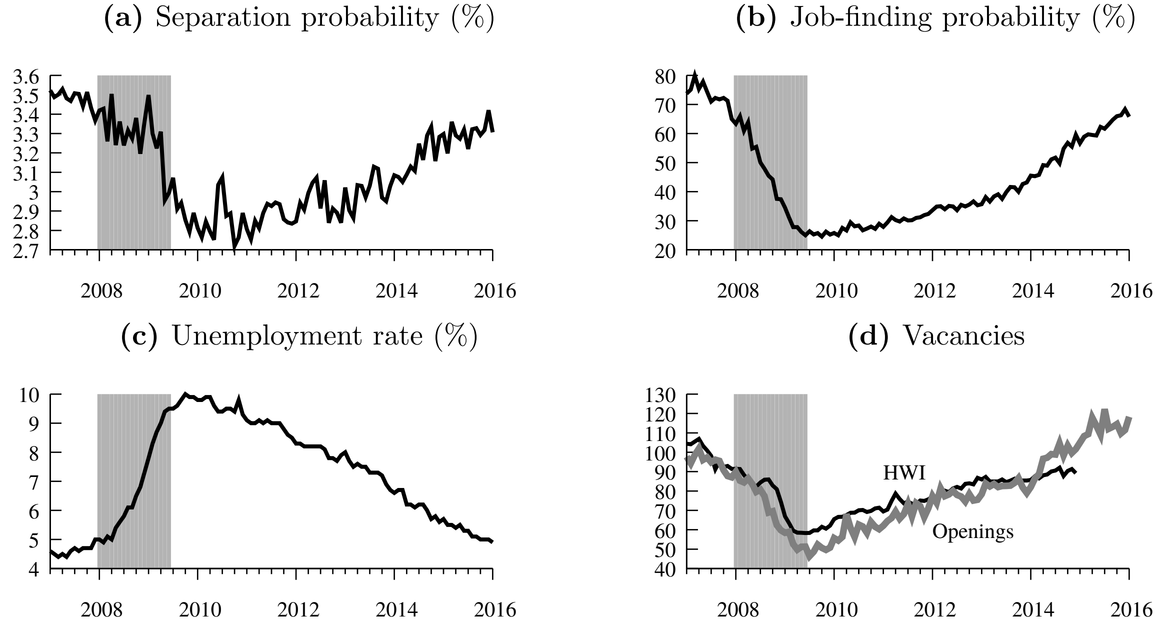
[5] The effective tax rates were computed as in Mendoza, Razin, and Tesar (1994), as updated by Gomme, Ravikumar, and Rupert (2011).

Figure 1: Great Recession Facts: Macroeconomic Variables



Note: The shaded area corresponds to the NBER definition of the Great Recession, that is from peak to trough.

Figure 2: Great Recession Facts: The Labor Market



Note: The shaded area corresponds to the NBER definition of the Great Recession, that is from peak to trough. Job openings from JOLTS is normalized to equal 100.0 in December 2000. HWI refers to the help wanted index, as extended by Barnichon (2010).

the labor force, unemployment evolves according to

$$u_{t+1} = (1 - f_t)u_t + s_t e_t$$

where e_t is the number of employed workers, and u_t the number unemployed. The two probabilities, f_t and s_t, can be directly measured using JOLTS (Job Openings and Turnover Survey) and CPS (Current Population Survey) data. Specifically, the job-finding probability is given by the number of hires (JOLTS) divided by the number unemployed (CPS), while the separation probability is measured by separations (JOLTS) divided by employment (CPS).[6] As shown in Figure 2(a), the probability of a job separation actually fell during the Great Recession. The substantial rise in the unemployment rate during the Great Recession can be traced to a collapse in the job-finding probability which fell from around 75% per month to roughly 25%. The subsequent 'jobless recovery' can likewise be traced to a stubbornly low

[6] Appendix B evaluates alternative measures of these probabilities and explains why these measures are preferred to these alternatives.

probability of finding a job. Figure 2(d) shows that vacancies fell precipitously during the Great Recession, reflecting a reduction in firms' recruiting activity. The lower vacancies then lead to the lower job-finding probability.

3 The Model

In order to maintain the representative agent fiction, private agents are modeled as belonging to a large family. This family values both private and government consumption, the latter being taken as exogenous by the family. The family's problem is broken into a number of parts. Taking as given wage and employment determination, the family decides on its private consumption as well as accumulation of assets in the form of both physical capital and holdings of government debt. After presenting this part of the household's problem, the analysis proceeds to the determination of wages and employment.

3.1 The Family

Households value a private good, c_t, and a government good, g_t.[7] Preferences over these goods are summarized by

$$\sum_{t=0}^{\infty} \beta^t U(c_t, g_t), \quad 0 < \beta < 1. \tag{1}$$

The household pays a tax, τ_{ct}, on its consumption purchases as well as taxes on its wage income, τ_{wt}, and capital income, τ_{kt}. Capital income taxes payable are partially offset by a capital consumption allowance. Capital adjustment costs,

$$\Phi_t = \frac{\phi}{2}(k_{t+1} - k_t)^2,$$

are included so that the dynamics of investment better fit the data during the Great Recession. The household's share of distributed profits is π_t. Government debt is modeled as a perpetual or console: a unit of debt is a promise to pay one unit of consumption forever. At the start

[7] As is common in the search-and-matching literature, the role or leisure or participation is suppressed.

of period t, the household holds d_t units of such debt. After receiving the current coupon payment, the household can sell a unit of debt at the price p_t. Finally, households also receive a lump-sum transfer, T. Letting e_t denote the fraction of household members gainfully employed, and u_t be the fraction collecting unemployment (with $e_t + u_t = 1$), the household's date t budget constraint is

$$\begin{aligned} &(1+\tau_{ct})\, c_t + k_{t+1} + \Phi_t + p_t d_{t+1} \\ &\quad = (1-\tau_{wt})\,(w_t e_t + b_t u_t) + [1 + (1-\tau_{kt})(r_t - \delta)]\, k_t + (1+p_t)d_t + \pi_t + T. \end{aligned} \tag{2}$$

Taking as given for the moment the determination of wages and employment (and so unemployment), the household's Euler equations for capital and bond accumulation are

$$\underbrace{1 + \phi(k_{t+1} - k_t)}_{q_t} = \Delta_{t,t+1} \underbrace{[1 + \phi(k_{t+2} - k_{t+1}) + (1 - \tau_{k,t+1})\,(r_{t+1} - \delta)]}_{q_{t+1} + R_{k,t+1}}, \tag{3}$$

$$p_t = \Delta_{t,t+1}(1 + p_{t+1}), \tag{4}$$

where

$$\Delta_{t,t+1} = \beta \frac{U_1\,(c_{t+1}, g_{t+1})}{1 + \tau_{c,t+1}} \Big/ \frac{U_1\,(c_t, g_t)}{1 + \tau_{ct}} \tag{5}$$

is the household's effective discount factor between date t and $t+1$.

In the spirit of Christiano, Eichenbaum, and Trabandt (2015), a "financial shock," Ω_{t+1}, is introduced to the capital accumulation equation as

$$q_t = \Delta_{t,t+1}(1 + \Omega_{t+1})(q_{t+1} + R_{k,t+1}). \tag{6}$$

This financial wedge is intended to capture the effects of the financial crisis during the Great Recession.

3.2 Workers and the Unemployed

Within the family, individuals account for their marginal contributions to private, family consumption. The value of being employed is given by

$$W_t = (1 - \tau_{wt})w_t + \Delta_{t,t+1}\left[(1 - s_t)W_{t+1} + s_t U_{t+1}\right], \tag{7}$$

where s_t is the exogenous separation probability. Separations occur at the end of a period, after production has taken place. An individual then spends at least one period unemployed since matching occurs at the end of a period. The first term on the right-hand side is the after-tax wage, representing the current contribution to family consumption. The second term represents the expected present value over future employment statuses: with probability $1 - s_t$, the individual remains employed and the capital value of remaining employed is W_{t+1}; and with probability s_t, the individual loses his job and enters the pool of unemployed which has capital value U_{t+1}. The discount factor, $\Delta_{t,t+1}$, takes care of converting these future values into units of current consumption goods.

Similarly, the value of searching (that is, unemployed) is

$$U_t = (1 - \tau_{wt})b_t + \Delta_{t,t+1}\left[(1 - f_t)U_{t+1} + f_t W_{t+1}\right], \tag{8}$$

where f_t is the probability of being matched with a firm at the end of the current period. On the right-hand side, the first term is the after-tax unemployment insurance benefit; the other term is the expected value of search.

3.3 Firms

Firms act in the best interests of their owners, namely the representative household. Unlike the usual Mortensen-Pissarides model, a firm is modeled as a collection of jobs and rents capital to produce goods.[8] The value of the *marginal* worker is

$$J_t = F_2(k_t, e_t; z_t) - w_t + \Delta_{t,t+1}\left[(1 - s_t)J_{t+1} + s_t V_{t+1}\right], \tag{9}$$

where V_{t+1} is the value of the position remaining vacant. The term $F_2(k_t, e_t; z_t) - w_t$ is the net contribution of the marginal worker, his marginal product less his wage. The last term in Eq. (9) is the expected value of the match into next period. Notice that the firm applies the same effective discount factor, $\Delta_{t,t+1}$, as was used by employed and unemployed family members.

The value of a vacant position is

$$V_t = -\kappa_t + \Delta_{t,t+1}\left[a_t J_{t+1} + (1 - a_t)V_{t+1}\right], \tag{10}$$

where κ_t is the per period cost of posting a vacancy, and a_t is the probability that a vacancy is matched with an unemployed worker. As usual in the Mortensen-Pissarides model, there is free entry with respect to vacancies which drives the equilibrium value of a vacancy to zero. This condition implicitly determines the equilibrium number of vacancies posted, v_t.

Firms rent capital from households on a spot market. Consequently, firms will hire capital up to the point that the marginal product of capital equals its rental rate, or

$$F_1(k_t, e_t; z_t) = r_t. \tag{11}$$

Finally, firm profits are given by

$$\pi_t = F(k_t, e_t; z_t) - w_t e_t - r_t k_t - v_t \kappa_t. \tag{12}$$

[8] In the usual formulation of the Mortensen-Pissarides model, a firm is a job. Left unspecified is how a vacant firm/job finances the cost of posting a vacancy. An advantage of specifying that a firm is a collection of jobs is that the cost of vacancies is financed by the firm's current revenues.

3.4 Wage Determination

Wages are determined as the solution to Nash bargaining which maximizes the geometric average of worker and firm surpluses,

$$w_t = \text{argmax } (W_t - U_t)^{\theta}(J_t - V_t)^{1-\theta}, \tag{13}$$

where θ measures the worker's 'bargaining power' in the match. Using Eqs. (7)–(8) along with the free-entry condition (which implies $V_t = 0$), wages are implicitly given by the first-order condition,

$$(1-\theta)(W_t - U_t) = \theta(1-\tau_{wt})J_t. \tag{14}$$

It is assumed that wages are renegotiated every period, and so w_t is the wage that will prevail in all matches.

3.5 Evolution of Employment

The behavior of employment over time is governed by

$$e_{t+1} = (1-s_t)e_t + m_t \text{ where } m_t = M(v_t, u_t). \tag{15}$$

The matching function, M, is constant returns to scale and has positive first derivatives. Given the matching function, the job-finding probability is

$$f_t = \frac{m_t}{u_t} = M\left(\frac{v_t}{u_t}, 1\right), \tag{16}$$

while the probability that a vacancy matches with a worker is

$$a_t = \frac{m_t}{v_t} = M\left(1, \frac{u_t}{v_t}\right). \tag{17}$$

3.6 Government

Government debt evolves according to

$$p_t d_{t+1} - (1 + p_t) d_t = \text{def}_t, \tag{18}$$

where the primary deficit is

$$\text{def}_t = g_t + T + (1 - \tau_{wt}) b_t u_t - \tau_{ct} c_t - \tau_{wt} w_t e_t - \tau_{kt} (r_t - \delta) k_t. \tag{19}$$

The first two terms on the right-hand side of Eq. (19) are government spending on goods and services, g_t, and a lump-sum transfer, T. The next term represents the government's expenditures on unemployment insurance, net of tax. The final terms are government tax revenue from the consumption tax, labor income, and capital income (net of the depreciation allowance).

