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When are the Effects of Fiscal Policy Uncertainty Large?

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Abstract

Using a new-Keynesian model with endogenous capital accumulation, I show that uncertainty about fiscal policy can cause large declines in consumption, investment, and output when the zero lower bound (ZLB) binds, but has modest effects when the monetary authority is not constrained by the ZLB. I study uncertainty about the level of government spending and uncertainty about tax rates on consumption, wages, capital income, and investment. In my model, uncertainty about government spending and the wage tax rate has particularly large effects. I show that the effects of fiscal policy uncertainty are largest when the nominal interest rate is on the cusp of the ZLB and also that delaying fiscal policy uncertainty diminishes its effects only if the resolution of uncertainty occurs after ZLB no longer binds.

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1 Introduction

Starting early in the Great Recession, pundits and policy makers argued that fiscal policy uncertainty hampered the recovery.[1] The expiration of the Bush-era tax cuts, the debt ceiling debates, and the government shutdown of 2013 have all been cited as events that damaged the economy because of the policy uncertainty surrounding them. In this paper I ask when fiscal policy uncertainty should be expected to have large and adverse effects on the economy. I argue that fiscal policy uncertainty can be particularly damaging when the monetary authority is constrained by the zero lower bound (ZLB) on nominal interest rates, a position central banks in many parts of the world found themselves in during the Great Recession.

I carry out the analysis in a new-Keynesian model with endogenous capital accumulation and a monetary authority that follows a Taylor-type rule when it is not constrained by the ZLB. In order to study the effects of uncertainty, it is important that the model includes capital so that the precautionary saving motive of households can potentially be satisfied by an increase in investment. In my model, the fiscal authority purchases government consumption and sets an array of tax rates, including a tax on consumption, wages, capital income, and investment. Evaluating a fully nonlinear model in which the ZLB can bind distinguishes my work from previous studies on the effects of fiscal policy uncertainty and offers an explanation as to why fiscal policy uncertainty may have been more harmful during the Great Recession than during other periods of fiscal turbulence.

Motivated by the disruptions in financial markets at the beginning of the Great Recession, I use a fall in the marginal efficiency of investment as the catalyst that causes the ZLB to bind. As detailed in Justiniano, Primiceri, and Tambalotti (2011), a decline in the marginal efficiency of investment can be interpreted as a proxy for a more fundamental shock that causes

[1] See, for example, the International Monetary Fund's World Economic Outlook for October 2012 at `http://www.imf.org/external/pubs/ft/weo/2012/02/pdf/text.pdf`. Also see Chairman Bernanke's press conference on September 13, 2012. `http://www.federalreserve.gov/mediacenter/files/FOMCpresconf20120913.pdf`

financial intermediation to be less efficient. In response to the fall in the marginal efficiency of investment, households avoid capital investment and instead prefer saving through bonds. The decreased demand for investment causes the economy to contract and inflation to fall, which prompts the monetary authority to lower the nominal interest rate until the ZLB binds.

I model fiscal policy uncertainty as a distribution over a temporary change in fiscal instruments (government consumption and tax rates). An increase in uncertainty about fiscal policy is a mean-preserving spread in the distribution of the fiscal instruments. In this context, I ask: What are the effects of an increase in uncertainty about fiscal policy?

When the ZLB binds, I show that an increase in fiscal policy uncertainty causes large and adverse effects on the economy. The driving force behind this result is that the response of the economy to a change in fiscal policy is not symmetric if the monetary authority is constrained by the ZLB. Consider uncertainty about government spending. In my model, as in Christiano, Eichenbaum, and Rebelo (2011), a rise in government spending has large expansionary effects while the ZLB binds. However, if the expansion is large enough so that the ZLB no longer binds (or is binding for a shorter period of time), the effects of any further policy changes are relatively small. In contrast, a decrease in government spending causes a large contraction in the economy. Unlike the increase in government spending, there is no decline in the marginal effect of a decrease in government spending because the ZLB continues to bind. When faced with a large enough spread in the distribution over fiscal policy instruments, risk-averse households want to insure against the possibility that the economy will contract by a relatively large amount. The desire to work and save rises, which causes inflation to fall. When the ZLB binds, the associated rise in the real interest rate discourages investment and consumption, and the economy contracts.

I show that the effects of fiscal policy uncertainty are most pronounced when the nominal interest rate is on the cusp of the ZLB. The reason is that any change in fiscal policy that increases the rate of inflation can be offset by the monetary authority raising the nominal interest rate. However, any change in fiscal policy that causes inflation to fall will not be met with a decline in the nominal interest rate because of the ZLB. That is, households face large downside risks and only modest upside potential at the cusp of the ZLB. This result gives one way to rationalize claims that policy uncertainty is particularly harmful in a fragile recovery.

Naturally, the exact value of the effects of uncertainty about fiscal policy depends on the details and parameters of the model. However, in my analysis I show that parameters that imply larger fiscal multipliers also magnify the effects of uncertainty about fiscal policy when the ZLB binds. The reason is that larger multipliers imply that the monetary authority will raise the nominal interest rate in response to smaller expansionary changes in fiscal policy, which magnifies the asymmetries introduced by the ZLB. Furthermore, I show that, if the ZLB binds, delaying fiscal policy uncertainty reduces its harmful effects on the economy only if it can be delayed until the monetary authority is no longer constrainted.

My paper adds to the rapidly growing literature on the effects of fiscal policy uncertainty by explicitly modeling the ZLB. My results give one way to interpret the empirical evidence from Baker, Bloom, and Davis (2012) that suggests that fiscal policy uncertainty has been an important force behind the fall in consumption, investment, and output that we have seen during the Great Recession. In addition, my model is consistent with the relatively small effects from stochastic volatility in the fiscal policy process reported by Born and Pfeifer (2011), because they do not consider the impact of the ZLB. Contemporaneous work by Fernández-Villaverde, Guerrón-Quintana, Kuester, and Rubio-Ramírez (2012b) extends the stochastic volatility literature to address the ZLB, and reports larger effects when the ZLB binds than when it does not. My paper considers a fully nonlinear model, documents when the effects of uncertainty are largest, considers the timing of uncertainty, and is able to isolate the effects of different fiscal instruments.

A complementary literature examines the effects of expected fiscal consolidation. Work by Denes, Eggertsson, and Gilbukh (2012) shows that the form of a fiscal consolidation can determine the effectiveness of changes in fiscal policy when the ZLB binds. Bi, Leeper, and Leith (2012), show that uncertainty about the timing and form of a fiscal consolidation can have important effects on the economy. My work abstracts away from the mean change in policy that is associated with a fiscal consolidation to isolate the effects of uncertainty.

