Debt Hangover in the Aftermath of the Great Recession

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Keywords:

Fiscal policies, tax reforms, government debt, government deficits

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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. An increase in government spending and fall in effective tax rates has lead to a increase in the level of government debt which 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 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

[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.

benefits extensions. Second, a financial shock: motivated by Christiano, Eichenbaum, and Trabandt (2015), this shock modeled as 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 which is beyond the scope of this paper. 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. This result dovetails nicely with the finding in Brinca, Chari, Kehoe, and McGrattan (2016) that a labor market wedge served as the chief propagation mechanism of the Great Recession in the United States; we provide a structural interpretation of their wedge. 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 consumption tax, although the gain over either the labor income tax or straight government spending cuts is quite small.[3] Switching policy to the capital income tax is quite costly, largely because of the very long period that the capital income tax rate is held above its steady state value.

Diamond and Şahin (2015) and 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

[3] As mentioned above, government spending is valued by the representative household, and so cutting government spending is not a trivial policy prescription.

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.[4]

Since the paper considers the effects of fiscal consolidation conditional on the current 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. Perhaps surprisingly, our model provides a good fit with the data despite the fact that the financial shock has very little effect.

Elsby, Hobijn, Sahin, and Valletta (2011) and Elsby, Hobijn, and Şahin (2010) characterize the dynamics of the labor market since 2008 and show that flows from non-participation 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) explains most of the rise of the unemployment rate in the U.S. after 2008. Furlanetto and Groshenny (2016) 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

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

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 (2013) 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)–1(d) are detrended by band pass filtering, removing frequencies over 100 quarters – that is, the long run trend.[5] 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.

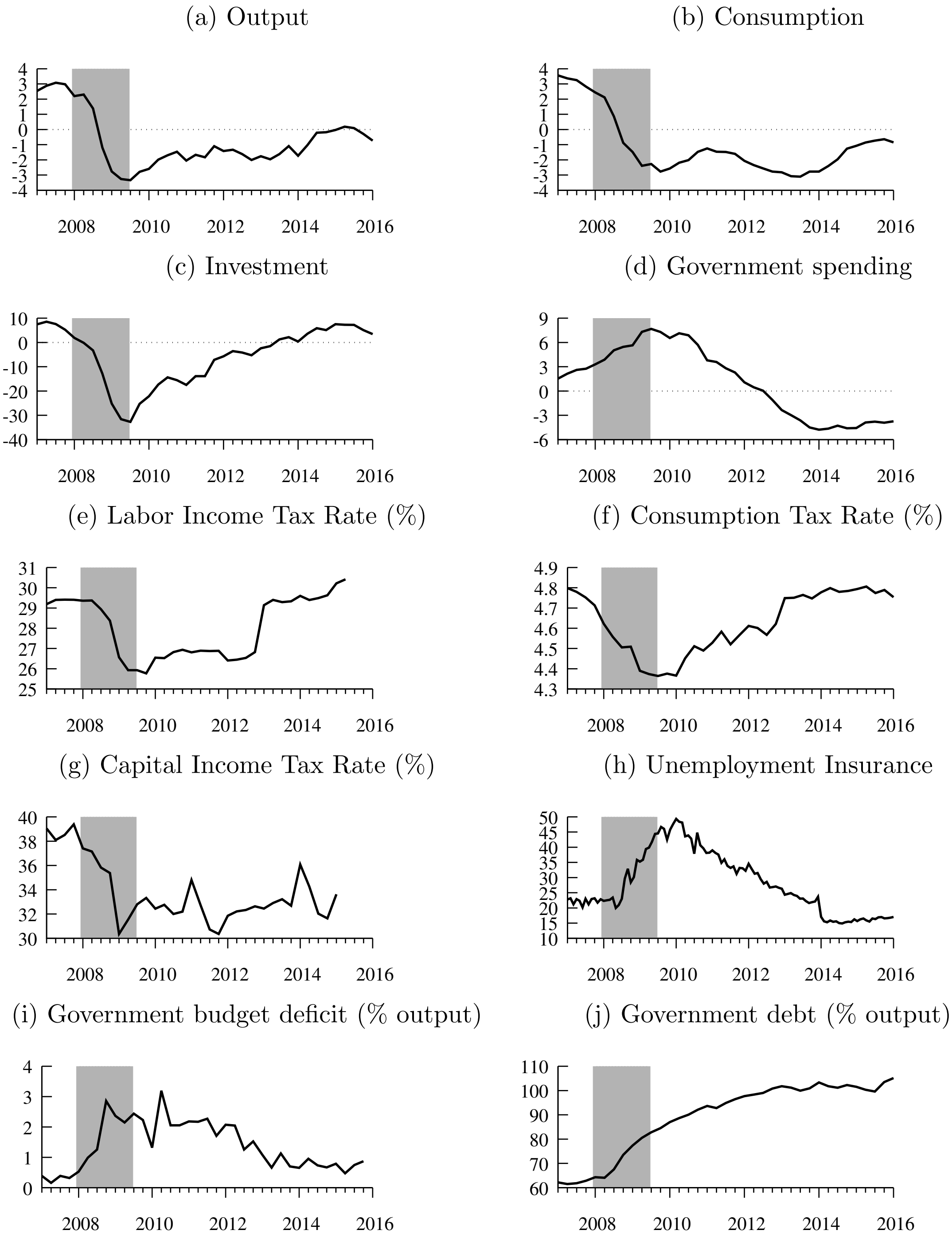
The falls in consumption and investment, in Figures 1(b) and 1(c), are likewise large – particularly for investment which, by the end of the Great Recession, was more than 30% below trend. While consumption has yet to recover to trend, by late 2013 investment had risen above trend.

Figures 1(d)–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.[6] 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

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

[6] 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

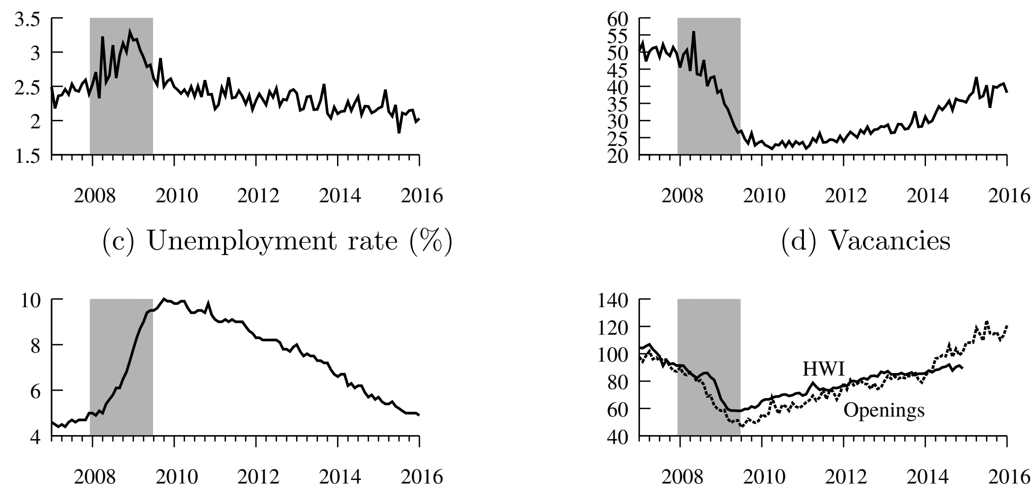


Note: The shaded area corresponds to the NBER definition of the Great Recession, that is from peak to trough.

Figure 2: Great Recession Facts: The Labor Market

(a) Separation probability (%) (b) Job-finding probability (%)

(c) Unemployment rate (%) (d) Vacancies



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).