It is well known that, absent any feedback, the debt dynamics in Eqs. (18) and (19) are inherently unstable. We impose the fiscal policy rule

$$\frac{\text{def}_t}{y_t} - \frac{\text{def}}{y} = -\omega \left[\frac{d_t}{y_{t-1}} - \frac{d}{y} \right], \quad \omega > 0. \tag{20}$$

The government chooses one of its fiscal policy instruments (spending or one of the tax rates) to satisfy this rule. In Eq. (20), d/y is the target for the debt-output ratio and def/y is the corresponding value for the primary deficit-output ratio. Eq. (20) says that when the government debt-output ratio is above target, the government must apply austerity measures (higher taxes or lower government spending) in order to reduce the primary deficit. It is this feedback mechanism that renders the debt-output ratio stationary.

4 Calibration

A model period is set to one month, shorter than the typically-used quarter in macroeconomics. The monthly frequency is chosen so that the model can match the observed duration of

U.S. unemployment spells which is considerably shorter than a quarter: prior to the Great Recession, Figure 2(b) shows that the monthly job-finding probability was roughly 70%. This job-finding probability implies an average duration of unemployment of 1.4 months – much less than one quarter.

The utility function is of the constant relative risk aversion variety:

$$U(c,g,u) = \begin{cases} \ln C(c,g) & \gamma = 1, \\ \frac{C(c,g)^{1-\gamma}}{1-\gamma} & \gamma \in (0,1) \cup (1,\infty). \end{cases}$$

The consumption aggregator is

$$C(c,g) = \left[\psi c^{\frac{\xi-1}{\xi}} + (1-\psi) g^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}},$$

where ξ is the elasticity of substitution between private and government goods.

As is common in the Mortensen-Pissarides literature, the matching function is Cobb-Douglas:

$$M(v,u;\mu) = \mu v^{\nu} u^{1-\nu}.$$

Production is Cobb-Douglas:

$$y = F(k,e;z) = z k^{\alpha} e^{1-\alpha}.$$

As summarized in Table 1, there are 17 model parameters that must be assigned values. To start, some values are set exogenously. The coefficient of relative risk aversion, γ, is set to 2, a value within the range typically used in business cycle models. The elasticity parameter ξ in the consumption aggregator is also set to 2 which implies that private and public consumption are fairly easily substituted; the implications of smaller values of ξ are explored in Appendix D. The workers' bargaining parameter, θ, is set to $1-\nu$ where ν is the elasticity of matches with respect to vacancies; this setting is motivated by the so-called Hosios condition which ensures constrained efficiency. Steady state total factor productivity, z, is normalized to equal 1. The fiscal policy feedback parameter, ω, is set to 0.05 which is within

Table 1: Benchmark Parameters

Preferences		
β	Discount factor	0.9967
γ	Coefficient of relative risk aversion	2
ξ	Consumption aggregator elasticity of substitution	2
ψ	Consumption aggregator weight on private consumption	0.6412
Production		
α	Elasticity of output with respect to capital	0.3
δ	Depreciation rate	0.0059
z	Steady state total factor productivity	1
ϕ	Capital adjustment cost	2
$1+\Omega$	Financial shock or wedge	0.9955
Matching and Bargaining		
μ	Match efficiency	0.61
ν	Elasticity of matches with respect to vacancies	0.8
θ	Workers' bargaining power	0.2
κ	Steady state vacancy cost	5.7449
Fiscal Policy		
τ_c	Consumption tax rate	4.85%
τ_w	Labor income tax rate	28.59%
τ_k	Capital income tax rate	37.10%
ω	Feed back parameter, government policy rule	0.05
T	Lump-sum tax	0.1738

the range of estimated reported by Bohn (1998), the only evidence we have found regarding the policy feedback parameter. Sensitivity with respect to this parameter is reported in Appendix D. The final exogenously-set parameter is ϕ which governs the capital adjustment costs; it is set to 2 in order to roughly match the observed decline in investment during the Great Recession.

There remain 12 parameters. Seven parameters are chosen so that the model matches observations for the U.S. economy averaged over 2005–2007. This period was chosen since it is just prior to the Great Recession, and because it took until nearly 2005 for the effects of the so-called jobless recovery following the 2001 recession to dissipate. The targets are: the tax rates, τ_w, τ_c and τ_k, computed using the methodology of Mendoza, Razin, and Tesar (1994); an average separation probability of 3.5% per month; a job-finding probability of 73%; the government budget must balance given a government share of output of 19.16% and an annual government debt-output ratio of 0.6137. The remaining five targets are: an annual depreciation rate of 7.8% as reported in Gomme and Rupert (2007); an annual real interest rate of 4%, a conventional value; an elasticity of matches with respect to vacancies of 0.8, a value somewhat higher than estimated by Petrongolo and Pissarides (2001); an elasticity of output with respect to capital of 0.3, close to the value computed by Gomme and Rupert (2007); and the marginal utilities of private and public consumption are equalized (that is, $U_1 = U_2$). The resulting parameter values can be found in Table 1.

Notice that the values for the separation probability and job-finding probability imply that the steady state unemployment rate is around 4.6%, roughly its value just prior of the Great Recession. Next, the normalization that vacancies equal unemployment implies that the match efficiency parameter, μ, equals both the job-finding and worker-finding probabilities, f and a. As a result, the model matches the job-finding probability. This value for the worker-finding probability seems reasonable in that its value implies an average duration of a vacancy of 1.6 months. According to Dice-DFW, just prior to the Great Recession, the average duration of a job vacancy was around 23 (working) days, or one calendar month.

The model counterpart to the duration of a vacancy may be longer if there is a delay between when the firm recognizes that it has a job to fill and when it actually posts the vacancy, and if there is a lag between filling a vacancy and the worker's start date.

Exogenous Processes

The model has a total of 10 exogenous processes. On the fiscal side, there are: government spending (g_t); tax rates on labor income (τ_{wt}), capital income (τ_{kt}) and consumption (τ_{ct}); and the unemployment insurance benefit (b_t); see the discussion in Section 2.

Combining the household's Euler Eqs. (3) and (4) suggest that the financial shock can be measured as

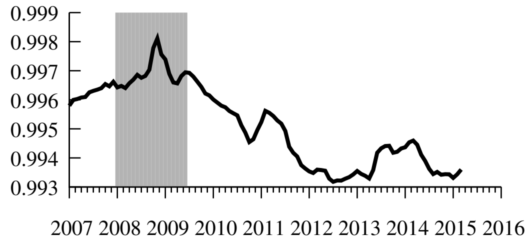
$$1 + \Omega_t = \frac{1 + R_{kt}}{1 + R_{bt}}.$$

Here, the returns, R_{kt} and R_{bt} are the data counterparts to the returns to capital and government bonds. To operationalize this measurement, the return to capital is the after-tax return to capital as measured by Gomme, Ravikumar, and Rupert (2011), updated to 2015; and the return to government debt is measured by the 20-year Treasury Inflation-Indexed Security. It is, perhaps, of interest that the annualized mean of $-\Omega$ is 5.6% which reflects the premium paid to capital vis-à-vis relatively safe government debt. The time series behavior of the financial shock is summarized in Figure 3.

In the labor market, the separation rate, s_t, is taken directly from the data while the vacancy cost, κ_t, is chosen so that the model matches the observed job-finding probability; see Figures 2(a) and 2(b). Finally, total factor productivity, z_t, is chosen to match the path of output.

In order to focus on medium term fluctuations, we either band pass filter the data, allowing through frequencies corresponding to 2 to 25 years (for series exhibiting secular growth), or smooth using a spline (for series without secular growth). Details on data measurement and other calculations are in Appendix A. As discussed earlier, a model period is a month; where necessary, quarterly data is spline interpolated to a monthly frequency. This interpolation is fairly innocuous, particularly in light of our focus on medium run fluctuations.

Figure 3: The Financial Shock



Starting in 2015, all exogenous shocks decay fairly rapidly to their average values over 2005–2007. The autoregressive parameter on total factor productivity is $0.95^{1/3}$, the monthly analog of the decay typically used in quarterly business cycle analysis; the autoregressive parameters for the remaining shocks is 0.9 which, given that a model period is a monthly, implies fairly rapid return to steady state.

The model is solved as a perfect foresight, two point boundary problem; see Auray, Eyquem, and Gomme (2016) for a detailed description of the solution method.[9] Since four alternative fiscal policies are considered, there are four paths for each variable of interest, one for each of the fiscal policy instruments, for the entire horizon over which the model is solved. Model simulations start in December 2000 so that the initial steady state does not influence the paths of variables leading up to the Great Recession. The initial steady state is set up to closely mimic conditions in December 2000 while the terminal steady state is chosen to be consistent with averages for 2005–2007, a period chosen since it seems to correspond to normal conditions in the labor market.[10]

[9]Taking as given Eqs. (5), (11), (16), (17) and (19), the set of equations solved are: Eqs. (2)–(4), (7)–(10), (14), (15) and (18) along with $e_t + u_t = 1$ and Eq. (20) after the Great Recession.

[10]The start date, December 2000, corresponds to when JOLTS data first comes available. This date is early enough that the initial conditions have little effect on the period of interest, that is starting in 2007.

5 Results

Section 5.3 contains the results of the policy experiments, namely the analysis of using alternative fiscal policy instruments to reduce the debt-output ratio to its pre-Great Recession level, and welfare results are studied in Section 5.4. The precursor to the policy analysis is contained in Section 5.1 which focuses on the model simulations to the end of 2014. The importance of this subsection is to ensure that macroeconomic conditions at the end of the recovery are close to those that actually prevailed. In particular, the set of shocks need to be set appropriately. The fiscal shocks (government spending, tax rates and unemployment insurance benefit) get the debt-output ratio 'right;' the labor market shocks ensure that the unemployment rate is 'right;' and the reduced-form financial shock captures the conventional wisdom that financial factors were the root case of the Great Recession.

5.1 The Great Recession

Recall that the model takes as given the job separation probability, and fits the job-finding probability. Almost by construction, the model does well in capturing the observed variation in the unemployment rate as shown in Figure 2(c). In particular, both the model and the data see a rise the unemployment rate from 4.5% prior to the Great Recession, to around 10% early in 2010; the unemployment rate then remains rather high for a considerable period of time, as shown in Figure 4(e).

To match the job-finding probability, the model requires roughly a 40% decline in vacancies; see Figure 4(b). As can be seen, the model understates, by perhaps 10 percentage points, the decline in job openings through to the end of 2008, and somewhat under-predicts openings during the recovery.[11] Given macroeconomic conditions, this drop in vacancies comes through roughly a doubling in the cost of posting a vacancy; see Figure 4(a). One way to measure the reasonableness of such a large increase in the vacancy cost is to look at the worker-finding

[11]The model comes closer to matching the time series behavior of vacancies as measured by Barnichon's (2010) help wanted index which fell by around 40%.

probability; the model predicts a rise in this probability from between 70 and 75% prior to the Great Recession to almost 95% at the end of 2009. In other words, just after the trough, firms presumably found it quite easy to fill vacancies. This change in probabilities implies a fall in the average duration of a vacancy of 35% (from 1.4 months to 1.05 months). Coincidentally, this percentage decline matches that measured by Davis, Faberman, and Haltiwanger (2013) for the national mean vacancy duration, 35% (from 23 working days to 15 working days).

Curiously, as shown in Figure 5(f), the model predicts a marked increase in real wages early in the Great Recession; real wages fall below trend only after the NBER-determined trough in mid-2009. What is going on is that the rapid rise in the vacancy cost increases the value of existing matches, and the Nash bargaining-determination of wages implies that workers receive their share of this increased surplus. In the data, real wages also rose, albeit later than predicted by the model, and the increase is smaller.