My analysis is also related to the large literature on fiscal policy when the ZLB binds that builds on the work of Eggertsson and Woodford (2003). Several papers, including Eggertsson (2009), Erceg and Lindé (2010), Mertens and Ravn (2010), Woodford (2011), Correia, Farhi, Nicolini, and Teles (2011), Werning (2011), and Christiano et al. (2011), consider the effects of changes in government spending and changes in tax rates when the ZLB binds. My paper adds to this literature by considering the effects of increases in uncertainty about fiscal policy rather than changes in fiscal policy. This also distinguishes my work from Mendes (2011) and Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramíerez (2012a) who have emphasized the nonlinearities associated with the ZLB in a stochastic environment, and Gust, Smith, and López-Salido (2012) who have focused on estimating which first-moment shocks were important during the Great Recession.

My results are broadly consistent with Nakov (2008) and Nakata (2011), who show that household and firm decision rules are influenced by the calibrated variance of shocks to a greater degree when the ZLB binds than when it does not. I focus on fiscal policy uncertainty, study the effects of a temporary increase in uncertainty at different horizons, and include capital in my model so that investment is possible for households that have a precautionary saving motive. My results are also consistent with contemporaneous work by Basu and Bundick (2012), who find that an increase in uncertainty about the household's rate of time discounting has larger effects when the ZLB binds than when it does not. My work instead focuses on fiscal policy uncertainty and uses a shock to the marginal efficiency of investment to cause the ZLB to bind. Studying fiscal policy uncertainty directly is critical because other forms of uncertainty, such as those studied in Basu and Bundick (2012), have different implications for inflation than an increase in uncertainty about fiscal policy in my model, and changes in the rate of inflation have large effects on the economy when the ZLB binds. Additionally, using a shock to the marginal efficiency of investment to make the ZLB bind instead of a shock to the household's rate of time discounting allows me to study uncertainty at the ZLB without altering the household's stochastic discount factor and risk preference.

I structure the rest of the paper as follows. I present the model in section 2. In section 3, I discuss the benchmark parameters and my solution method. I present my benchmark results about fiscal policy uncertainty in section 4. I consider alternative specifications of fiscal policy uncertainty in section 5. Section 6 contains robustness analysis and section 7 concludes.

2 Model Economy

In this section I describe the model that I use to analyze the effects of fiscal policy uncertainty. The model consists of a representative household, competitive final good producers, monopolistically competitive intermediate goods producers, a monetary authority, and a fiscal authority.

2.1 Representative Household

A representative household maximizes lifetime utility, which is given by

$$E_t \sum_{\ell=0}^{\infty} \beta^{\ell} \left\{ \frac{C_{t+\ell}^{1-\sigma}}{1-\sigma} - \frac{\chi}{\gamma+1} H_{t+\ell}^{\gamma+1} + v(G_{t+\ell}) \right\}$$

Where C_t, H_t, and G_t denote time t household consumption, hours worked, and government consumption, and β represents the rate at which the household discounts utility over time. I assume $\gamma \geq 0$, and that $v(\cdot)$ is increasing and concave.

The flow budget constraint of the household is given by

$$P_tC_t(1+\tau_{C,t}) + B_t + P_tI_t(1+\tau_{I,t}) + P_tAC_K(K_{t+1},K_t) \leq P_tW_tH_t(1-\tau_{H,t})$$
$$+ R_{t-1}B_{t-1} + P_tr_t^K K_t(1-\tau_{K,t}) + P_tT_t$$

where P_t is the price level, B_t are nominal bonds, W_t is the real wage, and R_t is the gross nominal interest rate, r_t^K is the rental rate of capital, and I_t is capital investment. The values $\tau_{C,t}$, $\tau_{H,t}$, $\tau_{I,t}$, $\tau_{K,t}$, and T_t represent the consumption tax rate, the wage tax rate, the investment tax rate, the capital income tax rate, and real lump sum taxes net transfers, respectively. Finally, I include adjustment costs to capital, $AC_K(K_{t+1},K_t)$. I assume that capital is accumulated so that

$$K_{t+1} = (1-\delta)K_t + I_t\mu_t$$

where $\delta \in (0,1)$ and μ_t is a stochastic process that affects the marginal efficiency of investment. The steady state value of μ_t is 1, and the stochastic properties of μ_t are defined in my experiments below. Capital adjustment costs are modeled symmetrically to price adjustment costs and are given by

$$AC_K(K_{t+1},K_t) \equiv \frac{\phi_K}{2}\left(\frac{K_{t+1}}{K_t}-1\right)^2 K_t$$

where $\phi_K \geq 0$.

2.2 Final Good Producers

Final output, denoted by Y_t, is produced by competitive firms that aggregate intermediate goods, denoted by $Y_{j,t}$. The final goods firms have technology defined by

$$Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\epsilon-1}{\epsilon}} \, dj \right)^{\frac{\epsilon}{\epsilon-1}}$$

where $\epsilon > 1$. The assumptions of perfect competition in final good production and profit maximization yield a demand curve for intermediate goods given by

$$Y_{j,t} = Y_t \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon}$$

for every j, where $P_{j,t}$ is the price of intermediate good j, and P_t is the price of the final good.

2.3 Intermediate Goods Producers

Intermediate good j, denoted by $Y_{j,t}$ is produced by a monopolist using technology given by

$$Y_{j,t} = K_{j,t}^{\theta} H_{j,t}^{1-\theta}$$

where $\theta \in (0,1)$, $H_{j,t}$ denotes the amount of labor, denominated in hours, hired by firm j, and $K_{j,t}$ is capital rented by firm j.

Intermediate goods firms take aggregate quantities and prices as given and maximize the expected discount value of profits by choosing a sequence of prices, $P_{j,t}$, and quantities $H_{j,t}$ and $K_{j,t}$. The expression for profits is given by

$$E_t \sum_{\ell=0}^{\infty} \beta^{\ell} \lambda_{t+\ell} \left\{ (1+s) P_{j,t+\ell} Y_{j,t+\ell} - P_{t+\ell} W_{t+\ell} H_{j,t+\ell} - P_{t+\ell} r_{t+\ell}^{K} K_{j,t+\ell} - P_{t+\ell} AC_{\pi}(P_{j,t+\ell}, P_{j,t+\ell-1}) Y_t \right\}$$

Here, λ_t is the value of the Lagrange multiplier on the household budget constraint, s is a subsidy paid to overcome monopoly distortions in steady state, and $AC_\pi(P_{j,t+\ell}, P_{j,t+\ell-1})$ are price adjustment costs in the vein of Rotemberg (1982), given by

$$AC_\pi(P_{j,t}, P_{j,t-1}) \equiv \frac{\phi_\pi}{2}\left(\frac{P_{j,t}}{P_{j,t-1}\pi^*} - 1\right)^2$$

where $\phi_\pi \geq 0$ and π^* is the monetary authority's target for consumer price price inflation.