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 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. As described in Shimer (2005), the job-finding and separation probabilities can be computed from CPS data. As shown in Figure 2(a), the probability of a job separation rose from an average of 2.43% per month in 2007 to 2.89% (2008m1–2009m6). At the same time, the job-finding probability fell sharply, from 50.3% (2007) to 23.0% (2010). The subsequent 'jobless recovery' can be traced to a stubbornly low 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

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

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. 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 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

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

at the price p_t. Finally, households also receive a lump-sum transfer, T.[8] 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

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

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

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

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

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

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

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

[8] The only role for the lump-sum transfer is to ensure that the government's primary deficit is consistent with its debt in steady state.

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.[9] 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

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

[9] 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

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

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

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

where the primary deficit is

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

The left-hand side of Eq. (18) can be rewritten in terms of d_t, total coupon payments on existing debt, and $p_t(d_{t+1} - d_t)$, new debt issuance (or retirement if negative). 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

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

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:

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

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

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	0.6399
Production		
α	Elasticity of output with respect to capital	0.3
δ	Depreciation rate	0.0059
z	Steady-state total factor productivity	1
$1+\Omega$	Financial shock or wedge	0.9955
Matching and Bargaining		
μ	Match efficiency	0.5075
ϕ	Elasticity of matches with respect to vacancies	0.544
θ	Workers' bargaining power	0.456
κ	Steady state vacancy cost	2.3285
s	Steady state job separation probability	0.0253
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	0.1871

explored in Appendix C. The elasticity of matches with respect to vacancies, ϕ, is set to 0.544 based on the estimates of Mortensen and Nagypál (2007). The workers' bargaining parameter, θ, is set to $1 - \phi$, 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 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 C.

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 2.5% per month; a job-finding probability of 51%; 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 next four 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 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, $U_1 = U_2$) by normalizing the value of ψ.

Finally, as is common in the search and matching literature, the ratio of vacancies to unemployed is set to one. This normalization implies that the worker-finding probability, a, equals the job-finding probability, f. The value for a implies that, in steady state, it takes 2 months, or 60 days, for a firm to fill a job. Dice-DFH reports the average duration of a vacancy in 2016 is around 29 working days, or roughly 40 calendar days (see footnote 4 for the data source). If one includes the time it takes to actually open a vacancy and for the worker to actually start a job, the model's 60 day vacancy duration seems plausible.

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 4.8%, roughly its value just prior of the Great Recession.

Exogenous Processes

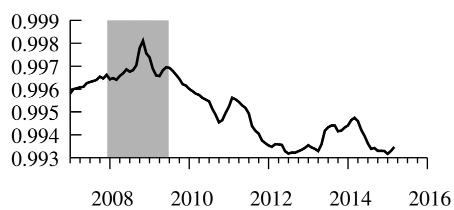
The model has a total of 9 exogenous processes. On the fiscal side, there are: government spending (g_t); tax rates on labor income (τ_{wt}), capital income (τ_{kt}) and consumption (τ_{ct}); and the unemployment insurance benefit (b_t); see the discussion in Section 2.

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.

Figure 3: The Financial Shock



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).[10] 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.

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 are assigned the same value. Given that a model period is a month, these autoregressive parameters imply a fairly rapid return to steady state.

The model is solved as a two point boundary problem via an extended path algorithm (first described by Fair and Taylor, 1983); see Auray, Eyquem, and Gomme (2016) for a detailed description of the basic solution method.[11] In fact, the model is solved as a sequence of two point boundary problems. To understand what was done, and why, consider a single two point boundary problem. In this case, the model is solved over the period September 1995 (early enough so that the initial conditions do not matter) through to the year 2515 (that is, 500 years after the end of the 'recovery' from the Great Recession). Between September 1995 and December 2014, the stochastic processes of the model are chosen as above (either exogenously, or to fit actual data). Since the solution method relies on perfect foresight, model agents know not only that the Great Recession is coming, they also know how long it will last and how severe it will be. As a result, households lower their consumption and capital accumulation well before the onset of the Great Recession, and very quickly reduce both consumption and investment early in the Great Recession. This implications of perfect foresight seems implausibly strong.

[10] We use Matlab code for the Christiano-Fitzgerald band pass filter. R's `spline.smooth` command is used to smooth the other series with a value of `lambda` of 0.0000001.

[11] 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.

To better capture the surprise nature of the Great Recession, as well as uncertainty regarding its duration and severity, the model is first solved assuming that the Great Recession never occurred. In this case, starting in January 2008, all of the model's stochastic processes are assumed to smoothly return to steady state, and government spending is chosen to satisfy the government's fiscal feedback rule. Next, using data for December 2007 as an initial value, the model is solved with one month (January 2008) of the Great Recession, followed once more by smooth adjustment of the stochastic processes to steady state, and the fiscal policy rule is in play. This process is repeated, advancing the date for the initial value of the boundary problem by one month and allowing the model to 'see' another month of actual data followed by smooth convergence of the stochastic variables to steady state. The procedure ends with the end of the recovery, December 2014. In solving the model in this way, each month of the Great Recession and recovery becomes a 'surprise' to model agents, and they do *not* adjust their behavior in anticipation of the Great Recession; nor do they fully adjust their behavior during the Great Recession. Initially, agents think that the downturn will be modest and short-lived, leading to only a modest decline in consumption and investment. As the Great Recession continues, its severity and duration become more apparent and agents further adjust their behavior. The end result is a tractable way of capturing the uncertainty surrounding the Great Recession and recovery.

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;' and the labor market shocks ensure that the unemployment rate is 'right.'

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 4(e). 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.

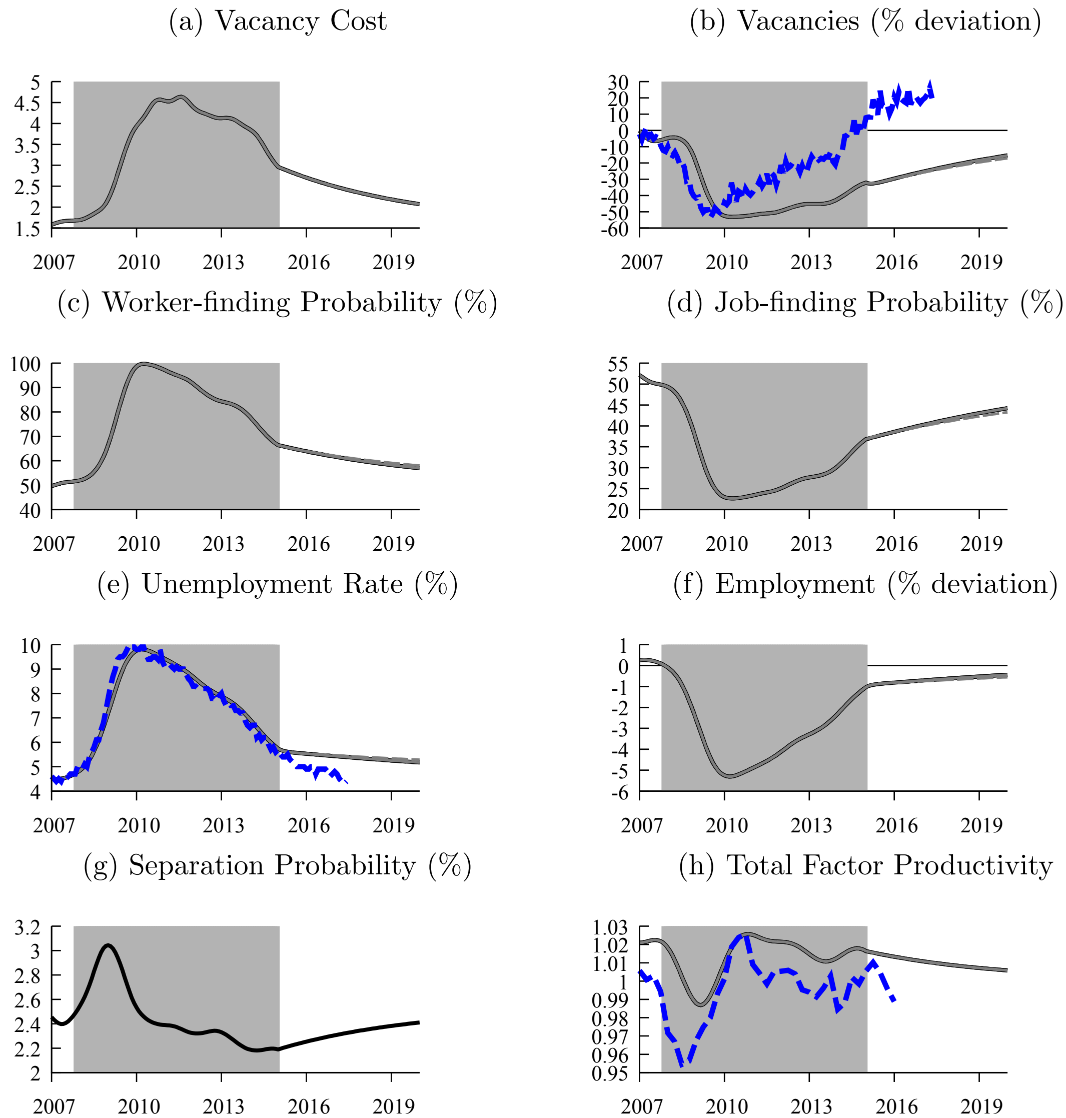
To match the job-finding probability, the model requires roughly a 40% decline in vacancies; see Figure 4(b). The data has a similarly large decline in vacancies, the model's predicts that the fall in vacancies occurred somewhat after the actual drop. Starting in 2010, the model under-predicts vacancies during the recovery.[12] Given macroeconomic conditions, this drop in vacancies comes through roughly a tripling of 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 probability; the model predicts a rise in this probability from around 50% prior to the Great Recession to nearly 100% 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 50% (from 2 months to 1 months). The data (DICE-DFW) records a somewhat smaller decline: the national mean vacancy duration fell from 23 working days to 15 working days, or 35%.