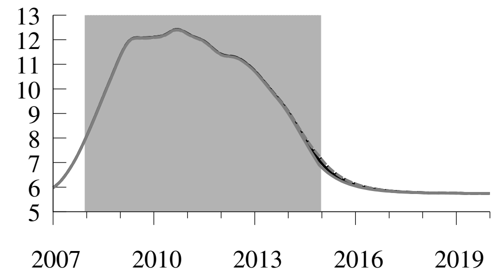
Given the employment dynamics, the model requires a 2% decline in total factor productivity in order to match the observed 6.3% fall in output; see Figures 4(h) and 5(a). Interestingly, total factor productivity rises to nearly its pre-Great Recession level (1.5% above trend) by mid-2010, remaining above trend until the end of the recovery. Solow growth accounting reveals that the bulk of the drop in output (6.3%) is accounted for by the fall in total factor productivity (2%), and the contribution of the fall in employment (4.1% computed by the 5.8% decline in employment multiplied by the output elasticity with respect to employment, 0.7); very little of the fall in output is attributed to changes in the capital stock.

Recall that the capital adjustment cost parameter, ϕ, was chosen to roughly match the observed downturn in investment (35%). As seen in Figure 5(c), the model predicts that the recovery in investment lags actual investment by as much as a year, and its return to trend is more leisurely than observed in the data.

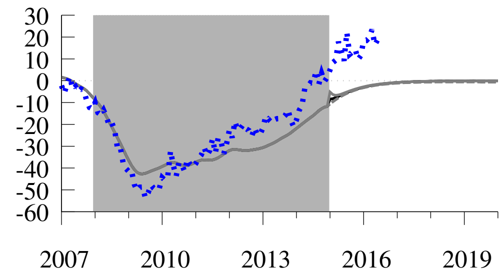
While the model broadly captures the observed movements in consumption, as shown

Figure 4: The Labor Market During and After the Great Recession

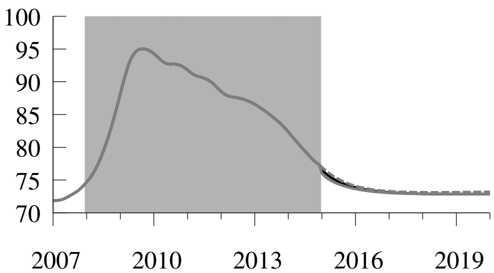
(a) Vacancy Cost



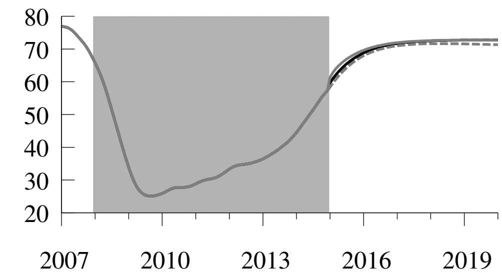
(b) Vacancies (% deviation)



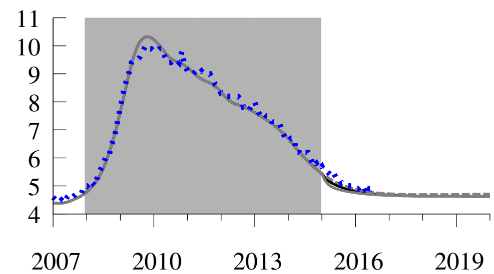
(c) Worker-finding Probability (%)



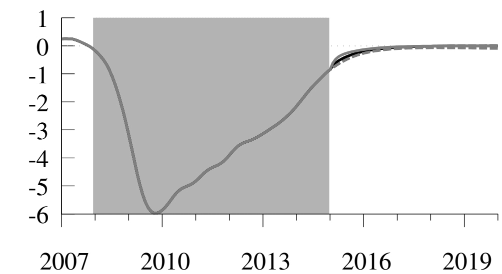
(d) Job-finding Probability (%)



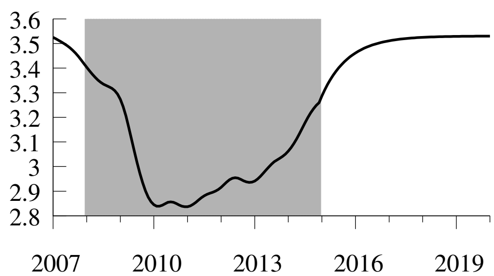
(e) Unemployment Rate (%)



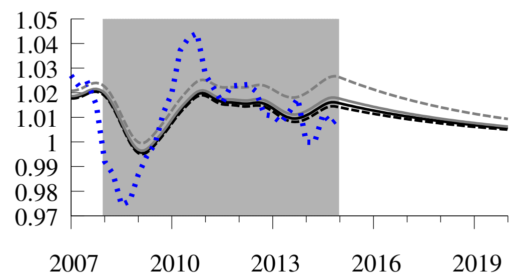
(f) Employment (% deviation)



(g) Separation Probability (%)

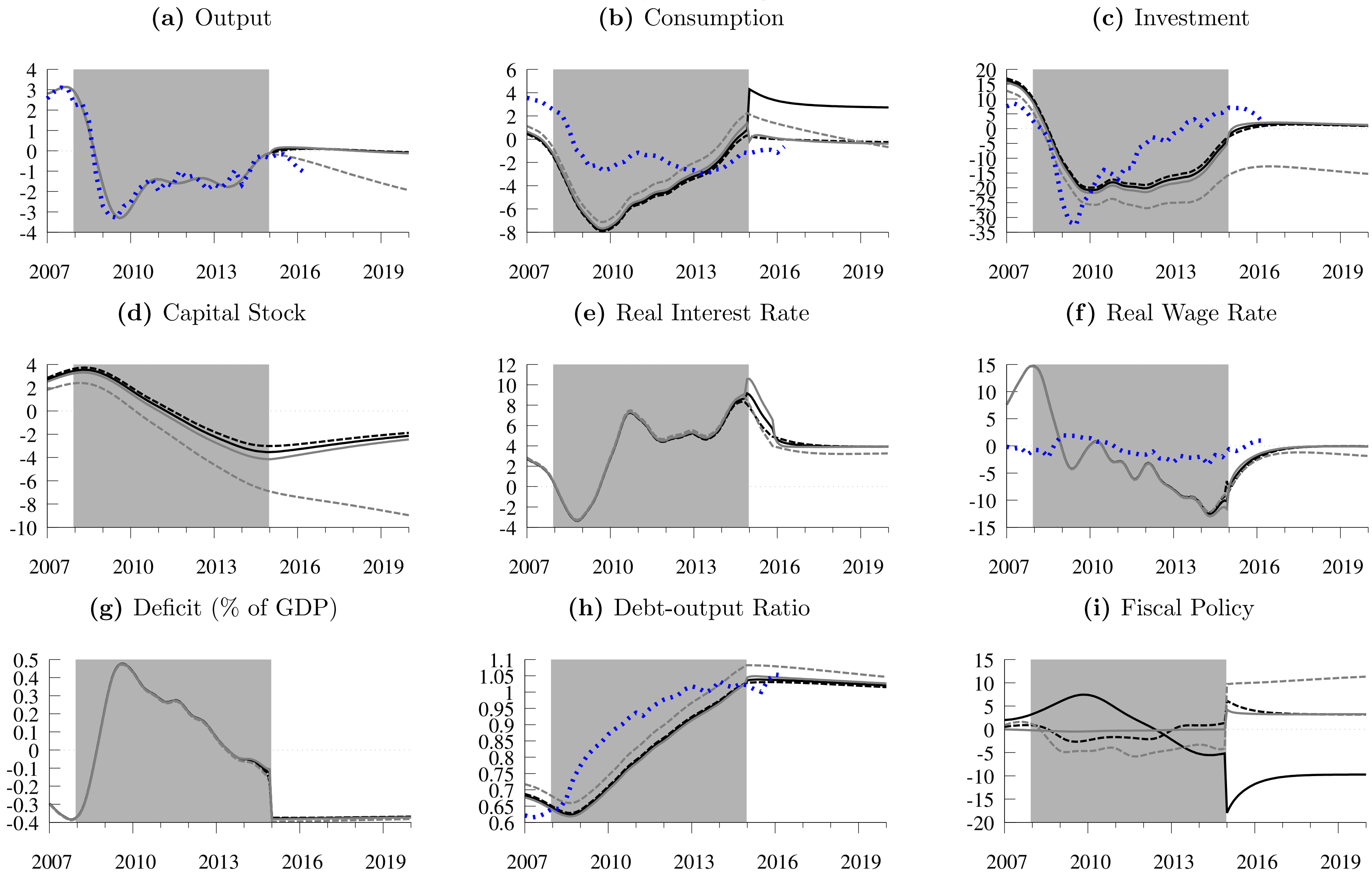


(h) Total Factor Productivity



Legend: Solid black lines: government spending; dashed black lines: labor income tax; solid gray lines: consumption tax; dashed gray lines: capital income tax; blue dotted lines: U.S. data (when available). The shaded area corresponds to the Great Recession and recovery (to the end of 2014).

Figure 5: Fiscal Policy Following the Great Recession



Legend: Lines are coded as in Figure 4. Output, consumption, investment and capital are expressed as percentage deviations from steady state; for fiscal policy, government spending is likewise expressed as a percentage deviation from steady state while the tax rates are percentage point changes from steady state; all other variables are in levels. The real interest rate is computed via compounding over the previous 12 months to give an annual interest rate. The debt-output ratio is expressed at an annual rate.

in Figure 5(b), the model's path for consumption is too low, and it exaggerates the fall in consumption during the Great Recession.

Turn now to fiscal policy during the Great Recession and recovery. Figure 5(g) shows a swing from a primary surplus to a primary deficit, driven by a combination of higher government spending, increased unemployment insurance payments, and diminished tax revenues arising from both lower overall economic activity and lower tax rates. The debt-output ratio actually falls early in the Great Recession. This peculiar result arises from an increase in the price of government debt, or equivalently a drop in the real interest rate, which makes it easier for government to finance its deficits. In fact, as shown in Figure 5(e), the real interest rate is quite negative in the early years of the Great Recession. While the financial shock, Ω_t, inserts a wedge between the returns to government debt and private capital, there is nonetheless a no arbitrage condition between these two returns, and the decline in the real interest rate can be traced to a drop in the marginal product of capital resulting from a combination of lower total factor productivity and lower employment.

5.2 Evaluating the Role of the Shocks

To evaluate the role played by various shocks, we solve the model holding one or more shocks constant. The difference between the original paths and these new paths then gives the contribution of the shock(s). To avoid overwhelming the reader with a plethora of experiments, attention is focused on the government spending rule. All of the figures referenced in this subsection are available in online Appendix C.

To start, the labor market shocks (job separation probability and cost of vacancies) and unemployment insurance benefits are the only shocks that have substantial effects on labor market variables. Recall that the unemployment insurance benefit series is designed to capture the effects of the various extensions to unemployment insurance benefits during the Great Recession and its aftermath. Figure 10(e) suggests that the effect of these extensions was to increase the peak of the unemployment rate from 7.7% (no change in unemployment benefits) to 10.3%. Since higher unemployment necessarily means lower employment, the extended unemployment benefits lower overall macroeconomic activity, reducing government tax revenues which, combined with the higher unemployment benefits paid out, lead to higher deficits and debt; see Figures 11(g) and 11(h). Consequently, starting in 2015, the government has to apply more fiscal austerity as shown in Figure 11(i).

Recall that during the Great Recession, the separation probability fell. Had this fall not occurred, the unemployment rate is predicted to have peaked at 12.3% rather than 10.3%; see Figure 10(e). Firms do not need to post as many vacancies in light of the higher employment level (again, relative to the path implied by the higher separation probability); see Figure 10(b). The macroeconomic effects of higher employment are, then, qualitatively similar to those predicted for the unemployment insurance benefit.

Next, the baseline model predicts a doubling in the vacancy cost. Had this cost not risen, the fall in vacancies would have been smaller, the unemployed would have found it easier to find a job, and the unemployment rate would have peaked at 5.8% as opposed to 10.3%; see Figures 10(b), 10(d) and 10(e). The higher path for employment then leads to greater macroeconomic activity overall, and the effects are, again, qualitatively similar to those associated with unemployment insurance benefits.