2.4 Monetary Authority

The monetary authority sets the nominal interest rate according to a truncated version of the policy rule studied by Taylor (1993) given by

$$R_t - 1 = \max\left\{0, \frac{\pi^*}{\beta}\left(\frac{\pi_t}{\pi^*}\right)^{\alpha_\pi}\left(\frac{GDP_t}{GDP_t^*}\right)^{\alpha_{GDP}} - 1\right\}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is gross inflation, $\pi^* > 0$ is target gross inflation, $GDP_t \equiv C_t + I_t + G_t$ is gross domestic product, and GDP_t^* is the level of gross domestic product in an equivalent economy with flexible prices. I assume that $\alpha_\pi > 1$ in order to satisfy the Taylor principle that the nominal interest rate respond more than one-for-one to deviations of inflation from its target value. In the interest rate rule, I include the deviation of gross domestic product from its natural level so that inflation alone does not have to cause the ZLB to bind. The results are robust to setting $\alpha_{GDP} = 0$.

2.5 Fiscal Authority

The government consumes G_t, sets lump-sum taxes (transfers) T_t, and sets tax rates

$$\tau_t = \{\tau_{C,t}, \tau_{H,t}, \tau_{I,t}, \tau_{K,t}\}.$$

I assume that the government budget constraint is cleared by lump-sum taxes and I specify the stochastic process for the other fiscal instruments in the experiments that follow.

2.6 Equilibrium

The symmetry among firms implies that I can drop the subscript j from equilibrium conditions and specify the equilibrium in terms of aggregate quantities. The economy's resource constraint is given by

$$Y_t = C_t + G_t + I_t + AC_{\pi,t} + AC_{K,t}.$$

An equilibrium is a collection of stochastic processes

$$\{C_t, D_t, H_t, I_t, K_t, L_t, Q_t, R_t, W_t, Y_t, \pi_t\}$$

such that given the processes for G_t, T_t, τ_t, and μ_t, the household and firm problems are solved, the resource constraint is satisfied, markets clear, and the nominal interest rate is set according to the monetary policy rule.

3 Parameterization and Solution Method

The model is of quarterly frequency and I set $\beta = 0.995$ so that the steady state annual real short-term interest rate is 2 percent. Following Christiano, Eichenbaum, and Evans (2005), I set $\sigma = 1$ and $\gamma = 1$, which implies log utility over consumption and a Frisch labor supply elasticity of one. I normalize χ so that in steady state the household supplies one unit of labor. As in Altig, Christiano, Eichenbaum, and Lindé (2011), I set $\epsilon = 11$, which implies a 10 percent steady state markup. The value of θ is set to 1/3 and δ is set to 0.02.

The price adjustment cost parameter is set to $\phi_\pi = 116$. I chose this value in the following way. The linearized version of my model has a one-to-one mapping with a model that includes Calvo-style sticky prices where only a fraction of firms are allowed to adjust their prices in any given period.[2] I set the parameter ϕ_π to imply that a firm adjusts its price on average once per year in the equivalent linear model with Calvo price stickiness. The capital adjustment cost parameter is set to $\phi_K = 17$ so as to be consistent with Christiano et al. (2011).

I assume that the monetary authority targets a 2 percent steady state rate of annual inflation, so I set $\pi^* = 1.005$, and I set $\alpha_\pi = 1.5$ so as to satisfy the Taylor principle. In my baseline parameterization, I set $\alpha_{GDP} = 0.25$. I calibrate the baseline level of government spending so that it is 20 percent of steady state output, which corresponds to levels observed in the United States in the later part of the twentieth century. Baseline tax rates are chosen so that

$$\tau_C = 0.05,\ \tau_K = \tau_H = 0.30,\ \tau_I = 0.00$$

I arrive at these values in the following way. To compute the consumption tax rate, I use NIPA data provided by the Bureau of Economic Analysis.[3] I divide sales taxes collected by consumption expenditures to calculate the tax rate. I set the capital income and wage tax rates equal to each other, which I interpret as an income tax. The value 0.3 is roughly consistent with recent values of the income tax from the Barro-Redlick TAXSIM data.[4] As a benchmark, I set investment taxes to zero. Positive investment taxes can be interpreted as taxes directly or as increases in regulatory requirements, and negative investment taxes can be interpreted as tax credits to firms for investment projects.

The ZLB complicates the model solution. I cannot use perturbation methods, which are standard in the new-Keynesian business cycle literature, because they are unable to deal with inequality constraints. Furthermore, my model includes an endogenous state variable, capital, meaning it cannot be solved exactly, as in Braun, Korber, and Waki (2012). The solution

[2] See Keen and Wang (2005) for further discussion.

[3] `http://www.bea.gov/`

[4] `http://users.nber.org/~taxsim/barro-redlick/`

method I use follows Coleman (1991). Given policy functions for consumption, investment, and inflation, the equilibrium conditions determine all of the other variables in the model. Three Euler equations are not used when determining the other variables, and those equations define a nonlinear system, Ψ, that must equal zero in expectation. A set of functions for consumption, investment, and inflation that satisfy

$$E_t \Psi(C, I, \pi) = 0,$$

constitute an equilibrium. In my model, μ_t and the fiscal policy instruments are random, and expectations are taken with respect to their distribution. I solve for unknown policy functions by conjecturing a set of decision rules that will be operative in the next period and then solve for the current values of consumption, investment, and inflation that satisfy the system of equations. If these new policy functions are the same as the conjectured policy functions, I have an equilibrium. If not, I continue iterating on the system of equations by updating the next period's policy functions with the current period policy functions. When the policy functions have converged, I have found an equilibrium. I present the details of my solution method in Appendix C.

4 The Effects of Fiscal Policy Uncertainty

In this section, I use the model to study the effects of increasing uncertainty about fiscal policy.