As shown in Figure 5(f), the model predicts that the average real wage fell throughout the Great Recession and subsequent recovery.[13] It may seem curious that the model predicts

[12] A larger elasticity of the matching function with respect to vacancies would bring the model's prediction for the time path of vacancies closer to the data.

[13] It is well known that within-match wages are not well determined in the Mortensen-Pissarides model.

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



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).

that real wages remained above trend through to the end of 2011. 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 actually rose starting in 2009, but subsequently fell.

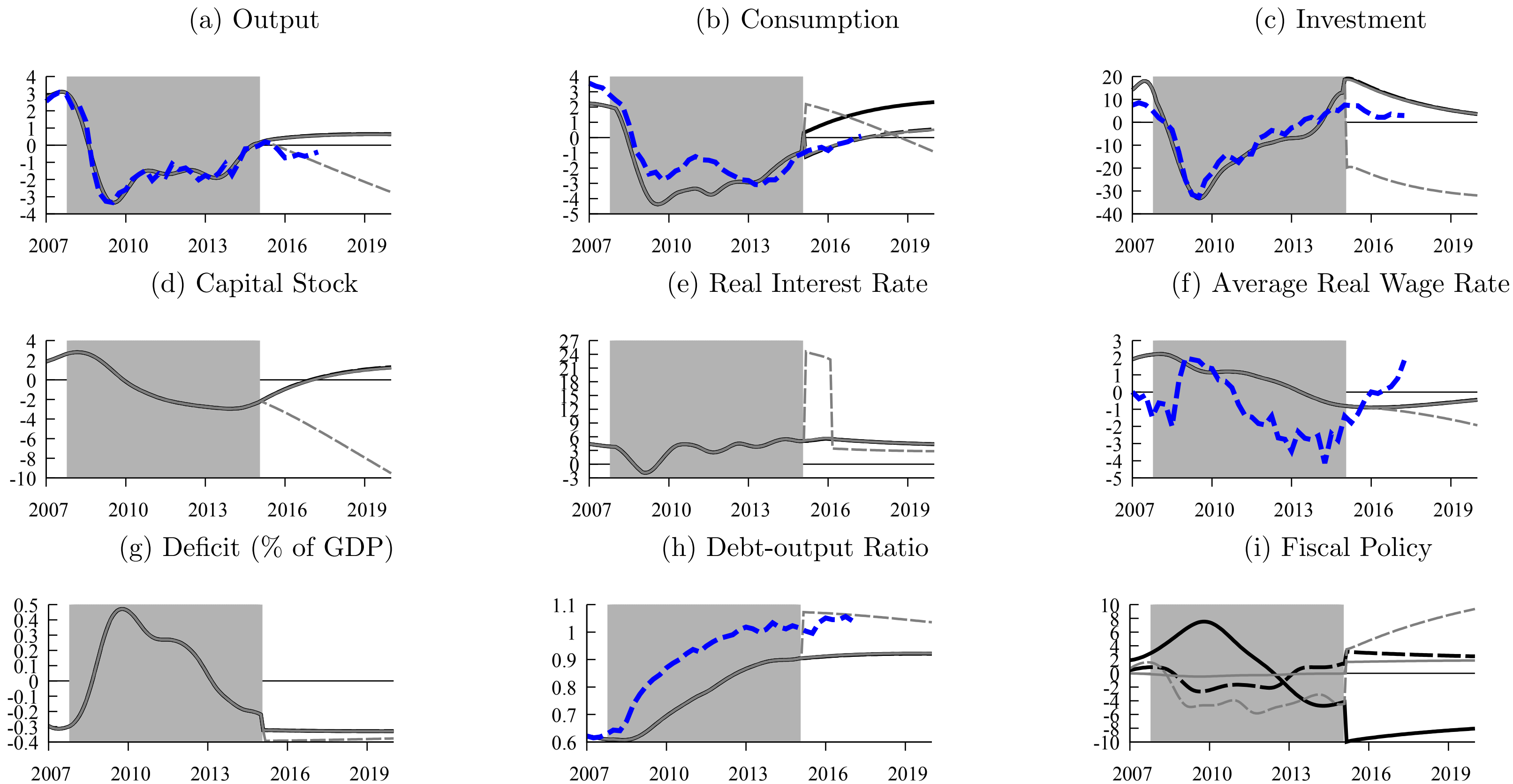
Given the employment dynamics, the model requires a 3.5% decline in total factor productivity in order to match the observed 6.3% fall in output; see Figures 4(h) and 5(a). Interestingly, the model's prediction for total factor productivity in late-2010 is as high as it was just prior to the Great Recession (2.2% above trend). Figure 4(h) also reports U.S. total factor productivity based on calculations in Gomme and Rupert (2007). The model's prediction for total factor productivity lies above actual, and exhibits far less pronounced swings than actual. Performing a Solow growth accounting for the model reveals that the bulk of the drop in output (6.3%) is accounted for by the fall in total factor productivity (3.5%), and the contribution of the fall in employment (3.9% computed by the 5.6% 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.

The model does remarkably well in capturing the magnitude of the fall in both consumption (6 percentage points) and investment (around 40 percentage points) during the Great Recession, although as seen in Figures 5(b) and 5(c), the model under-predicts the level of consumption and over-predicts the level of investment just prior to the Great Recession. Starting in 2011, the model over-predicts the path for consumption, and under-predicts the path of investment. Nonetheless, the model's predictions for consumption and investment are all the more impressive in light of the fact that these series were not targeted when solving for the model's stochastic processes, and no model features were introduced to specifically improve the model's fit for these series. In a sense, it is remarkable that in response to such a severe event as the Great Recession, such an unadorned model does so well.

Turn now to fiscal policy during the Great Recession and recovery. Figure 5(g) shows a

The average wage is computed as $\overline{w}_t = [(1 - s_t)e_t\overline{w}_{t-1} + m_t w_t]/e_{t+1}$ where w_t is the wage determined in new matches.

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.

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. As a result, the model predicts a rise in the debt-output ratio during the Great Recession and its aftermath, albeit somewhat smaller than observed. At the end of the recovery, December 2014, the model's prediction for the level of debt is 90% of output, compared to the actual value of just over 100%.