Now, consider the implications of the financial shock. Figure 3 shows that just prior to and during the Great Recession, the financial shock was somewhat higher than its 2005-07 average value of 0.9955. Starting in 2010, the financial shock fell below its mean. Since a lower value of the financial shock lowers households' perceived return to capital, these lower future values of the financial shock depress investment and capital accumulation, and so output, during the Great Recession; see Figures 9(a), 9(c) and 9(d). That said, the output and consumption effects are fairly modest as seen in Figures 9(a) and 9(b). The paths of the deficit and debt are little changed, and so the required fiscal austerity is quite similar; see Figures 9(g) to 9(i). Clearly, these results do not conform very well with the accepted wisdom that financial shocks were important contributors to the Great Recession (see, for example, Christiano, Eichenbaum, and Trabandt, 2015) and may suggest the need to go beyond simple reduced-form wedge shocks.

Next, consider the joint effects of the tax rate shocks. Recall that all three effective tax rates fell during the Great Recession; see Figures 1(e) to 1(g). For the dynamics of macroeconomic variables, the most important of these tax rates is the one on capital income since it has the strongest influence on investment and so capital; see Figures 9(c) and 9(d). Had the effective capital income tax rate not fallen during the Great Recession, the capital stock would have been quite a bit smaller. However, as seen in Figure 9(a), the effect on output is fairly modest.[12] Figure 9(g) reveals that deficits would have been much lower during the Great Recession if effective tax rates had not fallen, and the debt-output ratio would have increased only modestly. As a result, less fiscal austerity would have been necessary following the recovery; see Figure 9(i).

Finally, to understand the effects of holding total factor productivity at trend, it is important to notice that over the entire 2007–14 period, total factor productivity is seldom below trend. To the contrary, it is often substantially above trend. The net effect is that holding total factor productivity at its trend moderates the decline in output during the Great Recession, although this is only because output starts much closer to trend; see Figure 9(a). At the trough, there is little difference in the deviation of output from trend. During the recovery, the higher actual path for total factor productivity serves to put output closer to trend. Higher total factor productivity also raises the return to capital, thus boosting investment and the capital stock; see Figures 9(c) to 9(e). The resulting higher macroeconomic activity increases government tax revenue, lowering deficits, and so the debt-output ratio; see Figures 9(g) and 9(h). In other words, if total factor productivity had remained at trend, more fiscal austerity would have been necessary starting in 2015, as shown in Figure 9(i).

In summary, the most important shocks are those directly affecting the labor market (the job separation probability, the cost of vacancies, and unemployment insurance benefits). The

[12]As discussed earlier, these shocks have little effect on labor market variables.

fiscal policy shocks (government spending, tax rates and unemployment insurance) serve to push the model's debt-output ratio over 100% as seen in the data. Our model finds only a modest role for total factor productivity and financial shocks.

5.3 Fiscal Policy after the Recovery

To the end of 2014, the paths for the variables of interest are sufficiently similar that it has not been necessary to distinguish between the scenarios associated with the four different fiscal policy instruments; that changes when looking post-Great Recession.

To start, consider the model's predictions for the fiscal instruments themselves. Using government spending to bring down the debt-output ratio requires a 8.9% decline in the first year (bringing it from 5.4% below trend to 14.3% below). Since households desire a smooth path for utility, they compensate for this fall in public consumption goods by sharply increasing spending on private consumption goods. When the government instead uses a tax rate to satisfy its fiscal policy rule, it is assumed that government spending fairly rapidly returns to trend, implying an increase in public consumption goods. In these cases, smoothing utility leads households to reduce their private consumption. The hike in the labor income tax (3.96 percentage points) is somewhat larger than that in the consumption tax (2.62 percentage points). The capital income tax requires a much larger, 13.68 percentage point, increase. The differences in increases in the two factor income taxes can be traced to relative sizes of their tax bases. In particular, the tax base for the labor income tax is just over four times larger than that of the capital income tax. As a result, the percentage point increase in the capital income tax rate is a little over four times larger than that for the labor income tax.

What is common across the four fiscal policy instruments is that the fiscal policy rule leads to large primary surpluses as shown in Figure 5(g), and it is these large primary surpluses that drive down the government debt-output ratio in Figure 5(h). The reduction in this ratio is very protracted – for example, under the government spending rule, it is not until the

2080s (not shown in Figure 5(h)) that half of the gap between the debt-output ratio at the end of the Great Recession and its target value (102.6% and 61.37%, respectively).

The macroeconomic channels through which the various tax rates operate are as follows. The labor income tax reduces the contribution of the after-tax real wage to match surplus. The capital income tax affects the after-tax return to capital, and so capital accumulation. There are two effects associated with the consumption tax: the first is to make private consumption more expensive, and so reduces those expenditures; the second operates through the discount factor, $\Delta_{t,t+1}$ in Eq. (5). In the discount factor, the temporal pattern of the consumption tax acts as either a subsidy (when the consumption tax is falling over time), or a tax (when its rising over time) on returns.

Aggregate output and investment follow fairly smooth paths. The same cannot be said for consumption. Under either factor income tax, the consumption path is fairly smooth. When public spending satisfies the fiscal policy rule, the required drop in public consumption goods starting in 2015 leads households to increase their private consumption, in part because the fall in public spending frees up resources, and in part owing to utility smoothing. Finally, the hike in the consumption tax in 2015 raises the price of private consumption goods, and so leads to a jump down in private consumption.

Returning to the fiscal policy variables, notice that the path for the capital income tax rate in Figure 5(i) is rising after 2015. Looking at (much) longer horizons reveals that this tax rate does eventually return to its steady state value – it just takes a very long time. To give some perspective on how long, it is not until 2230 (not shown in Figure 5(i)) that the capital income tax rate falls below 40% (its steady state value is 37.1). An implication of these high capital income tax rates is that, relative to the other fiscal policy instruments, investment stays persistently below trend. As a result, so does the capital stock and so output. As shown in Appendix D, the transition dynamics are considerably shorter when the policy feedback parameter ω is set to larger values.

5.4 Welfare Implications

All of the policies considered involve short run pain in the form of contractionary fiscal policy, in return for a long run gain associated with returning the government debt-output ratio back to its pre-Great Recession level. Here, the question is whether it is better to implement such a reduction in the debt-output ratio through government spending, or one of the taxes. Since the employment rate is e_t while the unemployment rate is u_t, the expected value to a household member of living under the government spending policy is $e_0 W_0^g + u_0 U_t^g$ where W_0^g is the value of being a worker and U_0^g the value of being unemployed, both under the government spending rule. The welfare benefit of using, instead, a tax policy is measured by the fraction ζ of earnings that can be taken away each period such that the expected value to a typical household member is equal to that obtained under the government spending rule. More specifically, compute

$$\begin{aligned}
\tilde{W}_t^\tau &= (1-\zeta)(1-\tau_{wt}^\tau) w_t^\tau + \Delta_{t,t+1}^\tau \left[(1-s_t)\tilde{W}_{t+1}^\tau + s_t \tilde{U}_{t+1}^\tau \right], \\
\tilde{U}_t^\tau &= (1-\zeta)(1-\tau_{wt}^\tau) b + \Delta_{t,t+1}^\tau \left[(1-f_t^\tau)\tilde{U}_{t+1} + f_t^\tau \tilde{W}_{t+1} \right],
\end{aligned}$$

and adjust ζ until

$$e_0 W_0^g + u_0 U_0^g = e_0 \tilde{W}_0^\tau + u_0 \tilde{U}_0^\tau$$

where g superscripts refer to variables obtained under the baseline government spending policy, and τ superscripts pertain to an alternative, tax-based fiscal policy.[13]

The welfare measure ζ can alternatively be computed from

$$(1-\zeta) \sum_{t=0}^{\infty} \Delta_{0,t}^\tau \left[(1-\tau_{wt}^\tau) \left(e_t^\tau w_t^\tau + u_t^\tau b \right) \right] = \sum_{t=0}^{\infty} \Delta_{0,t}^g \left[(1-\tau_{wt}^g) \left(e_t^g w_t^g + u_t^g b \right) \right].$$

On the right-hand side is the present discounted value of earnings and unemployment insurance compensation when government spending satisfies the fiscal policy rule, where the discounting is given by the discount factor $\Delta_{0,t}^g$. The sum on the left-hand side has a similar interpretation

[13] Since the first few periods of the model time paths are influenced by the initial condition, the welfare metric is computed after discarding the first 12 months of these paths.

when a tax rate is the fiscal policy instrument. To convert this measure into a fraction of income, multiply by labor's share of income which, given our calibration, is roughly 0.7.[14]

Table 2: Welfare Benefit Relative to the Baseline Government Spending Policy

	τ_w	τ_c	τ_k
$U_1 = U_2$	-1.14	-0.55	1.17
$U_1 < U_2$	-0.18	0.41	2.42
$U_1 > U_2$	-2.81	-2.23	-1.06

The benchmark case is when $U_1 = U_2$ in steady state which corresponds to setting the parameter on private consumption in the consumption aggregator, ψ, so that the marginal utility of private consumption goods equals that of public consumption goods. Welfare results for the benchmark case are reported in the first row in Table 2. For this case, switching from the government spending fiscal policy to the labor income tax results in a welfare *loss* of 1.14% of income. Switching instead to the consumption tax is associated with a smaller welfare loss, 0.55% of income. Fiscal austerity through the capital income tax leads to a welfare *gain* of 1.17% of income. This latter result may appear puzzling in light of the earlier discussion about how long the capital income tax is kept above its steady state value. While this tax tends to depress economic activity, the lower path for investment allows for a higher path for consumption which benefits households.

The potential welfare benefit (or loss) of switching from government spending to one of the tax instruments is quite large, particularly in light of the relatively small differences in the model's time paths summarized in Figures 4 and 5. To understand what is driving these welfare numbers, Table 3 isolates the effects of the variables going into the calculation of the welfare metric. For example, the effect of the different employment (and unemployment) paths is obtained by recomputing the welfare metric, ζ, replacing the employment path under the tax policy with the one prevailing under the government spending policy. Subtract this new value of ζ from the original to obtain the contribution of employment. Repeat for the

[14] Labor's share will be a little less than the elasticity of output with respect to labor due to the Nash bargaining-determination of wages.

other variables that factor into the calculation of the welfare benefit.

Across the three taxes, Table 3 shows that the induced differences in either employment or the job-finding probability have essentially no effect on the welfare calculation. For the capital income tax, the wage rate contributes negatively owing to its lower path; see Figure 5(f). Changes in discounting contribute positively in the factor income tax cases, and negatively for the consumption tax. Recall that using public spending to implement the necessary fiscal austerity reduces public consumption; while private consumption rises, it is not enough to prevent a decline in the discount factor. Under the capital income tax, the paths of both private and public consumption are fairly smooth, and the discount factor is well above that associated with the government spending rule. Thus, the large positive contribution to welfare under the capital income tax. The story is broadly similar for the labor income tax except that the differences between the paths for the discount factor are more similar than under the capital income tax. Finally, when policy is implemented via the consumption tax, on impact the discount factor falls quite sharply leading to its negative contribution to welfare.

Table 3: Decomposition of the Welfare Benefit Relative to Baseline Government Spending Policy

	τ_w	τ_c	τ_k
Employment	0.000	0.000	0.000
Job-finding	−0.001	0.002	−0.070
Wage	−0.003	0.000	−1.723
Discounting	0.479	−0.554	2.943
Labor income tax	−1.614		
Sum	−1.133	−0.553	1.152

The final factor in the welfare calculation is the change in the labor income tax which is only in play when considering this tax rate. The penultimate row in Table 3 reveals that the bulk of the welfare cost associated with switching between the government spending and labor income tax policies is driven by the simple fact that a higher labor income tax rate directly lowers after-tax labor income.