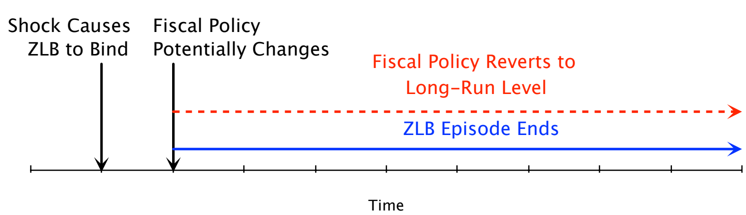
4.1 The Nature of the Experiment

Time begins at $t = 0$, at which point the economy is in its non-stochastic steady state and $\mu_0 = 1$. At $t = 1$, an unexpected shock causes $\mu_1 \leq 1$. Afterward, with probability ρ_μ, μ_t will remain at the value μ_1 and with complementary probability μ_t will return to its long-run value, 1, forever.

The shock to μ_t is similar to the shock considered in Justiniano, Primiceri, and Tambalotti (2010) and Justiniano et al. (2011). Both Christiano and Davis (2006) and Justiniano et al. (2011) map this shock into unmodelled credit market friction. The form of the stochastic process for μ_t is similar to the shock to preferences studied in Eggertsson and Woodford (2003), who instead study a temporary increase in β. I consider the shock to μ_t for four reasons. First, the shock to μ_t does not affect the household stochastic discount factor, which allows me to study uncertainty without altering the household's risk preference. Second, the relationship between a fall in μ_t and a rise in credit market frictions makes this an attractive shock for thinking about the Great Recession. Third, in a model with capital the shock to β has the undesirable implication that investment and output rise for small shocks and fall for large shocks. The shock to μ_t unambiguously decreases investment and output. Fourth, even if μ_t were to remain low forever, my model would have a well defined steady state. In contrast, if β were permanently above 1, the steady state of the model would not exist.

In period 1, I assume that the household and firms know that the government might change the value of its fiscal policy instruments in period 2, independent of the value of μ_t. If a change in policy takes place, the change persists with probability ρ_G and returns to its initial level with complementary probability. Figure 1 shows the time line of events.

Figure 1: Timeline



The model is greatly simplified by the assumption that the change in μ_t is unexpected and transitory and that the fiscal policy uncertainty is unexpected and transitory. These assumptions allow me to clearly specify the timing of events and isolate the effects of fiscal policy uncertainty. Notably, the results are robust to making the environment richer so that μ_t and the fiscal policy instruments have stationary stochastic processes. In Appendix D, I explain how the setup can be modified to make the stochastic processes stationary.

I abstract away from the effects of a mean change in fiscal policy in period 2 in order to isolate the effects of uncertainty. Thus, I consider distribution over the fiscal instruments in period 2 that is a mean preserving spread around the period 1 levels. To simplify the analysis I allow only one fiscal instrument to be uncertain in each experiment. To make clear the effects of the spread in the distribution, I allow the support of the distribution to have three points that are equally spaced. That is, for a given uncertain tax rate, τ_i, I assume that

$$\tau_{i,2} = \begin{cases} \tau_{i,1} + \Delta & \text{with probability } \frac{1}{3} \\ \tau_{i,1} & \text{with probability } \frac{1}{3} \\ \tau_{i,1} - \Delta & \text{with probability } \frac{1}{3} \end{cases}$$

Similarly, when government spending is allowed to be stochastic, its distribution is given by

$$G_2 = \begin{cases} G_1 + \Delta & \text{with probability } \frac{1}{3} \\ G_1 & \text{with probability } \frac{1}{3} \\ G_1 - \Delta & \text{with probability } \frac{1}{3} \end{cases}$$

To make the experiment stark, I choose a symmetric distribution for the fiscal instruments, but I relax this assumption in section 5.3. I study the effects on the economy as Δ increases.

I focus on uncertainty about transitory change in fiscal policy by abstracting away from the way that tax rates or spending might change in the future as a result. If I were to specify a fiscal rule that determines what happens to spending and tax rates as debt and deficits change, the effects of uncertainty about a change in fiscal policy would be influenced by that rule. Though a change in fiscal policy will alter government revenue or expenditure, I assume that lump-sum taxes clear the government budget constraint in order to best isolate the effects of uncertainty.

It is worth reviewing the effect of the shock to μ_t without any fiscal policy uncertainty. When μ_1 declines, households would prefer to save in bonds, rather than saving through capital investment, which decreases demand for investment goods. As investment falls, so do output and inflation, and the monetary authority lowers the nominal interest rate according to the Taylor-type rule specified above. Once the ZLB binds, a further decline in inflation leads to an increase in the real interest rate, meaning capital investment falls even further, and the household's desire to save in bonds rises even more. In equilibrium, relatively large declines in output and consumption are required in order to make desired saving equal to investment. When μ_t returns to its long-run value of 1, households want to invest in capital, which increases demand, causing inflation to rise, and prompting the monetary authority to set the nominal interest rate above zero.

I set the probability that μ_t returns to its long-run value to $1 - \rho_\mu = 0.25$ in order to reflect the idea that the shock to μ_t is somewhat long-lasting. In this case, it has an expected duration of 4 quarters. I also set the probability that the fiscal policy instrument returns to its long-run value to $1 - \rho_G = 0.25$ and explore the implications of other values in section 5.2.

I consider two values of μ_1 that are less than 1, which I denote $\underline{\mu}$ and $\underline{\underline{\mu}}$. I set the value of $\underline{\mu}$ so that the nominal interest rate is on the cusp of the ZLB at time 1. That is, without any fiscal policy uncertainty the monetary authority would like to set the interest rate very near zero, even if it were not constrained by the ZLB.[5] I set $\underline{\underline{\mu}}$ so that the ZLB strictly binds and the monetary authority would like to set the nominal interest rate about five percentage points below zero at time 1. I also study the case in which $\mu_1 = 1$, but fiscal policy might change as in the other experiments. This scenario is used for comparison as the case when the monetary authority is free to change the nominal interest rate. Note that $1 > \underline{\mu} > \underline{\underline{\mu}}$.

[5] I set $\underline{\mu} = 0.905$ and $\underline{\underline{\mu}} = 0.895$. Notably, these values lie within three standard deviations of the process for μ_t estimated by Justiniano et al. (2011).

4.2 Uncertain Government Spending

Consider uncertainty about government spending. Figure 2 shows the percentage difference in consumption, investment, prices, and hours for different values of Δ as compared with the case that $\Delta = 0$. I consider values of Δ between 0 and 2 percent of steady state GDP. The solid line displays the case when $\mu_1 = 1$ and the monetary authority is unconstrained by the ZLB because it would like to set $R_t > 1$ for every realization of G_2. As in Fernández-Villaverde et al. (2012b) and Born and Pfeifer (2011), the solid line indicates that when the monetary authority is unconstrained macroeconomic aggregates move by relatively small amounts. The results are strikingly different when $\mu_1 = \underline{\underline{\mu}}$ and the ZLB binds. As shown by the dashed-dotted lines in Figure 2, as Δ increases, the economy contracts by a relatively large amount. For example, when Δ is equal to 2 percent of GDP, consumption is nearly half of a percent lower than in the case when $\Delta = 0$.