5.2 Evaluating the Role of the Shocks

To evaluate the role played by various shocks, we solve the model assuming smooth convergence to steady state of one or more shocks starting in 2008. The difference between the original paths and these new paths then gives the contribution of the shock(s). All of the figures referenced in this subsection are available in online Appendix B.

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. In the baseline simulation, the unemployment rate peaks at 9.8% in 2010m4. As shown in Figure 9(e), the model predicts that absent increased unemployment benefits, the unemployment rate would have been 7.9%. 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 10(g) and 10(h). However, given the small value of the policy feedback parameter, ω, the differences in the debt-output ratio are too small to induce much change in fiscal policy post-recovery; see Figure 10(i). The effects on macroaggregates like output, consumption and investment are modest during the recovery, and almost non-existent post-recovery.

As shown earlier, during the Great Recession the separation probability fell. Had this fall not occurred, the unemployment rate in 2010m4 is predicted to have been 9.7% rather than 9.8%. In fact, absent the changes in the separation rate, the model predicts that the unemployment rate would have peaked at 9.9% in 2010m9; see Figure 9(e). Given the similar paths for the unemployment rate, there are few differences in other labor market variables such as vacancies and the job-finding or worker-finding probabilities. The paths of consumption and investment are also fairly similar.

Next, the baseline model predicts somewhat nearly a tripling in the vacancy cost. Absent this increase, the model predicts that vacancies would have fallen 15% as opposed to the benchmark's value of 50%. The consequent smaller decline in the job-finding probability, and smaller increase in the worker-finding probability, lead to a very modest increase in the unemployment rate (peaking at 6.7%, compared to an average of 4.5% in 2007). Overall macroeconomic activity is, then, predicted to be much higher. Even if the cost of vacancies did not change, the model still predicts a recession starting in 2008. However, the model also predicts that the recession would have been far shorter, with output surpassing trend by 2010. The rise in the debt-output ratio is much smaller in this case, and there is no need for fiscal austerity; see Figure 10(i).

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 recovery; see Figures 8(a), 8(c) and 8(d). That said, the output and consumption effects are fairly modest as seen in Figures 8(a) and 8(b). The paths of the deficit and debt are little changed, and so the required fiscal austerity is quite similar; see Figures 8(g)–8(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.

Now, 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)–1(g). Had these tax rates not fallen, the model predicts that government deficits would not have been nearly as large, and consequently the debt-output ratio would not have risen as much. After the Great Recession, there is a far more modest need for fiscal austerity. As previously mentioned, there is almost not effect of tax rates on the labor market, and since the evolution of employment is the most important driver of output, the path of output is little changed. The same is true to private consumption and investment.

Finally, the smooth convergence of total factor productivity to its steady state value depicted in Figure 7(h) means that its large decline during the Great Recession would have been avoided, although its path would have been lower during the recovery. The net effect is somewhat higher output and investment during the Great recession, and lower values during the recovery. Government deficits are little changed under this scenario, and as a result the debt-output ratio is virtually the same as in the benchmark model, leading to a significant application of fiscal austerity.

In summary, the most important shocks are those directly affecting the labor market (principally, the cost of vacancies, and unemployment insurance benefits). The fiscal policy shocks (tax rates and unemployment insurance) serve to push up the model's debt-output ratio. Our model finds only a very modest role for total factor productivity and financial shocks.

5.3 Fiscal Policy after the Recovery

Starting in 2015, the fiscal policy rule Eq. (20) is in play. The benchmark model calls for government spending to satisfy this rule. However, we also consider the labor market and macroeconomic effects of an unanticipated switch to using one of the tax rates as the fiscal policy instrument.

To start, consider the model's predictions for the fiscal instruments themselves. Throughout, the impact responses are measured by comparing values averaged over all of 2014 (the last year of the recovery) with the average for 2015 (the first post-recovery year). Using government spending to bring down the debt-output ratio requires a 3.5% decline in the first year (bringing it from an average of 4.6% below trend to 8.1% below).When the government instead uses a tax rate to satisfy its fiscal policy rule, government spending is assumed to fairly rapidly return to trend, implying an increase in public consumption goods. Applying fiscal austerity via the labor income tax rate calls for a 1.6 percentage point increase in this rate. Using instead the consumption tax requires a 1.3 percentage increase in this tax rate. Finally, a 5.3 percentage point increase in required when the instrument of policy is the capital income tax. 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 needs to be larger than that for the labor income tax. As seen in Figure 4, the choice of policy instruments has no discernable implications for labor market variables.

What is common across the four fiscal policy instruments is that the fiscal policy rule maintains large primary surpluses as shown in Figure 5(g), and it is these 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 late 2090s (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 (89.19% and 61.37%, respectively). As already discussed, when policy operates through government spending, there is a sizable fall in government spending. In response, private consumption rises both because the fall in government expenditures frees up output for other purposes, and because households wish to smooth their utility over time.

In general, the labor income tax operates by reducing the surplus associated with a match, and so affects both newly negotiated wages, and the incentives for firms to post vacancies. However, given the rather modest nature of the increase in the labor income tax required to satisfy the fiscal policy rule, 1.6 percentage points, relative to the government spending scenario, there is not much change in either investment or output. There is a more substantial difference in the paths for private consumption.

The consumption tax affects two margins in the model. First, the discount factor, $\Delta_{t,t+1}$, rises as can be seen by inspection of Eq. (5). As a result, the overall surplus associated with a firm-worker match increases. Second, the increase in the discount factor also affects the Euler equation governing capital accumulation, Eq. (3). Here, the temporal pattern of the consumption tax acts like a subsidy to investment. However, as previously discussed, the change in the consumption tax rate is small, 1.3 percentage points, and as a result so are the effects on output and investment. As with the labor income tax rate, the policy switch from government spending to the consumption tax has larger effects on private consumption, and for the same reasons as for the labor income tax. The differences between the labor income tax and consumption tax scenarios are, even for private consumption, rather minor.

The capital income tax directly affects the return to capital, and so through Eq. (3) capital accumulation. The small setting for the policy feedback parameter, $\omega = 0.05$, results in a very protracted return of the debt-output ratio to its pre-Great Recession value, and as a consequence, higher capital income taxes for a considerable period of time. 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 the early 2200s (not shown in Figure 5(i)) that the capital income tax rate falls below 40% (its steady state value is 37.1). Indeed, Figure 5(i) exhibits a rising path for the capital income tax rate after 2015. Naturally, such a prolonged hike in the capital income tax rate discourages investment as seen in Figure 5(c), and so a sustained decrease in capital, Figure 5(d). The lower path for investment frees up output allowing households to boost their private consumption, shown in Figure 5(b).

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. Let g superscripts denote variables associated with the government spending rule, and τ_x denote the associated variables under some tax rate ($x \in \{w, c, k\}$). The welfare benefit is, then, given by the (unique) value of ζ satisfying

$$\sum_{t=0}^{\infty} \beta^t U\big((1-\zeta)c_t^{\tau_x}, g_t^{\tau_x}\big) = \sum_{t=0}^{\infty} \beta^t U(c_t^g, g_t^g).$$

That is, ζ is the constant fraction of consumption that can be taken from individuals under a tax-based rule that leaves them as well off, in a lifetime present value of utility sense, as under the government spending rule.

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

	τ_w	τ_c	τ_k
$U_1 = U_2$	0.025	0.032	−4.777
$U_1 > U_2$	2.705	2.720	−5.187
$U_1 < U_2$	−0.678	−0.676	−4.708

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 either the labor income tax or consumption tax results in a very modest welfare gain (far less than a tenth of a percent of private consumption). In contrast, fiscal austerity applied through the capital income tax leads to a welfare *loss* of 4.8% of private consumption. As seen earlier, under the capital income tax, private consumption initially rises, staying above the path associated with the government spending rule for nearly four years. This initial rise is fueled by the plunge in investment owing to the very large increases in the capital income tax rate. Given the very long transitions, the capital income tax rate stays above its long run value for a very long time, and so does private consumption. It is these “intermediate” run losses in consumption that come to dominate the welfare calculation under the capital income tax.