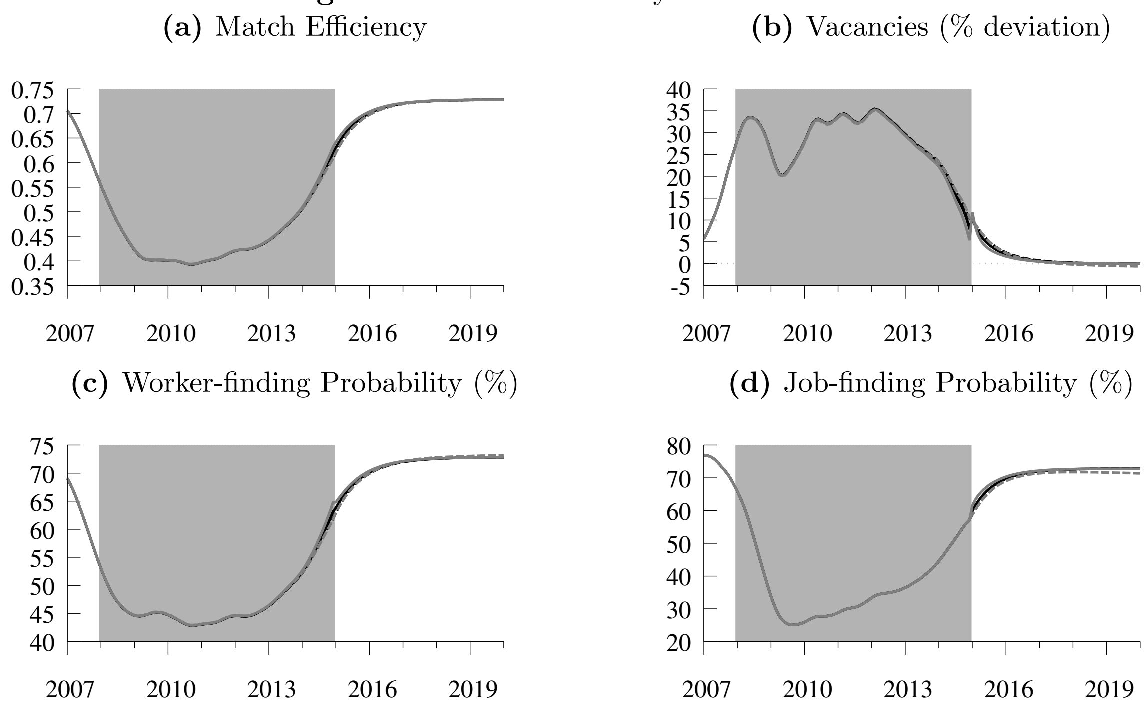
The benchmark calibration of ψ may be considered ‘reasonable’ in the sense that a benevolent planner choosing private and public consumption would allocate these consumptions to equate their marginal utilities. Yet, this calibration is also somewhat arbitrary. Those on the left of the political spectrum may believe that there is too little public spending. In this case, government spending is quite valuable relative to private consumption, and so $U_1 < U_2$. Calibrate ψ so that $U_1/U_2 = 1/3$. The dynamic paths of the model for this calibration are quite similar to those of the benchmark calibration and so are omitted. Since the marginal utility of public consumption goods is now much higher than that of private consumption goods, households should be more willing to switch to any of the tax-based policies since they are associated with an immediate rise in public consumption. Indeed, the second line in Table 2 shows that this intuition holds: the welfare benefit of switching to the capital income taxes is higher, the welfare loss of switching to the labor income tax is lower, and use of the consumption tax changes from being welfare-reducing to welfare-improving.

Alternatively, those to the right of the political spectrum probably think that there is too much government spending. To capture this scenario, calibrate ψ such that $U_1/U_2 = 3$. Again, the dynamic paths associated with this calibration are fairly close to those of the benchmark calibration. In this case, a policy switch to using any of the taxes is welfare-reducing. The intuition is the opposite of the previous case: Households care relatively little about the lost public consumption goods associated with using government spending to reduce the debt-output ratio, and so the distortionary effects of the tax rates plays a greater role in their welfare calculus. Consequently, switching from government spending to using any of the tax rates delivers a welfare loss.

5.5 Cost of Vacancies versus Match Efficiency

During the Great Recession, solving the benchmark model involved finding a sequence for the cost of vacancies so that, roughly speaking, the model fits the job-finding probability. As discussed in the introduction, shifts in the Beveridge curve, the empirical relationship between vacancies and unemployment, have lead some to speculate that match efficiency varied during the Great Recession. Rather than finding a series for the vacancy cost, we instead seek a series for match efficiency so that the model replicates the observed time series for the job-finding probability. Since the model's implications for total factor productivity and macroeconomic variables are quite similar to that of the benchmark model, attention is focused on the labor market implications of this alternative solution.

Figure 6: Match Efficiency: The Labor Market



Legend: Solid black lines: government spending; dotted black lines: labor income tax; solid gray lines: consumption tax; dotted gray lines: capital income tax. The shaded area corresponds to the Great Recession period extended to mid-2014 when output returns to its balanced growth path.

First off, the model infers a sharp drop off in match efficiency going into the Great Recession; match efficiency continues to drop through 2009. The fall in match efficiency is quite substantial: match efficiency falls from an average of 0.7 early in 2007 to as little as 0.393, a decline of more than 40%. As with the vacancy cost, it is difficult to directly judge whether the changes in match efficiency over the Great Recession are plausible. However, the model's implications for other variables can be used to indirectly assess the two alternatives, match efficiency or cost of a vacancy. The two alternatives have much different implications for the worker-finding probability. Relative to the average worker-finding probability in 2007, the match efficiency accounting of the Great Recession sees as much as a 26 percentage point *decline* in this probability; the vacancy cost explanation, roughly a 20 percentage point *increase*. As discussed earlier, the benchmark model's predicted decline in the duration of a vacancy, 35%, mathces that reported by Davis, Faberman, and Haltiwanger's (2013) measure for the U.S.. In contrast, changes in match efficiency imply a *increase* in the duration of a vacancy, rising from 1.4 months early in 2007 to 2.3 at the depth of the Great Recession.

The fall in the worker-finding probability reported in Figure 6(c) necessitates a large rise in the number of vacancies; see Figure 6(b). Again, the benchmark model makes the opposite prediction, a sharp decline in vacancies. For the U.S., Figure 2(d) shows that vacancies dropped during the Great Recession whether measured by the help wanted index (40%) or job openings (50%).

To sum up, choosing match efficiency so that the model's predicted path for workers' job-finding probability matches that seen in the U.S. data leads to counterfactual implications for the behavior of the number of vacancies and the average duration of a vacancy. The benchmark model which chooses, instead, a sequence for the cost of vacancies, *is* consistent with the data. As a single explanation of the dynamics of the labor market during the Great Recession, match efficiency is clearly lacking

6 Conclusion

We constructed a dynamic general equilibrium model of the U.S. Great Recession and recovery. The model was calibrated to observations for the U.S. prior to the Great Recession, and a set of shocks were obtained so that the model fit the U.S. experience during and after the Great Recession. The model was then used to evaluate austerity measures designed to return the debt-output ratio to its pre-Great Recession level.

The model delivers three important results. First, the Great Recession and recovery are largely a labor market phenomenon. The most important developments were: the job-separation probability, the cost of posting a job vacancy (chosen to match the job-finding probability), and increases in unemployment insurance payments (reflecting the effects of various extensions to unemployment insurance benefits). Our financial shock has only modest effects, arguably pointing to the limits of such a reduced form shock.

Second, the time paths of macroeconomic variables following application of fiscal austerity, starting in 2015, are quite similar across the four policy instruments, namely government spending, the labor income tax, the capital income tax, and the consumption tax. Nonetheless, there is a clear welfare ranking of these instruments with the capital income tax being the most preferred and the labor income tax the least.

Third, an alternative solution of the model was presented which held constant the vacancy cost, choosing instead a time series for match efficiency. This version of the model delivers counterfactual predictions for the temporal pattern of vacancies and their duration; our benchmark model, choosing a time series for the job-posting cost, does not suffer from these deficiencies.

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Appendix A Data Sources

All data downloaded from https://research.stlouisfed.org/fred2. Descriptions are as follows:

FII20: 20-Year Treasury Inflation-Indexed Security, Constant Maturity

UNRATE: Civilian Unemployment Rate

UNEMPLOY: Unemployment Level

CE16OV: Civilian Employment

JTSTSL: JOLTS: Total separations: total nonfarm

JTSHIL: JOLTS: Hires: Total Nonfarm

CNP16OV: Civilian Noninstitutional Population

W825RC1: Personal current transfer receipts: Government social benefits to persons: Unemployment insurance

CPIAUCSL: Consumer price index for all urban consumers: all items

PCECC96: Real personal consumption expenditures

GCEC96: Real Government Consumption Expenditures & Gross Investment

GPDIC96: Real Gross Private Domestic Investment, 3 decimal

GCE: Government expenditures on consumption and investment

GDP: Gross Domestic Product

GDPC96: Real Gross Domestic Product, 3 Decimal

DPCERD3Q086SBEA: Personal consumption expenditures (implicit price deflator)

USREC: NBER based Recession Indicators for the United States from the Period following the Peak through the Trough

GFDEGDQ188S: Federal Debt: Total Public Debt as Percent of Gross Domestic Product

M318501Q027NBEA: Federal government budget surplus or deficit (-)

LES1252881600Q: Employed full time: Median usual weekly real earnings: Wage and salary workers: 16 years and over

Code for data:

- https://paulgomme.github.io/usdata.r
- https://paulgomme.github.io/hangover.r
- https://paulgomme.github.io/hangover.m

Appendix B Alternative Measures of the Job-finding and Job-separation Probabilities

Shimer (2005) proposed measuring the job-finding and job-separation probabilities using CPS data alone. Not only is the number of unemployed reported for the U.S., so is the number of short term unemployed (less than 5 weeks), u_t^s. Using this methodology, the job-finding probability is given by

$$f_t = -\ln\left(\frac{u_t - u_t^s}{u_{t-1}}\right).$$

The separation probability, then, is given by the nonlinear solution to

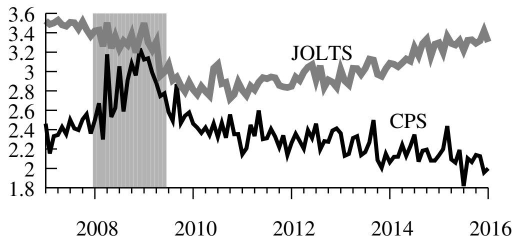
$$u_{t+1} = (1 - \exp(-f_t - s_t))\frac{(u_t + e_t)s_t}{f_t + s_t} + \exp(-f_t - s_t)u_t;$$

see Shimer for details on the derivation of this formula. The probabilities f_t and s_t are plotted in Figures 2(a) and 2(b), labeled 'CPS' since they are based on Current Population Survey data. According to these series, the sharp rise in the unemployment rate is largely due to a rise in the probability of losing a job which rises from roughly 2.4% per month in the year prior to the Great Recession, to well over 3% during the recession. This probability has, since, returned to around its pre-recession value. Meanwhile, during the Great Recession, the job-finding probability fell from around 40% to roughly half that, around 20%. The slow fall in the unemployment rate is, then, attributable to the fact that the job-finding probability has yet to return to its pre-recession level.

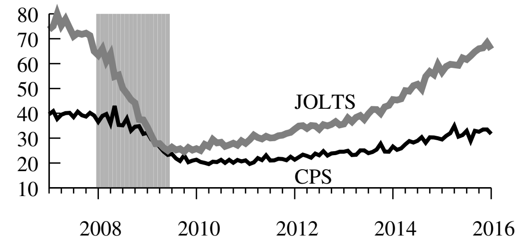
As shown in Figures 7(a) and 7(b), the CPS-based and JOLTS-based measures of the job-finding and job-separation probabilities behave somewhat differently, and so give very different interpretations of the labor market during the Great Recession and its aftermath.

Figure 7: Alternative Measures

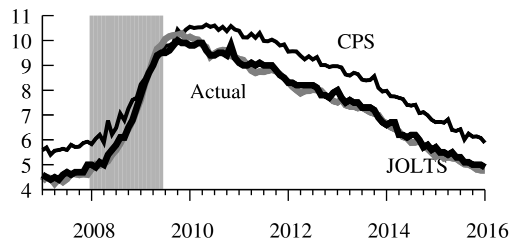
(a) Separation probability (%)



(b) Job-finding probability (%)



(c) Unemployment rate (%)



Note: The shaded area corresponds to the NBER definition of the Great Recession, that is from peak to trough.