The driving force behind these large and adverse effects when the ZLB binds is that the response of the economy to a change in government spending is not symmetric. In my model, as in Woodford (2011) and Christiano et al. (2011), when the ZLB binds an increase in government spending is initially very expansionary. The reason is that it encourages households to spend today rather than save for the next period, which makes prices rise and causes the real interest rate fall because the nominal interest rate is stuck at zero. As the real interest rate falls, investment, consumption, and output rise. After the ZLB no longer binds, the effects of a further increase in government spending are relatively small because the monetary authority offsets the fall in the real interest rate by raising R_t as inflation rises. This decline in the marginal effect of additional government spending has been studied by Erceg and Lindé (2010). For a decrease in government spending, there is no similar decline in the marginal effect of the policy change. Thus, for a large enough spread in the distribution of G_2, there is the potential for a dramatically larger contraction of the economy than the possible expansion due to the change in fiscal policy. In period 1, households want to work more and save more in order to insure against low government spending in period 2. However, the precautionary saving and increased willingness to work causes inflation to fall in period 1, which raises the real interest rate due to the binding ZLB, causing consumption and investment to fall. Thus, the potentially large contraction in the economy in period 2 has adverse effects in period 1.

The asymmetry in the response of the economy grows larger as the spread in government spending grows, which means the the effects on macroeconomic aggregates in period 1 also grow as Δ increases. This can be seen in Figure 2 by the larger declines in consumption, investment, prices, and hours worked associated with larger values of Δ when $\mu_1 = \underline{\underline{\mu}}$.

The dashed line in Figure 2 shows the effects of uncertainty when $\mu_1 = \underline{\mu}$, which is the case in which the nominal interest rate is on the cusp of the ZLB. Notice that as Δ increases the economy contracts by even more than in the case when $\mu_1 = \underline{\underline{\mu}}$. The reason is that the monetary authority can raise the nominal interest rate in response to an increase in government spending, just as it would when $\mu_1 = 1$, meaning that any increase in government spending has small effects. However, the inability of the monetary authority to decrease the nominal interest rate means that even a small decrease in government spending causes the ZLB to strictly bind. When the ZLB binds, the fall in inflation causes the real interest rate to rise, which causes large declines in investment, consumption, and hours worked. Thus, when the nominal interest rate is on the cusp of the ZLB, households face a situation where the asymmetry in the response of the economy to a change in government spending is largest. The exaggerated asymmetry in period 2 causes large declines in macroeconomic aggregates in period 1.

4.3 Uncertain Tax Rates

When considering uncertainty about tax rates instead of uncertainty about government spending, the asymmetric response of the economy when the ZLB binds has a similar counterpart. A change in any tax rate will cause inflation to rise in one direction and fall in the other. If inflation rises enough in response to the change in the tax rate, the ZLB will cease to bind and the monetary authority will raise the nominal interest rate, which will offset some of the effects of the change in the tax rate. In the other direction, there is no similar decrease in the marginal effect. Thus, for a large enough spread in the distribution of a tax rate, the economy will have an asymmetric response. This asymmetry is most pronounced exactly when the nominal interest rate is at the cusp of the ZLB, meaning the effects on macroeconomic aggregates are largest in this situation.

Consider uncertainty about the investment tax rate. Figure 3 shows the percentage change in consumption, investment, prices, and hours as a function of Δ for each value of μ_1 as compared to the case when $\Delta = 0$. A decrease in the investment tax rate, which here amounts to a subsidy, increases the expected return on investment and causes the economy to expand by increasing demand for investment goods. This expansion requires more labor input, which drives up wages and prices. Conversely, an increase in the investment tax rate depresses demand by decreasing investment. The low level of output requires fewer hours, wages decline, and inflation falls. When $\mu_1 = 1$ and the equilibrium interest rate is well above zero, the monetary authority is able to offset these changes by adjusting the nominal interest rate. As shown by the solid line, the effects of an increase in Δ are small when $\mu_1 = 1$. However, when the ZLB binds ($\mu_1 = \underline{\underline{\mu}}$) the monetary authority is unable to adjust the nominal interest rate. For a large enough value of Δ, the previously discussed asymmetry in the response of the economy to a change in the tax rate causes households to insure against the relatively large contraction in the economy associated with an increase in the investment tax rate in period 2. This makes them to want to work more and save more in period 1, which puts downward pressure on inflation and causes the economy to contract.

The effects of uncertainty about capital income tax rates are shown in figure 4, and are notably smaller than uncertainty about investment taxes. The reason is that investment decisions are not very responsive to transitory changes in the capital income tax. Newly created capital will be productive long after the transitory change in the capital income tax rate has expired, meaning that the vast majority of the return on capital will come from capital income that is taxed at its long-run tax rate. Thus, even though an increase (decrease) in the capital tax rate causes investment to fall (rise) and the economy to contract (expand), the change in macroeconomic aggregates is relatively small. Nevertheless, the effects of uncertainty are larger when the ZLB binds than when it does not and are largest when the economy is at the cusp of the ZLB for the same reasons discussed above.

The effects of uncertainty about the consumption and wage tax rates are shown in figures 5 and 6. In both cases, an increase in the tax rate causes households to shift hours from labor to leisure. The decreased desire to work increases marginal costs and inflation rises. As in Eggertsson (2009), the rise in inflation causes the economy to expand in response to an increase in the tax rate. A decrease in each tax rate has the opposite effect. The previously discussed asymmetric response of the economy to large enough increases or decrease in the tax rates causes uncertainty to have adverse effects in period 1.

Uncertainty about the wage tax rate has larger effects than uncertainty about the consumption tax rate because a temporary change in the consumption tax rate also causes households to adjust their spending over time. In particular, if the consumption tax rate is temporarily high, households have an incentive to delay consumption. This decreases demand and offsets some of the expansion in the economy. If the consumption tax rate is temporary low, households have an incentive to spend in the current period, which increases demand, and offsets some of the contraction in the economy. Because the effects of a change in the consumption tax rate are muted, relative to a change in the wage tax rate, the effects of uncertainty about the consumption tax rate are also muted.