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 qualitatively 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 – at least for the labor income and consumption taxes. The welfare gain associated with switching to these taxes is quite large: 2.7% of consumption. The welfare loss associated with switching, instead, to the capital income tax is even larger than under the benchmark calibration: over 5%.

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 similar 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. These welfare losses are substantial: 0.7% of consumption under either the labor income tax or consumption tax, and 4.7% for the capital income tax.

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

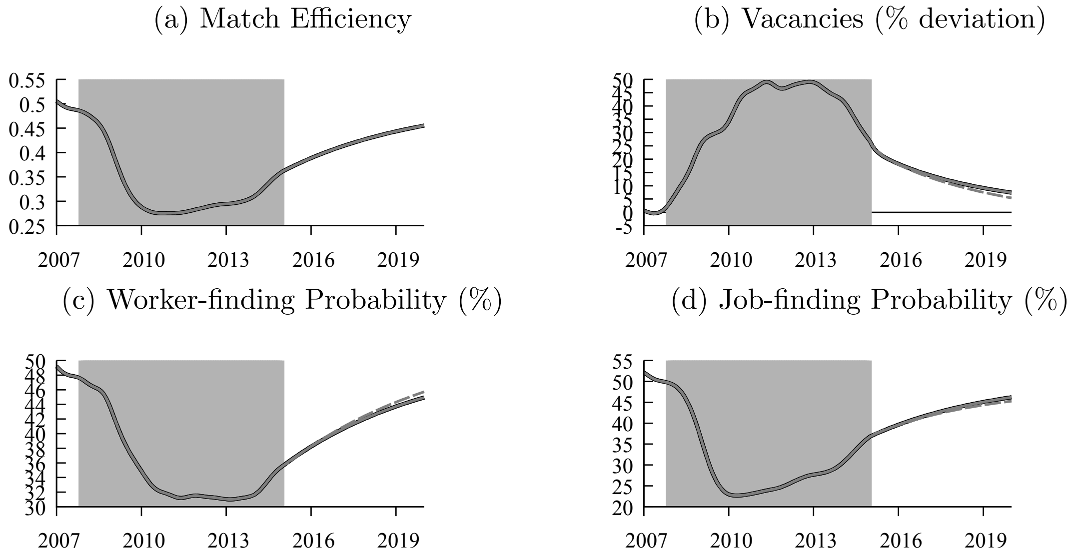
ω	τ_w	τ_c	τ_k
0.05	0.025	0.031	−4.777
0.1	0.007	0.094	−3.595
0.15	0.000	0.153	−2.9220
0.2	0.002	0.207	−2.440

Given the discussion of the welfare loss associated with the capital income tax for the benchmark calibration, one might think that increasing the policy feedback parameter, ω, should lower those costs. In particular, an increase in ω is associated with a stronger fiscal response. In the case of the capital income tax, this translates into a larger initial increase in this tax rate. Since an unexpected increase in the capital income tax operates much like a lump-sum tax, the initial cost of such a policy should be lower. By more rapidly reducing the debt-output ratio, larger values of ω mean more quickly dropping the capital income tax rate to its long run value. Table 3 shows that this intuition is generally true: increasing ω to 0.2 from 0.05 lowers the welfare cost of switching to the capital income tax policy from 2.58 percent of consumption to 1.33 percent.

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, here 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 and subsequent recovery (to the end of 2014)

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 0.493 in 2007 to as little as 0.275, a decline of 45%. 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. The match efficiency accounting of the Great Recession sees a *fall* in the worker-finding probability from 48.2% in 2007 to as little as 31%. In contrast, the vacancy cost explanation sees this probability *rise* from 50.9% to as much as 99.7%. As discussed earlier, the benchmark model's predicted decline in the duration of a vacancy, 50%, is reasonably close to 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 2 months early in 2007 to 3.6 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 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); variation in the job-separation probability played a minor role. 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 in the sense that the capital income tax clearly the least preferred; there is little to choose between the remaining fiscal instruments (government spending, labor income taxes, and consumption taxes).

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:

UNRATE: Civilian Unemployment Rate

UNEMPLOY: Unemployment Level

CE16OV: Civilian Employment

JTSJOL: JOLTS: Job Openings: Total Nonfarm

CNP16OV: Civilian Noninstitutional Population

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

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:

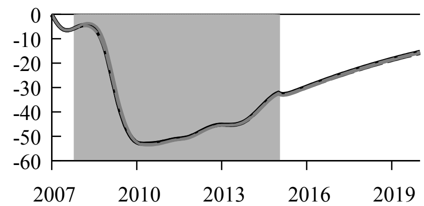
- https://paulgomme.github.io/usdata.r
- https://paulgomme.github.io/hangover.r
- https://paulgomme.github.io/hangover.m

Appendix B Additional Figures

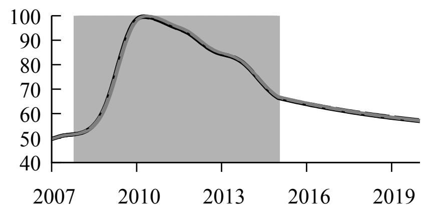
Figure 7: The Labor Market under the Government Spending Rule: Tax, Total Factor Productivity, and Financial Shocks

(a) Vacancy Cost

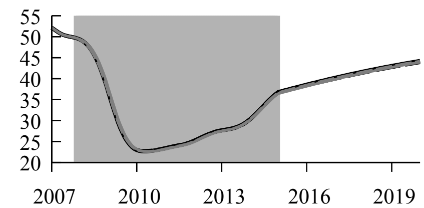
(b) Vacancies (% deviation)



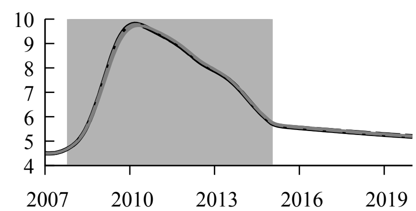
(c) Worker-finding Probability (%)



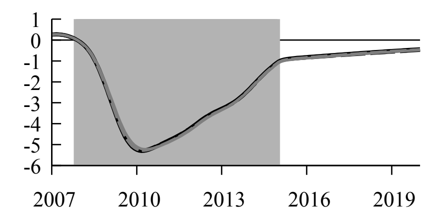
(d) Job-finding Probability (%)



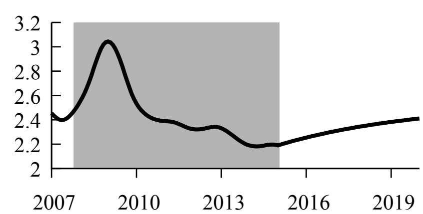
(e) Unemployment Rate (%)



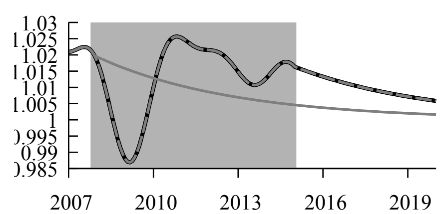
(f) Employment (% deviation)



(g) Separation Probability (%)