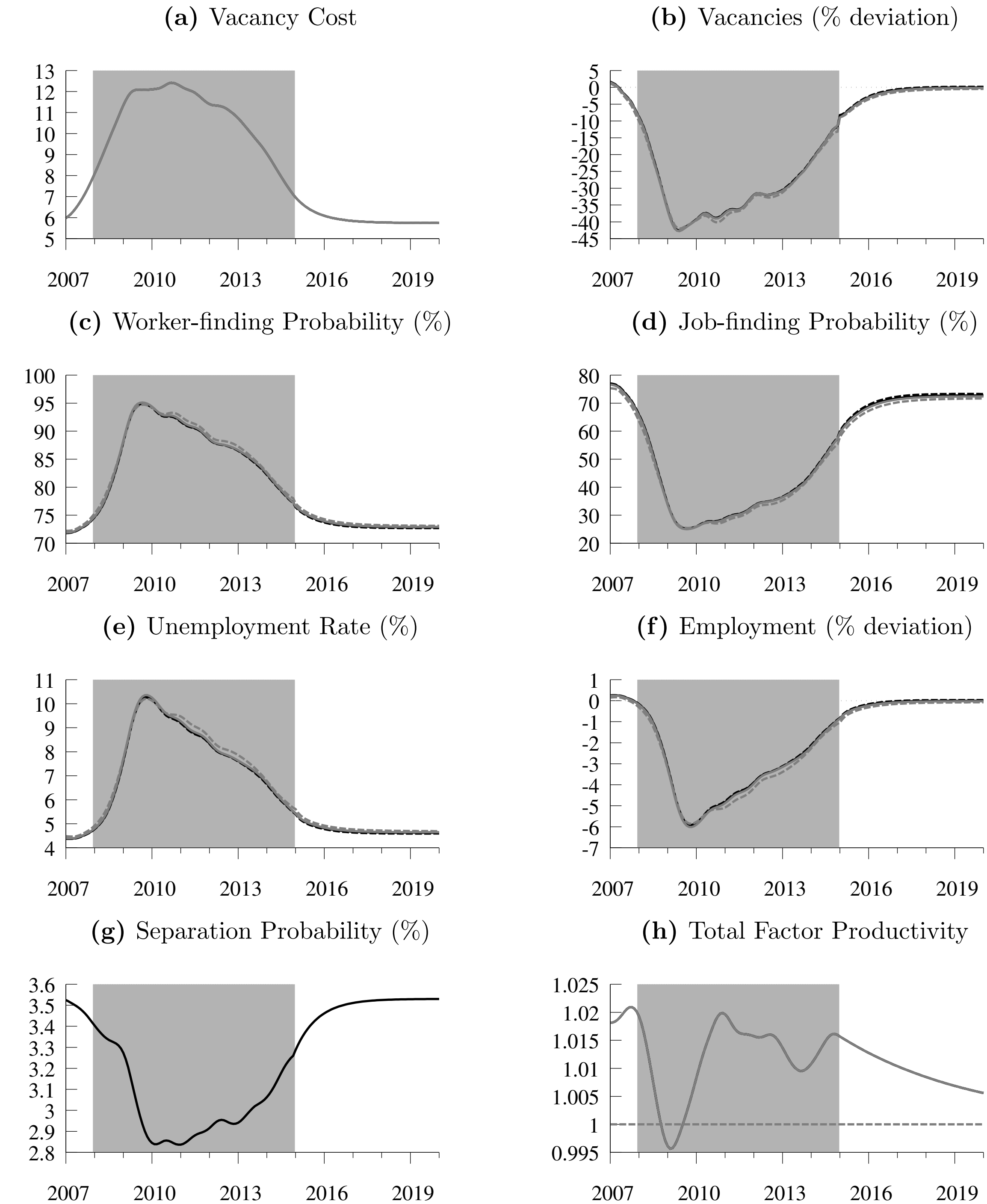
Which of the two comes closest to the 'truth'? One way to choose between them is to use the job-finding and separation probabilities to infer a time series for the unemployment rate. Starting with the unemployment rate in January 2007, compute inferred unemployment rates using

$$\tilde{u}_{t+1} = (1 - f_t)\tilde{u}_t + s_t(1 - \tilde{u}_t),$$

where $\tilde{u}_t$ is the unemployment rate (and so $1 - \tilde{u}_t$ is the employment rate). These fitted series, along with the actual unemployment rate, are plotted in Figure 2(c). Visually, it can be seen that the JOLTS-based probabilities deliver fitted unemployment rates that are much closer to actual than the CPS-based probabilities. The CPS-based measure of unemployment exceeds actual through 2007 and 2008, and after 2010; these differences are roughly one percentage point. While the JOLTS-based fitted unemployment rate peaks a bit higher than actual, it generally follows the actual unemployment rate fairly closely. Consequently, below we will focus on the JOLTS-based measures of the job-finding and separation probabilities.

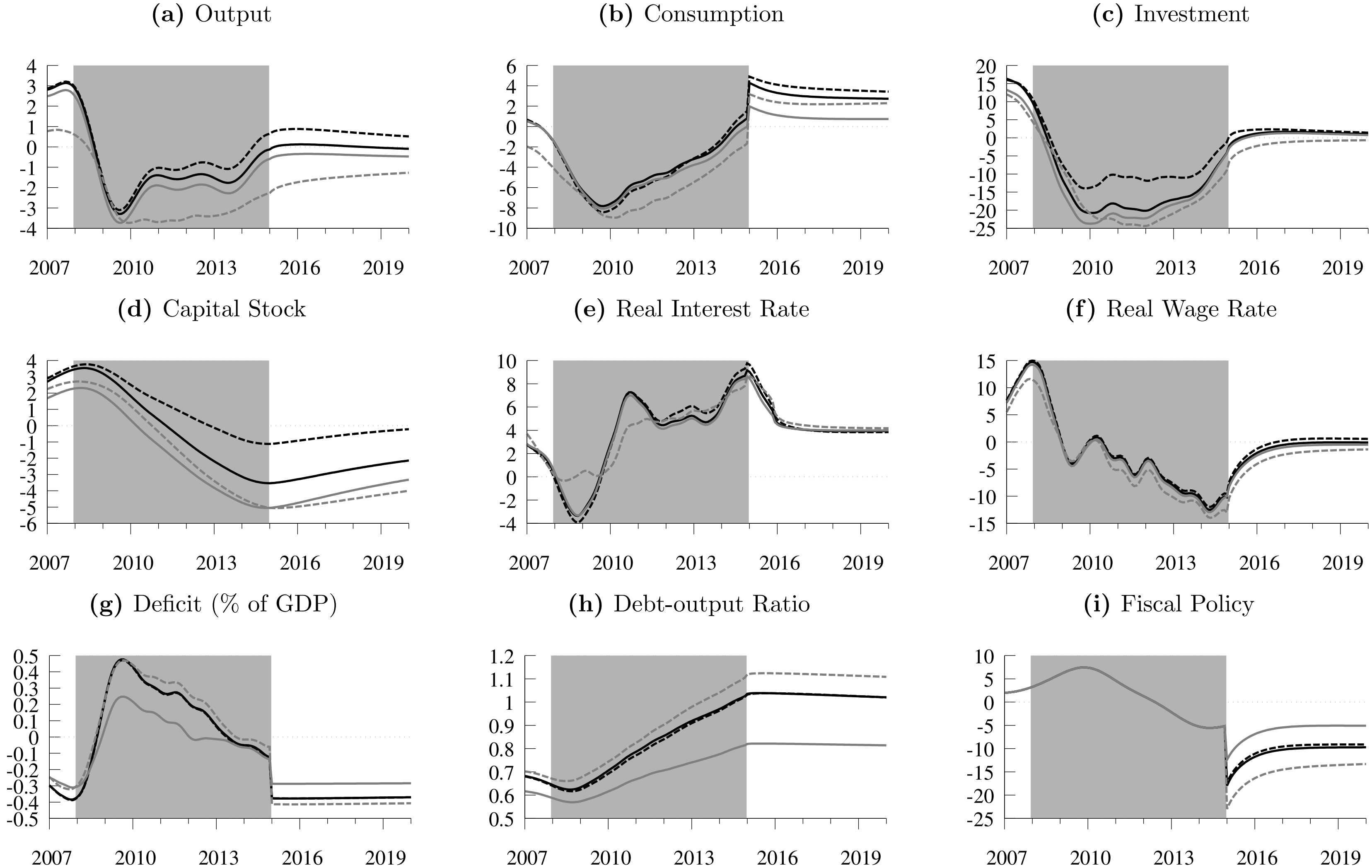
Appendix C Additional Figures

Figure 8: The Labor Market under the Government Spending Rule: Effects of Financial, Tax and Total Factor Productivity Shocks



Legend: Solid black lines: baseline (all shocks); dotted black lines: no financial shock; solid gray lines: no tax rate shocks; dotted gray lines: no total factor productivity shock. The shaded area corresponds to the Great Recession period extended to the end of 2014 when output returns to its balanced growth path.

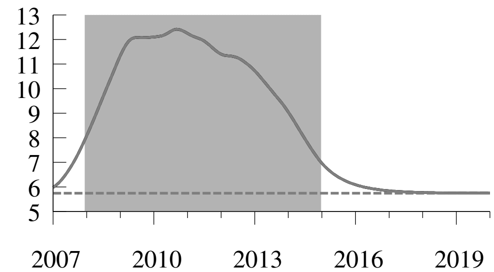
Figure 9: Macroeconomic Variables under the Government Spending Rule: Effects of Financial, Tax and Total Factor Productivity Shocks



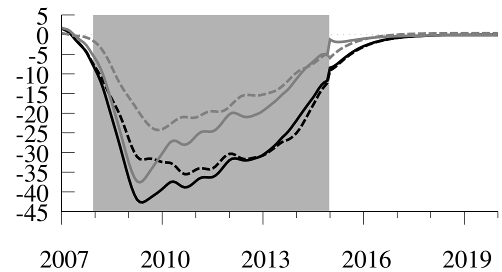
Legend: Lines are coded as in Figure 8. Output, consumption, investment and capital are expressed as percentage deviations from steady state; for fiscal policy, government spending is likewise expressed as a percentage deviation from steady state while the tax rates are percentage point changes from steady state; all other variables are in levels. The real interest rate is computed via compounding over the previous 12 months to give an annual interest rate. The debt-output ratio is expressed at an annual rate.