Though the effects of fiscal policy uncertainty vary in magnitude by tax rate, the main features of uncertainty about tax rates are the same as uncertainty about government spending. That is, the effects of fiscal policy uncertainty are larger when the economy is constrained by the ZLB than when it is not, and the effects are largest when the economy is at the cusp of the

ZLB.

5 Alternative Specifications of Uncertainty

In this section I consider several perturbations of the stochastic process for the fiscal instruments in my baseline model in order to extend my main qualitative results.

5.1 Timing of Policy Uncertainty

In my baseline model, fiscal policy instruments in period 2 are uncertain. As was the case with the expiration of the Bush-era tax cuts and the fiscal cliff of 2013, the date of a possible change in fiscal policy may be known, but may not be in the following period. To investigate the effects of the timing of fiscal policy uncertainty, I change the model so that in period 1 households and firms learn that fiscal policy might change one year later. As in my baseline model, in period 1, I assume that $\mu_1 = \underline{\mu} < 1$ and remains low with probability $\rho_\mu = 0.75$. Furthermore, I assume and that the fiscal policy instruments have the same distribution and follow the same stochastic process in the period that they are random, as they do in period 2 in my baseline model.

The solid line in Figure 7 show the effects in period 1 when government spending is uncertain in period 2, and the red dashed line shows the effects in period 1 of uncertainty about government spending one year later.[6] Notably, the effects are somewhat larger when the resolution of fiscal policy uncertainty is delayed. The reason for the larger response is that the period before the possible change in policy will look like period 1 in my baseline model. Households anticipate the decline in consumption in that period, and want to save in the preceding periods. The desire to save puts downward pressure on prices and inflation, which causes the real interest rate to rise and the economy to contract. Furthermore, households expect this contraction in

[6] Similar results hold when each tax rate is uncertain.

each period leading up to the possible change in fiscal policy, which adds to their precautionary saving motive. As in my baseline setup, the effects of fiscal policy uncertainty are largest when the nominal interest rate is on the cusp of the ZLB because the effects on the economy in the period before the potential change in fiscal policy are most dramatic at that point.

When the ZLB does not bind, delaying the resolution of uncertainty diminishes its effects in the current period because the monetary authority can offset the desire of the household to save by lowering the nominal interest rate. To illustrate this effect, I consider a version of the model in which government spending is random only after μ_t returns to its long-run value of 1. The effects in period 1 of this type of fiscal policy uncertainty are shown by the dashed-dotted line in Figure 7. In this case, the monetary authority is unconstrained by the ZLB for any realization of the stochastic process for government spending, which means that changes in fiscal policy have small and roughly symmetric effects on output and consumption. These small and symmetric effects prompt a small reaction from households in period 1.

These results indicate that delaying fiscal policy uncertainty can reduce its adverse consequences insofar as it can be delayed beyond the point when the monetary authority is no longer constrained by the ZLB. In my model, if the marginal efficiency of investment remains low for an extended period, the capital stock will fall because of low investment, causing marginal cost and inflation to rise so that monetary authority eventually sets the nominal interest rate above zero. However, delaying the resolution of uncertainty until the nominal interest rate is just at the cusp of the ZLB will not diminish the effects of fiscal policy uncertainty since it has its largest effects at that time. Instead, the effects of fiscal policy uncertainty are small so long as the monetary authority can fully respond to the change in fiscal policy without being constrained by the ZLB, meaning that the nominal interest rate needs to be larger than zero for any realization of the fiscal policy process.

5.2 Persistence of the Change in Fiscal Policy

In my benchmark model I assume that any change in fiscal policy reverts to its previous value with probability $1 - \rho_G = 0.25$. I have studied different levels of persistence of the change in fiscal policy, namely different values of ρ_G. The solid line in Figure 8 represents the benchmark case ($1 - \rho_G = 0.25$), and the dashed line represents the case when the change in fiscal policy is less persistent ($1 - \rho_G = 0.5$). Notably, the effects in period 1 of fiscal policy uncertainty are smaller when then change in fiscal policy is less persistent. The reason is that the fiscal policy instrument is more likely to revert back to its time 1 level before the ZLB ceases to bind, at which point an expansionary (contractionary) change in fiscal policy at time 2 will have contractionary (expansionary) effects. The increased likelihood of this possibility decreases the effects of the policy change at time 2 because agents anticipate that it may be undone. Since the response of the economy to the change in fiscal policy at time 2 is muted, so are the effects of uncertainty at time 1.

5.3 Asymmetric Fiscal Policy Uncertainty

In my main experiments, I specify a symmetric distribution over fiscal instruments to isolate the effects of the spread of the distribution. Here, I consider a distribution over government spending that is a mean preserving spread but is not symmetric. In particular, I modify the stochastic process so that the probability of an increase in government spending is twice as large as the probability of a decrease in government spending. However, I require that the expected change in government spending is zero. The distribution over G_2 is then given by

$$G_2 = \begin{cases} G_1 + \Delta/\sqrt{2} & \text{with probability } \frac{4}{9} \\ G_1 & \text{with probability } \frac{1}{3} \\ G_1 - \Delta\sqrt{2} & \text{with probability } \frac{2}{9} \end{cases}$$

where I have scaled by $\sqrt{2}$ so that, for a given Δ, the variance of the distribution is the same as in my baseline model. In this case, the distribution is skew down. I also consider a distribution over G_2 that is given by

$$G_2 = \begin{cases} G_1 + \Delta\sqrt{2} & \text{with probability } \frac{2}{9} \\ G_1 & \text{with probability } \frac{1}{3} \\ G_1 - \Delta/\sqrt{2} & \text{with probability } \frac{4}{9} \end{cases}$$

which is skew up.

I set $\mu_1 = \underline{\underline{\mu}}$ and do the same experiment as in my baseline model, but with each of these distributions. Figure 9 displays the effects of fiscal policy uncertainty on output, inflation, investment, and hours for each distribution of government spending. The effects of fiscal policy uncertainty are largest when the distribution is skew up. The reason is that the relatively large decline in government spending is more likely than the increase in government spending, and the increase in government spending has a large effect only until the ZLB no longer binds. The upward skewness makes the truncation of the large effects of an increase in government spending more severe for any given Δ, which causes larger expected contractions in period 2. In period 1, the desire of the household to work and save is higher, which causes prices to fall and the economy to contract.

When I set $\mu_1 = \underline{\mu}$ so that the nominal interest rate is at the cusp of the ZLB, the shape of the distribution of possible outcomes for G_2 has less of an effect. Figure 10 displays the effects of fiscal policy uncertainty when $\mu_1 = \underline{\mu}$ for the distributions considered above. Notably, the effects of fiscal policy uncertainty are little changed from my baseline scenario. The reason is that any increase in government spending already has muted effects in the baseline scenario. Thus, the skewness of the distribution of G_2 does not induce any further decline in the marginal effect of an increase in government spending.