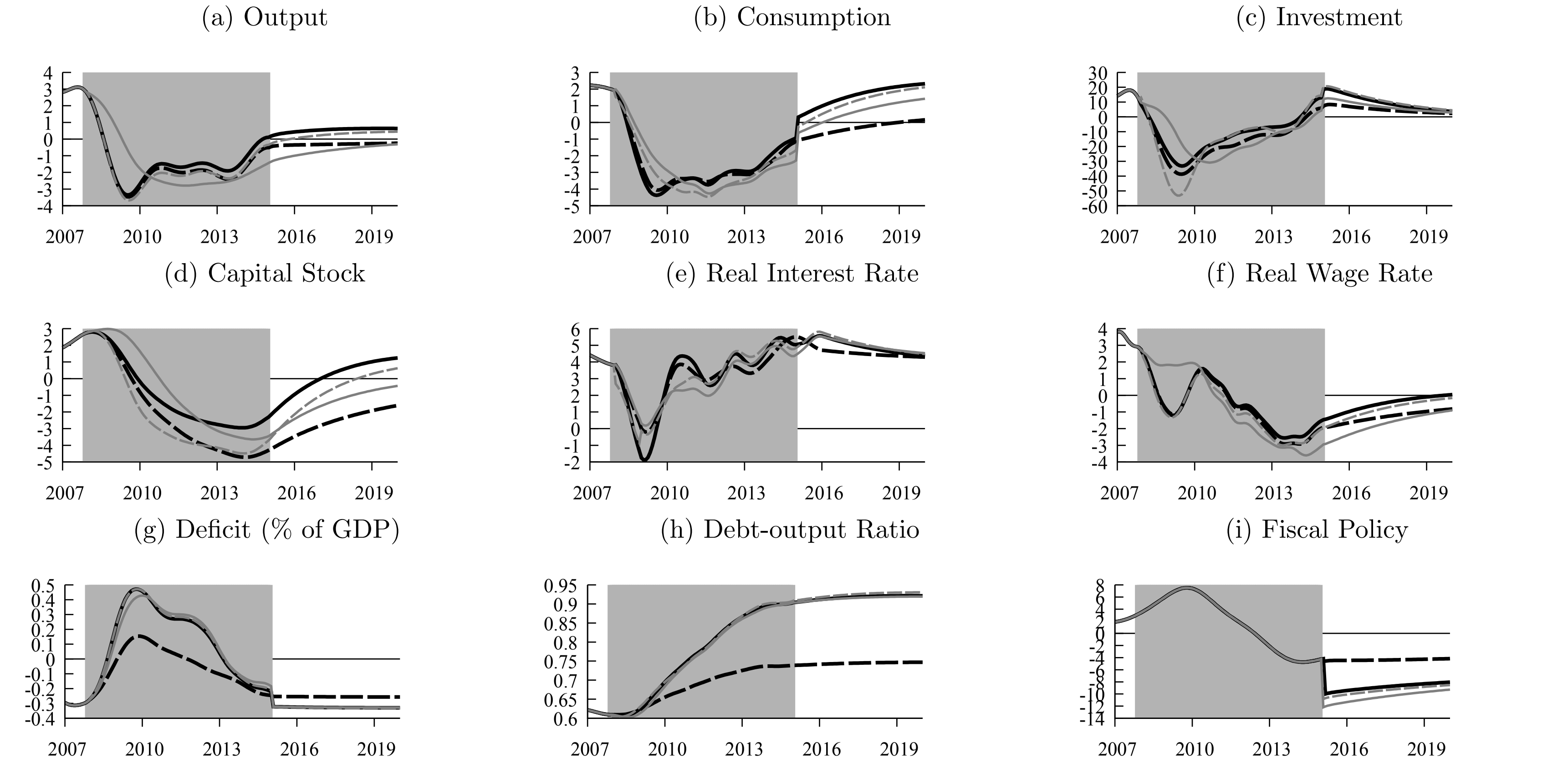


(h) Total Factor Productivity



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

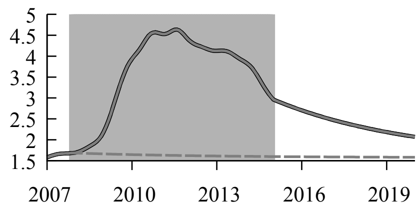
Figure 8: Macroeconomic Variables under the Government Spending Rule: Effects of Tax and Total Factor Productivity Shocks



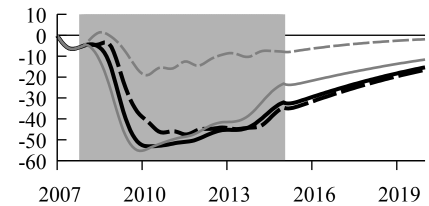
Legend: Lines are coded as in Figure 7. Output, consumption, investment and capital are expressed as percentage deviations from steady state; for fiscal policy, government spending is likewise expressed as a percentage deviation from steady state while the tax rates are percentage point changes from 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 9: The Labor Market under the Government Spending Rule: Effects of Labor Market and Unemployment Insurance Shocks

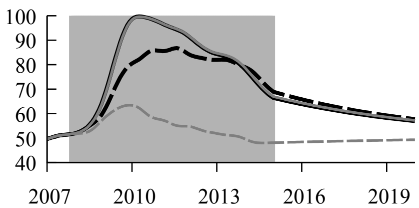
(a) Vacancy Cost



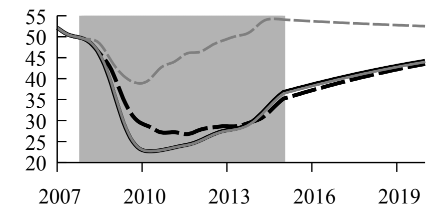
(b) Vacancies (% deviation)



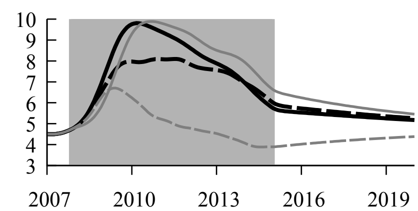
(c) Worker-finding Probability (%)



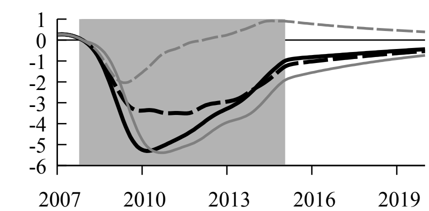
(d) Job-finding Probability (%)



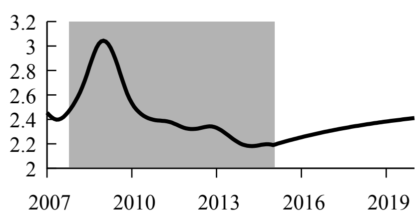
(e) Unemployment Rate (%)



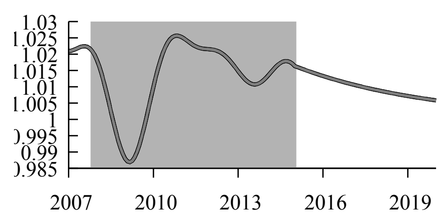
(f) Employment (% deviation)



(g) Separation Probability (%)