Figure 10: The Labor Market under the Government Spending Rule: Effects of Labor Market and Unemployment Insurance Shocks

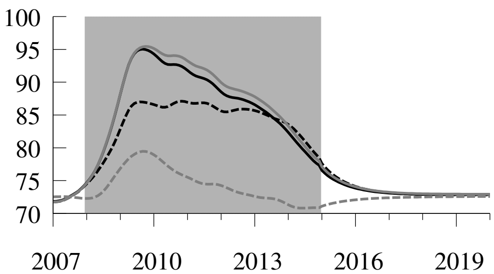
(a) Vacancy Cost



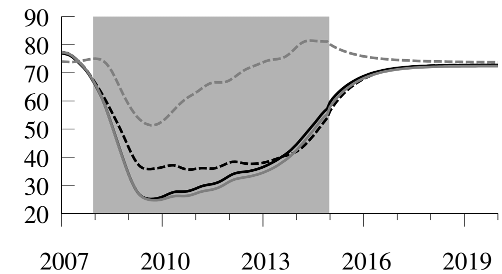
(b) Vacancies (% deviation)



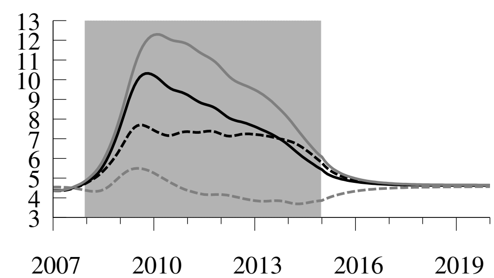
(c) Worker-finding Probability (%)



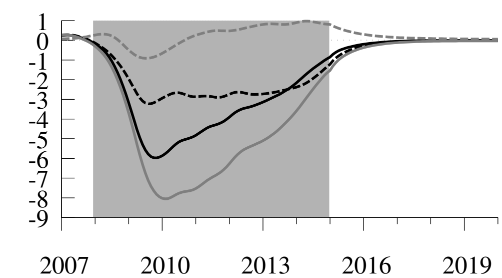
(d) Job-finding Probability (%)



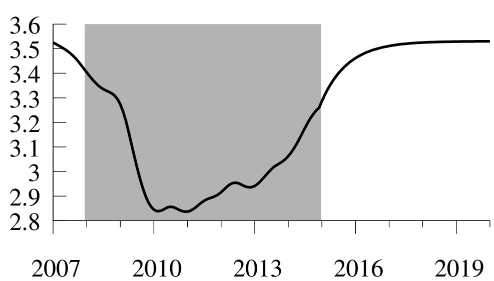
(e) Unemployment Rate (%)



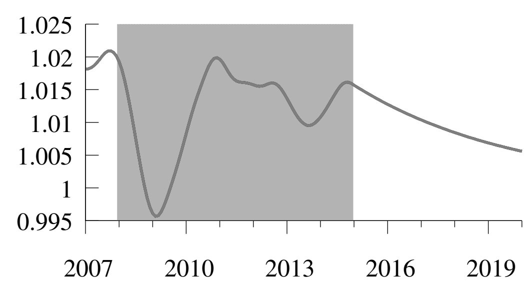
(f) Employment (% deviation)



(g) Separation Probability (%)

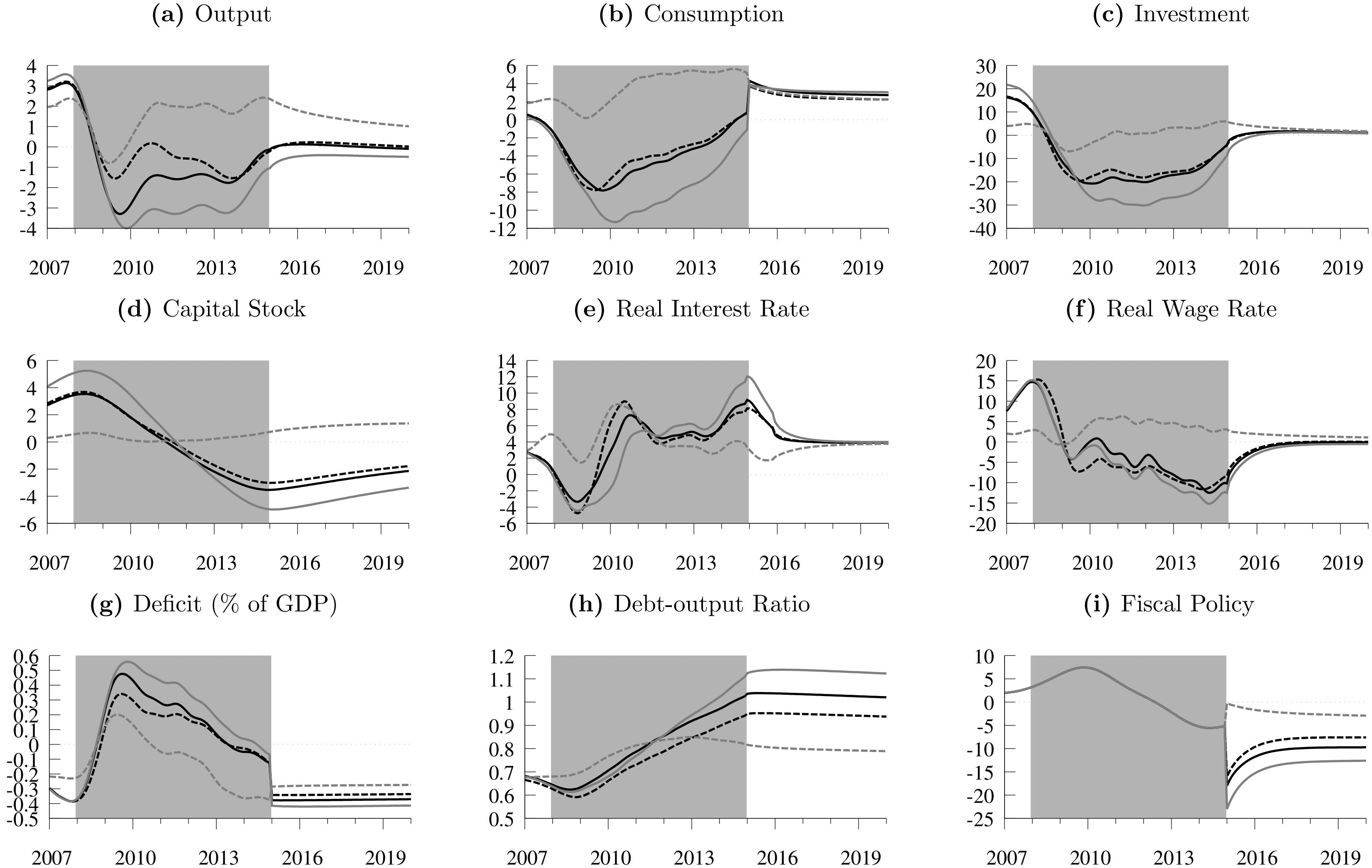


(h) Total Factor Productivity



Legend: Solid black lines: baseline (all shocks); dotted black lines: no unemployment insurance shock; solid gray lines: no separation probability shock; dotted gray lines: no vacancy cost shock. The shaded area corresponds to the Great Recession period extended to the end of 2014 when output returns to its balanced growth path.

Figure 11: Macroeconomic Variables under the Government Spending Rule: Effects of Labor Market and Unemployment Insurance Shocks



Legend: Lines are coded as in Figure 10. Output, consumption, investment and capital are expressed as percentage deviations from steady state; for fiscal policy, government spending is likewise expressed as a percentage deviation from steady state while the tax rates are percentage point changes from steady state; all other variables are in levels. The real interest rate is computed via compounding over the previous 12 months to give an annual interest rate. The debt-output ratio is expressed at an annual rate.

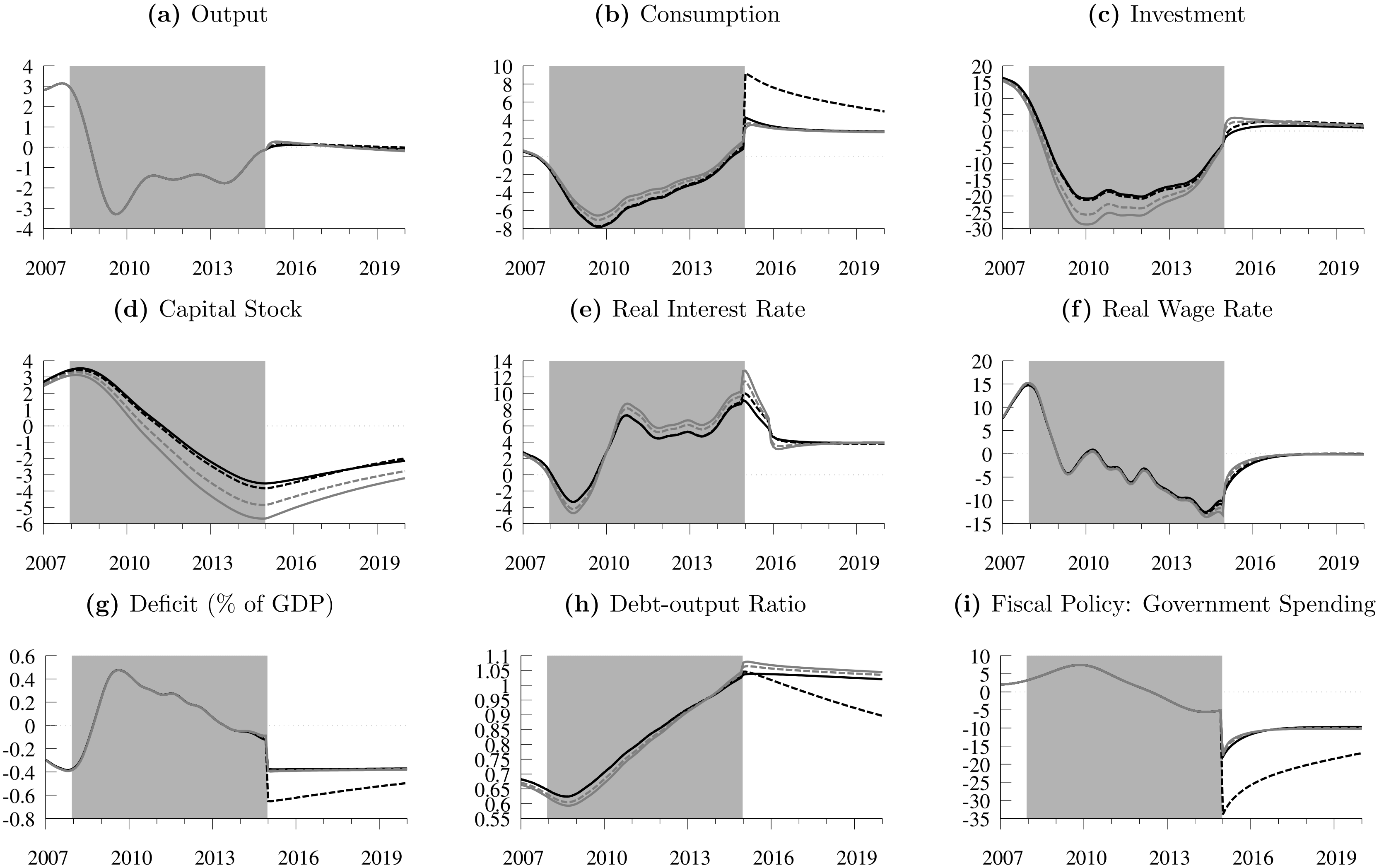
Appendix D Implications of Alternative Parameter Values

Most of the model parameters or targets, summarized in Table 1, are either commonly used in the business cycle literature (chiefly, preferences and technology), or are well pinned down by the data (the tax rates, government's share of output, the government debt-output ratio). Three parameters are relatively new to this paper and so there is less consensus regarding their values: ω, the policy feedback parameter; ξ, the elasticity of substitution between private and public consumption goods in preferences; and ψ which governs the importance of private versus public consumption goods in preferences. This section explores how the model's results change with these parameters. One parameter at a time is changed, the model is then re-calibrated and re-solved. Given that two of the three parameters being altered are those that govern the role of public consumption goods in preferences, it should not be too surprising that the results that are most sensitive to these parameters are those associated with using government spending as the policy instrument. With this in mind, and to avoid overwhelming the reader with results, attention is focused on the government spending scenario. These results are summarized in Figures 12 and 13.

To start, consider the effects of setting the policy feedback parameter to a higher value, $\omega = 0.125$; in the benchmark calibration, its value is 0.05. This setting for the policy feedback parameter puts outside the range estimated by Bohn (1998). This higher setting for the policy feedback parameter attenuates the policy response. For example, the larger policy feedback parameter value requires a 30 percentage point drop in government spending whereas the benchmark model requires a 8.9% fall. The responses of other variables under the tax rate policies are similarly stronger for $\omega = 0.125$. The net result is a far more extreme response of macroeconomic variables after the Great Recession. The debt-output ratio also comes down much more quickly.