6 Sensitivity Analysis

In this section, I consider alternative specifications of my baseline model to show that my main results are robust to a number of changes.

6.1 Adjustment Costs

I have studied versions of the model with different values of the adjustment cost parameters, ϕ_π and ϕ_K. For each adjustment cost parameter, changing the value in such a way so that fiscal multipliers are larger also increases the effects of fiscal policy uncertainty when the ZLB binds. The reason is that, with larger fiscal multipliers, a change in fiscal policy causes larger changes in output and inflation. At the ZLB, this implies that smaller changes in fiscal policy could cause the nominal interest rate to begin to rise, which exacerbates the asymmetric effects of fiscal policy changes.

To illustrate the effect of changing the price adjustment cost parameter, in figure 11 I show the effects of uncertain government spending for two values of ϕ_π ($\phi_\pi = 100$ and $\pi_\pi = 116$). I set μ_1 so that the economy is at the cusp of the ZLB in each case. Notably, for the lower adjustment costs the effects of a change in government spending are larger when the ZLB binds. This also implies that if government spending is uncertain in period 2, as in my baseline experiments, then the effects of fiscal policy uncertainty in period 1 are larger for lower values of ϕ_π, as the dotted line indicates.

In figure 12, I show the effects in period 1 when government spending is uncertain in period 2 for economies with two values of the capital adjustment cost parameter, ϕ_K ($\phi_K = 17$ and $\phi_K = 10$). I set μ_1 so that the economy is at the cusp of the ZLB in each case. As with price adjustment costs, lower capital adjustment costs magnify the effects of changes in fiscal policy when the ZLB binds, which also increases the effects of fiscal policy uncertainty.

6.2 Persistence of the Decline in the Marginal Efficiency of Investment

In my baseline calibration, I set the probability that μ_t returns to 1 to be $1 - \rho_\mu = 0.25$. Here, I consider the case when the probability that μ_t returns to 1 is $1 - \rho_\mu = 0.5$. Figure 13 shows the effects of fiscal policy uncertainty (when G_2 in uncertain) for the each value of ρ_μ. To make the results comparable, in each case I calibrate μ_t so that the nominal interest rate is at the cusp of the ZLB in period 1. The effects of fiscal policy uncertainty are markedly smaller when the persistence of the shock to μ_t is lower $(1 - \rho_\mu = 0.5)$.

When μ_t is less persistent, the probability that the economy will remain at the ZLB is lower. The expected effects of a change in fiscal policy are smaller because a change in fiscal policy will have large effects only so long as the ZLB binds. Because changes in fiscal policy have smaller effects on macroeconomic aggregates, the asymmetric response of the economy to a change in fiscal policy when the ZLB binds is muted, meaning the effects of fiscal policy uncertainty are smaller. Thus, decreasing the persistence of μ_t decreases the adverse effects of fiscal policy uncertainty.

6.3 Preferences

I have also considered a version of the model where preferences are specified so that the lifetime utility of the household is given by

$$E_t \sum_{\ell=0}^{\infty} \beta^\ell \left\{ \frac{(C_{t+\ell}(1 - H_{t+\ell})^\chi)^{1-\sigma}}{1-\sigma} + v(G_{t+\ell}) \right\}$$

as in King, Plosser, and Rebelo (1988). In standard business cycle parameterizations of these preferences, χ is set to ensure that the household spends about 25 percent of its time endowment working. The resulting elasticity of labor supply is relatively high, which, coupled with the complementarity between leisure and consumption tends to make uncertainty about the wage tax rate have relatively large effects. Overall, the qualitative conclusions from my main experiments using these preferences are unchanged. That is, the effects of fiscal policy uncertainty are larger when the ZLB binds than when it does not and are largest at when the nominal interest rate is at the cusp of the ZLB.

7 Conclusion

In this paper, I argued that fiscal policy uncertainty can have large and adverse effects when the ZLB binds. Using a new-Keynesian model with endogenous capital accumulation, I confirm the findings of past studies and show that the effects of fiscal policy uncertainty are small when the monetary authority is not constrained by the ZLB. In addition, I showed that uncertainty about government spending and an array of tax rates can have large effects when the ZLB binds, and that those effects are largest when the nominal interest rate is at the cusp of the ZLB.

These findings have important implications for government policy. My results indicate that fiscal policy uncertainty should be avoided while the ZLB binds. Studies like Eggertsson (2009) and Christiano et al. (2011) advocate raising government spending in response to an episode in which the ZLB binds. My findings suggest that clarity in the future path of fiscal policy could be an important determinant of the effectiveness of any such transitory change in policy. Moreover, Correia et al. (2011) have argued that with a flexible enough tax policy, the detrimental effects on the economy associated with the ZLB can be avoided. However, my results imply that uncertainty about the willingness or ability of the fiscal authority to implement the correct path of policy may mean that prices and allocations differ drastically from their desired levels. Given the varying fiscal policy responses around the world, quantifying the effects of fiscal policy uncertainty during the Great Recession remains an important topic for future research.