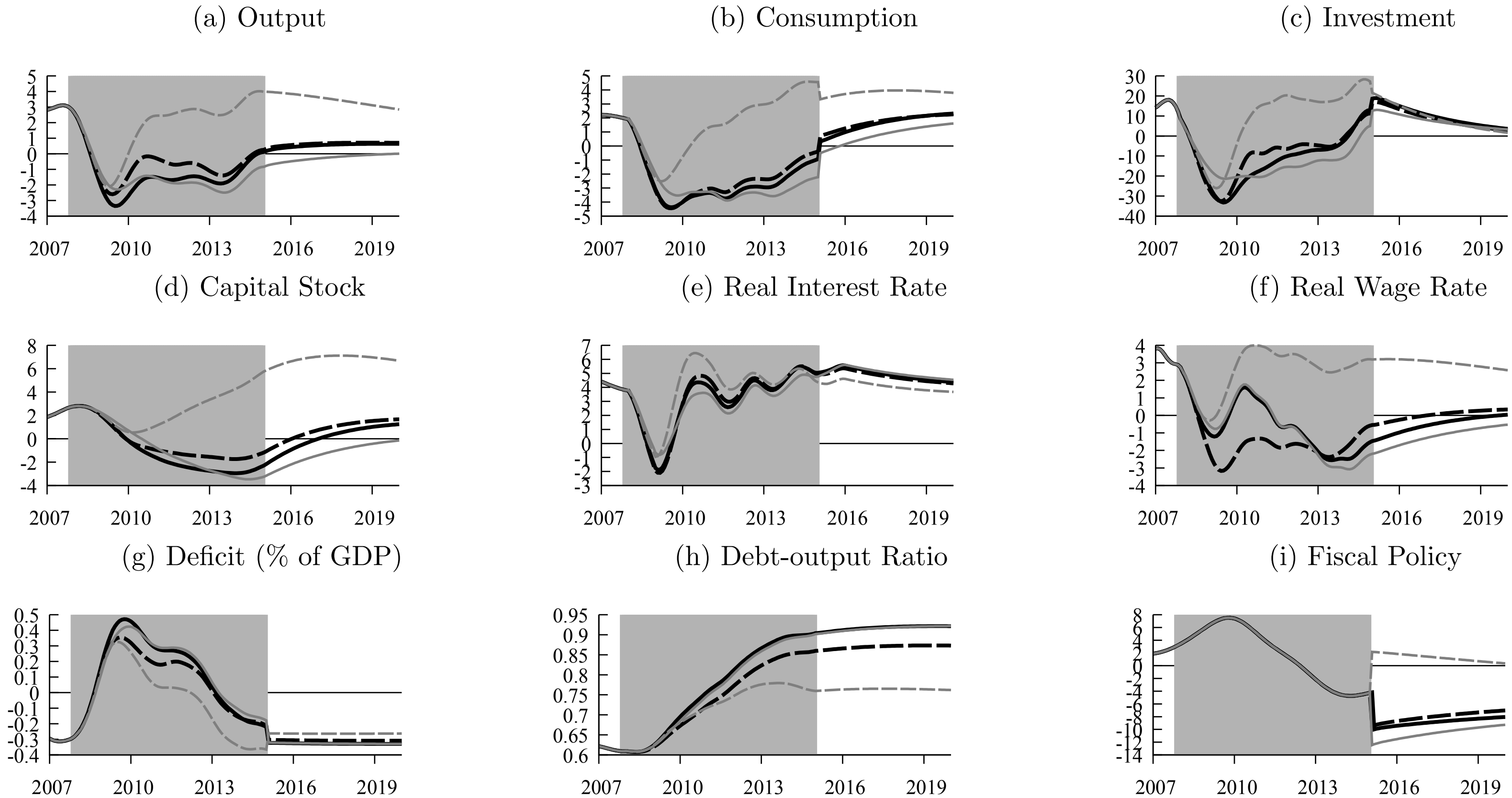


(h) Total Factor Productivity



Legend: Solid black lines: baseline (all shocks); dashed black lines: no unemployment insurance shock; solid gray lines: no separation probability shock; dashed 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 10: Macroeconomic Variables under the Government Spending Rule: Effects of Labor Market and Unemployment Insurance Shocks



Legend: Lines are coded as in Figure 9. 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.

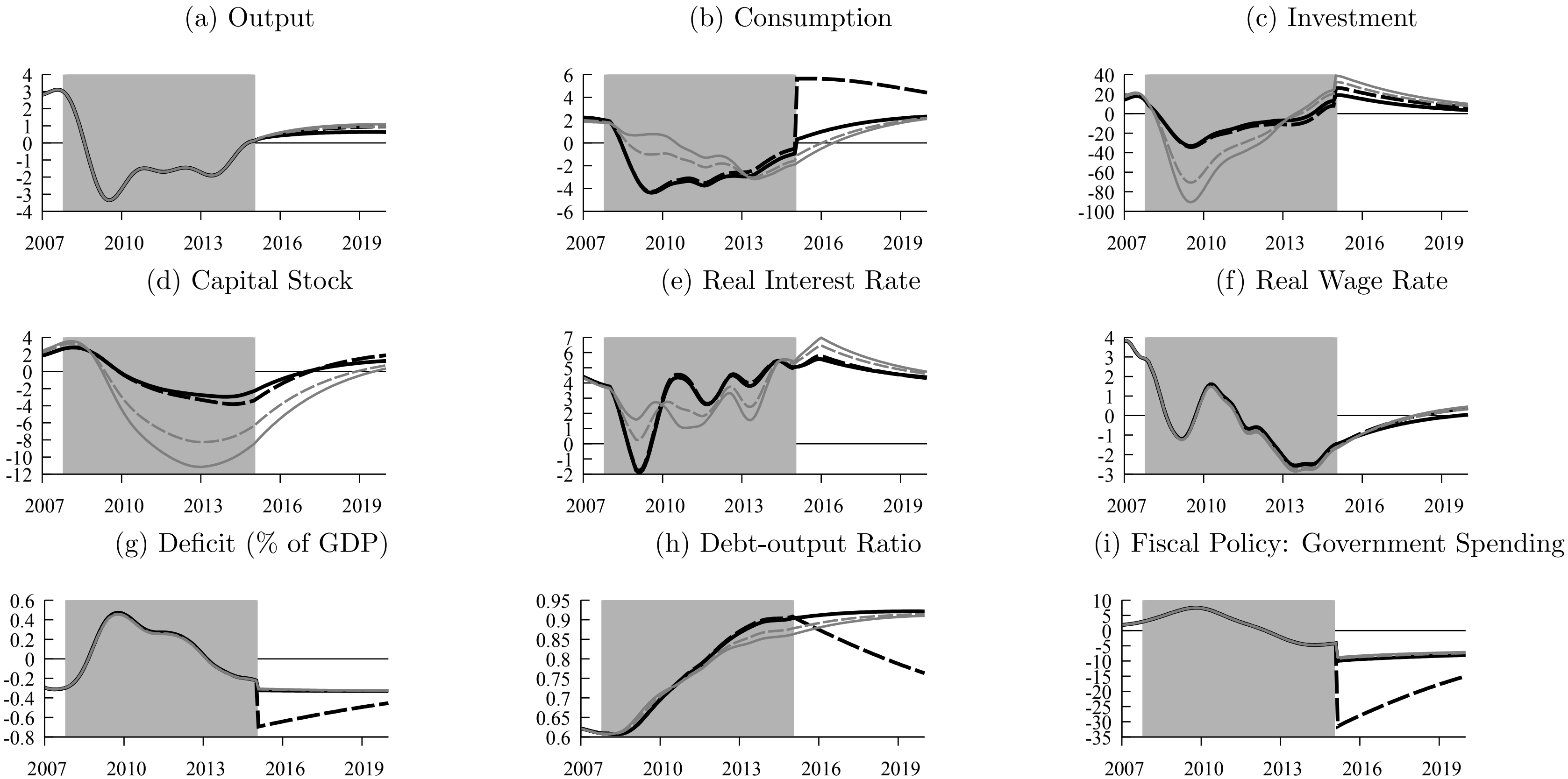
Appendix C Implications of Alternative Parameter Values

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 11 and 12.

To start, consider the effects of setting the policy feedback parameter to a higher value, $\omega = 0.2$; in the benchmark calibration, its value is 0.05. This setting for the policy feedback parameter puts far 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 3.5% fall. The responses of other variables under the tax rate policies are similarly stronger for $\omega = 0.2$. 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.