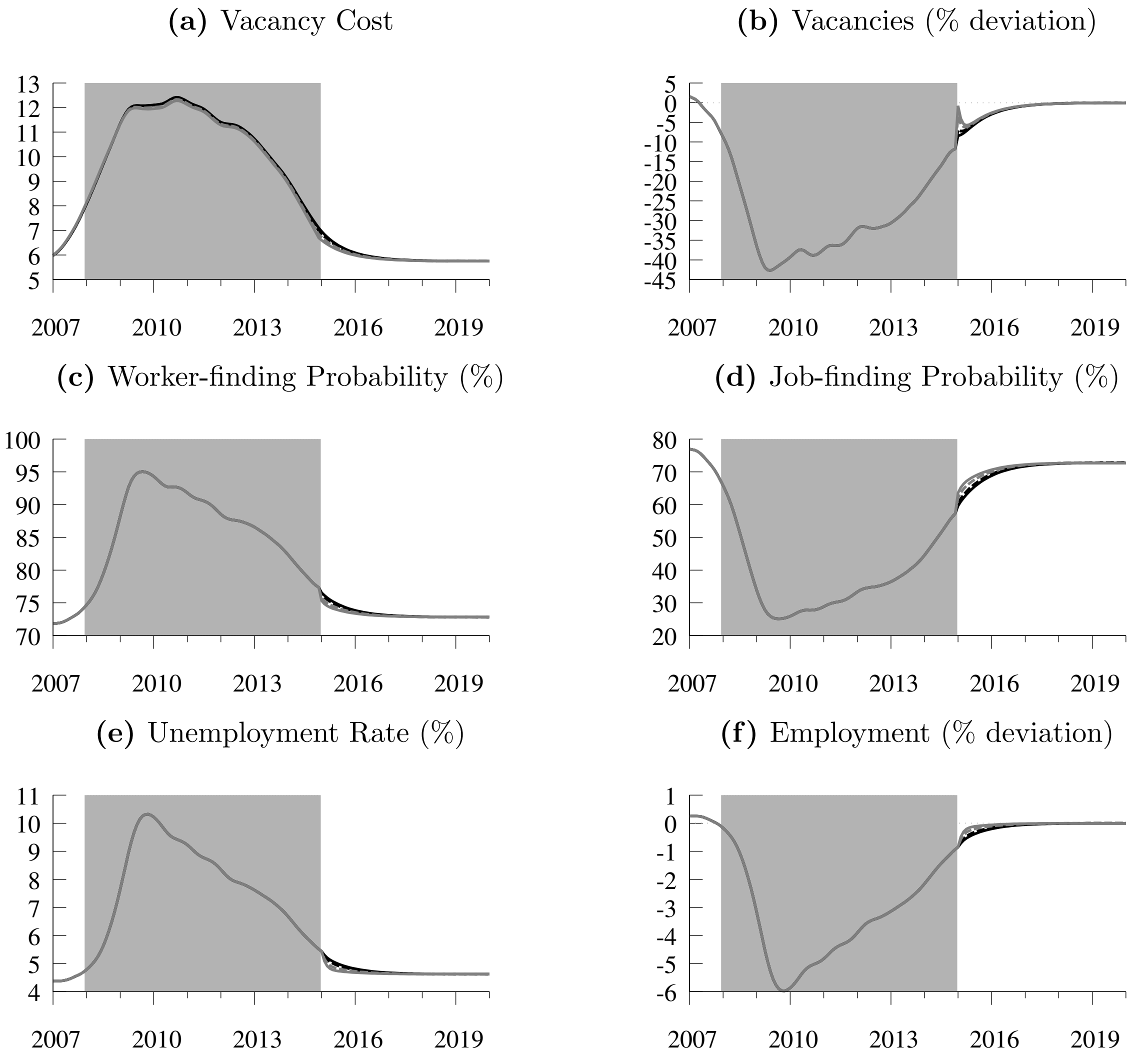
The other two cases are sufficiently similar to discuss them together. For one, the

Figure 12: Sensitivity Analysis: Government Spending Rule



Legend: Solid black line, benchmark calibration; dotted black line, $\omega = 0.125$; solid gray line, $\xi = 0.5$; and dotted gray line, $U_1/U_2 = 3$.

Figure 13: Sensitivity Analysis: The Labor Market



Legend: See Figure 12.

elasticity of substitution between private and public goods, ξ, is set to 0.5 which implies that these goods are much less substitutable in preferences (the benchmark calibration set this parameter to 2); for the other, the parameter ψ is calibrated so that the steady state marginal rate of substitution between private and public consumption goods is 3; in the benchmark calibration, the marginal rate of substitution is 1. Refer to these two cases collectively as the low substitutability calibrations. Consider events during the Great Recession. When private and public goods are less easily substitutable in preferences ($\xi = 0.5$), households' response to the eventual decline in government spending over the last half of the Great Recession is to substitute into private consumption. Given that the model is forced to replicate the path for output during the Great Recession, and since the path for government spending is fixed during the Great Recession, the only way to increase private consumption (relative to the benchmark path) is to reduce investment.

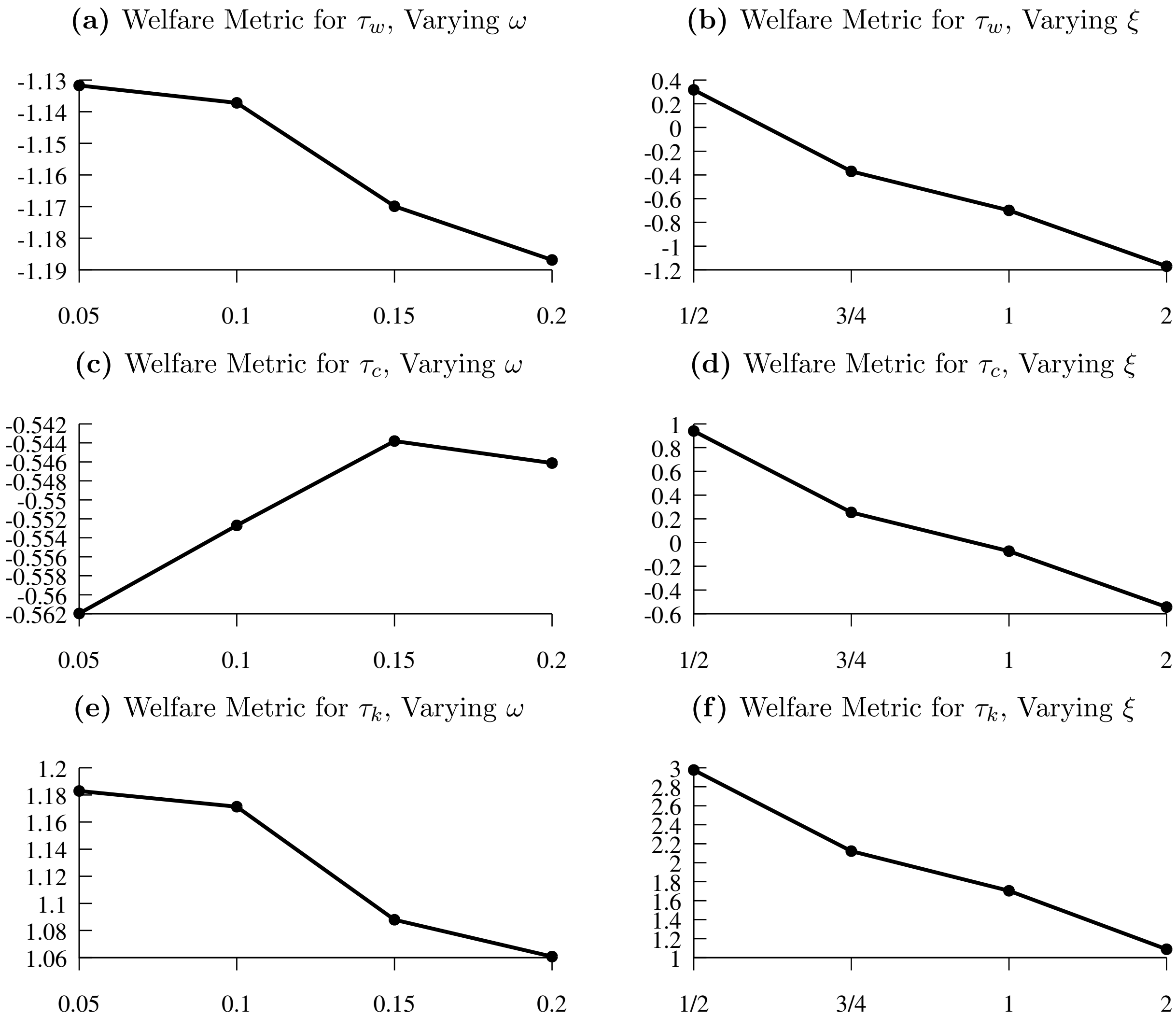
The same mechanics are in operation when the steady state marginal rate of substitution between private and public consumption is 3, but for different economic reasons. Whereas feasibility dictates that the trade-off between private and public consumption goods is 1, households would be willing to give up closer to 3 units of public consumption goods for an additional unit of private consumption. Faced with a drop in public consumption in the latter half of the Great Recession, households respond by increasing their private consumption (again, relative to the benchmark path). Once again, given the fixed paths for output and government spending, this (relative) increase in private consumption comes at the cost of reduced investment.

Given the lower level of investment, relative to the benchmark path, the capital stock is also lower. The lower capital stock – along with higher total factor productivity – pushes up the real return to capital, and via a no arbitrage condition, the real interest rate on government debt. This higher real interest rate during the Great Recession results in a slightly higher level of government debt: the benchmark model has a debt-output ratio of 0.90 over the last 12 months of the Great Recession; less substitutable private and public consumption results in a ratio of 0.92 while a larger marginal rate of substitution between these two goods sees a ratio of 0.91. As a result, somewhat greater fiscal austerity is needed relative to the benchmark model. Households increase their consumption in response to the larger drop in government expenditures. The economy increases its investment in order to build up its capital stock to allow for above-trend private consumption, and the rising path for government spending that results as the debt-output ratio gradually returns to its pre-Great Recession level.

In fact, for these latter two calibrations, immediately after the Great Recession (as fiscal austerity is being applied) the real interest rate rises which results in an even higher government debt-output ratio: in the first 12 months after the Great Recession, this ratio rises to 1.00 when $\xi = 0.5$, or 0.97 when $U_1 > U_2$. Through the fiscal policy rule, these higher debt-output ratios result in even more fiscal austerity: in the first 12 post-Great Recession months, the benchmark calibration calls for government spending 14.3% below trend; $\xi = 0.5$ results in a larger cut to 30% below trend. Calibrating to a higher marginal rate of substitution between private and public consumption goods leads to a government spending 29% below trend.

The labor market implications of these alternative calibrations are largely driven by the dynamics of the vacancy cost. While the $\omega = 0.05$ case looks quite similar to that of the benchmark calibration, the low substitutability calibrations do not. Specifically, to fit the data, the low substitutability calibrations require a sharper fall in the cost of vacancies towards the end of the Great Recession; see Figure 13(a). After the Great Recession when the 'natural' dynamics of the model are allowed to operate, these lower vacancy costs result in a spike in vacancies and so the job-finding probability. In turn, this higher probability results in higher employment, and a lower unemployment rate. In the first year after the Great Recession, the benchmark calibration has the unemployment rate sitting at 5.4%. In contrast, when $\xi = 0.5$, the unemployment rate is 5.0; for the marginal rate of substitution case, it is 5.1%. However, as shown in Figure 13(e), these effects are relatively short lived, lasting only a couple of years.

Figure 14: Welfare: Alternative Values of ω and ξ



Legend: The vertical axes measure the welfare benefit of switching policy to a particular tax rate. For the left-hand panels, the horizontal axis varies the value of ω (which governs the degree of policy activism'; the the right-hand panels, the value of ξ (the elasticity of substitution between private and public consumption goods).

The welfare implications of alternative values of the parameters ω and ξ are summarized in Figure 14. For the most part, the welfare benefit of switching from government spending to a tax-based policy are not very sensitive to the value of ω which governs how quickly the government returns the debt-output ratio to its pre-Great Recession value. That said, smaller values of ω (implying a longer transition) are associated with larger welfare benefits of switching from government spending to the consumption tax, and lower benefits of switching to the capital income tax.

The right-hand panels of Figure 14 show that the welfare results are more sensitive to the elasticity of substitution between private and public consumption, ξ. In particular, high elasticities are associated with larger welfare benefits of switching the policy instrument from government spending to a tax. This finding is easy to understand: when these goods are more substitutable, households place greater value in the immediate jump in the provision of public goods under a tax-based policy as opposed to the large drop when government expenditures are the policy instrument.