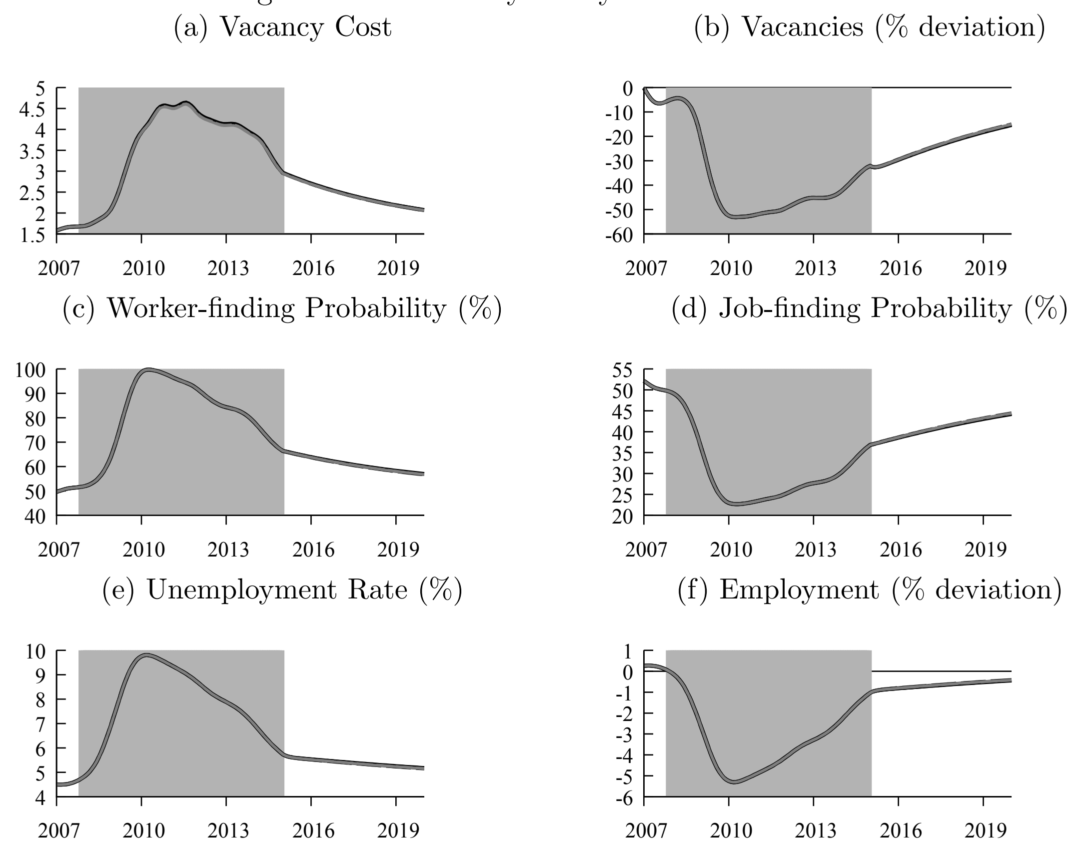
The other two cases are sufficiently similar to discuss them together. For one, the elastic-

Figure 11: Sensitivity Analysis: Government Spending Rule



Legend: Solid black line, benchmark calibration; dashed black line, $\omega = 0.2$; solid gray line, $\xi = 0.5$; and dashed gray line, $U_1/U_2 = 3$.

Figure 12: Sensitivity Analysis: The Labor Market



Legend: See Figure 11.

ity 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.

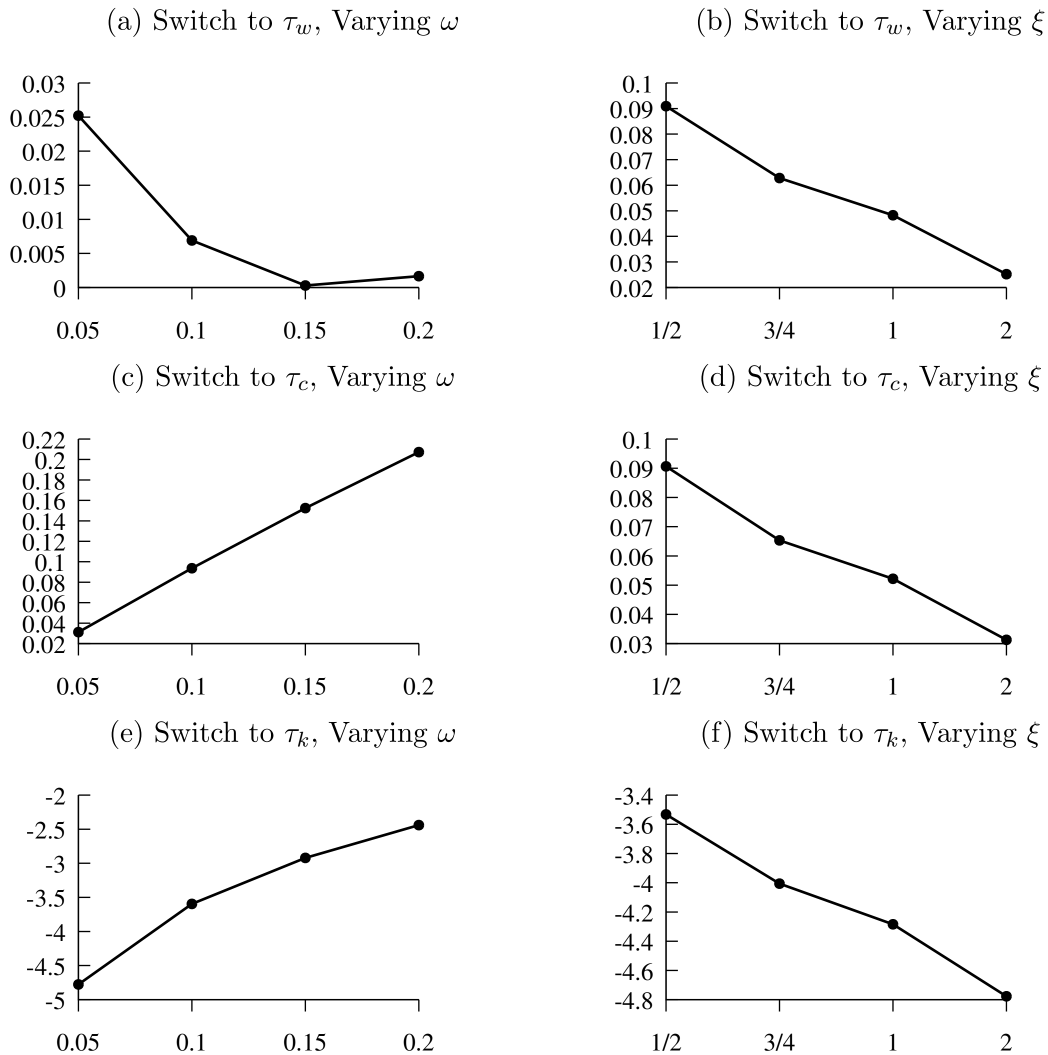
The same mechanics are in operation when the steady state marginal rate of substitution between private and public consumption is 3, but for different economic reasons. Whereas feasibility dictates that the trade-off between private and public consumption goods is 1, households would be willing to give 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. During the Great Recession, the lower capital stock pushes up the real return to capital. During the recovery, the capital stock is still below the benchmark path, but now total factor productivity is higher; the net result is a lower return to capital. Through a no arbitrage condition, the real return on government debt equals that on capital. The lower real interest rate during the recovery results in a somewhat lower government debt-output ratio at the end of the recovery, and so slightly less fiscal austerity starting in 2015 (government spending does not fall as much). For this low substitution case, the path for private consumption is fairly smooth, compared to the jump up for the benchmark calibration.

As discussed in the main text, the labor market is largely independent of the rest of the economy. This independence continues when comparing across the parameters varied in this appendix; see Figure 12.

The welfare implications of alternative values of the parameters ω (the left set of panels) and ξ (the right set) are summarized in Figure 13. At least for the range of parameters considered in these figures, the welfare benefit of switching from government spending to either the labor income tax or the consumption tax are uniformly rather small. In contrast, the cost of switching to the capital income tax *is* sensitive to these parameters – especially the policy feedback parameter, ω. Recall that this parameter governs the response of fiscal policy to deviations of the debt-output ratio to deviations of the debt-output ratio from its target. As a result, larger values of ω imply a faster return of the debt-output ratio to target. Figure 13(e) shows that the welfare cost falls (moves closer to zero) as ω rises, from 0.73% of private consumption for the benchmark setting ($\omega = 0.05$) to -0.22% ($\omega = 0.2$). Figure 13(f) shows that a lower elasticity of substitution between private and public goods also lowers the welfare cost of switching from government spending to the capital income tax rate, although quantitatively the effects are more modest.

Figure 13: Welfare Cost of Switching from Government Spending: 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 right-hand panels, the value of ξ (the elasticity of substitution between private and public consumption goods).