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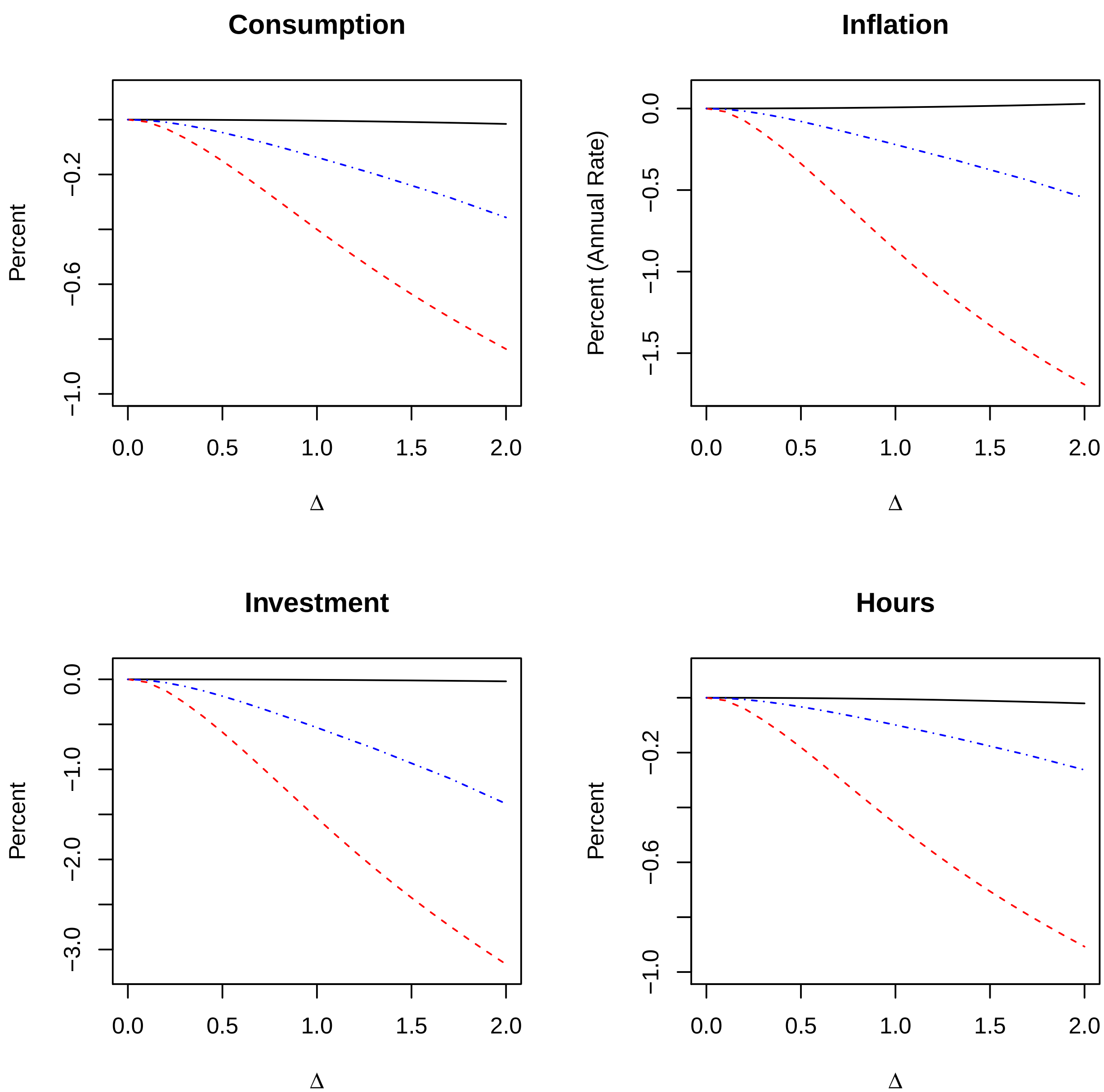
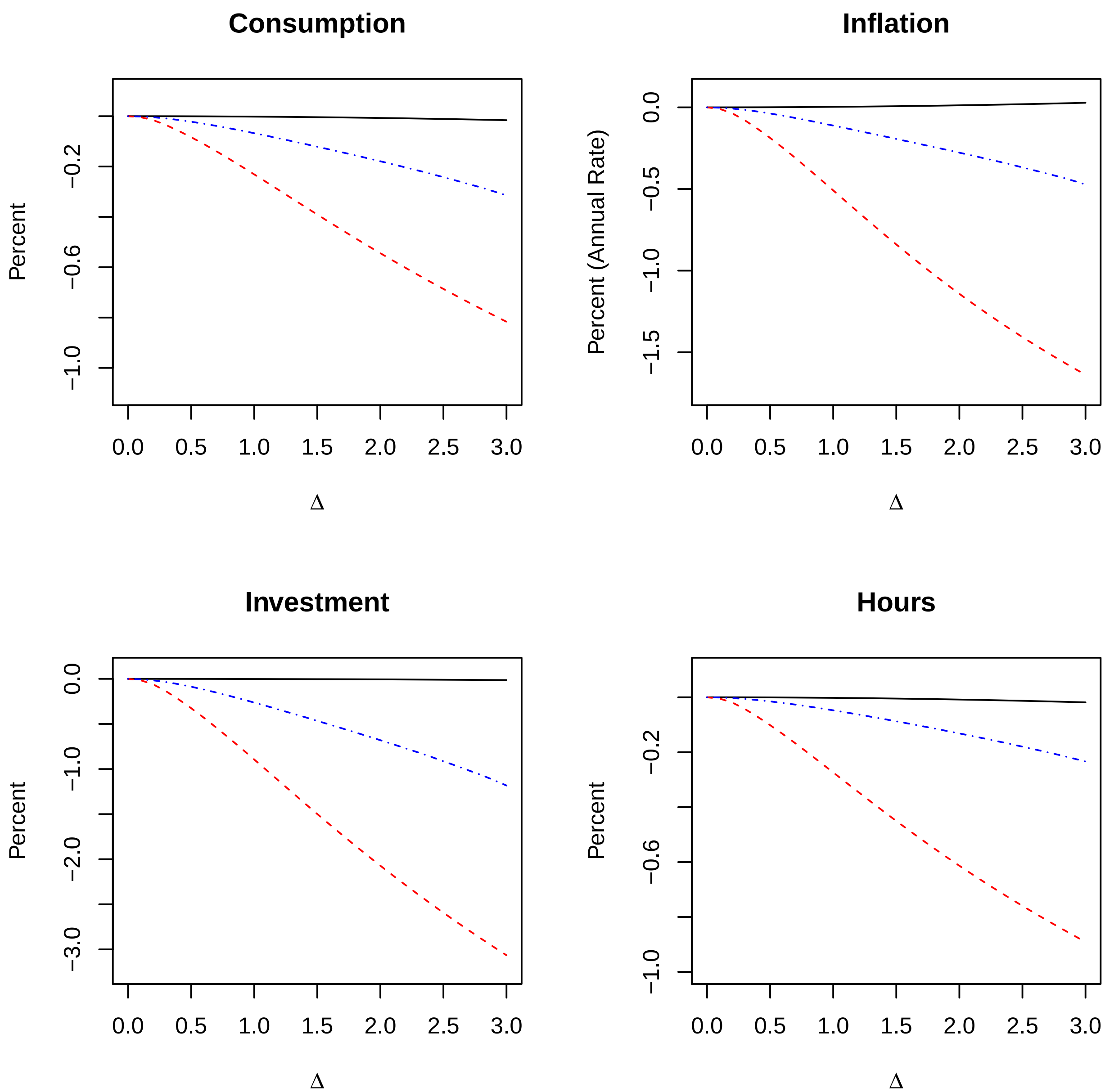
A Figures

Figure 2: Uncertain Government Spending



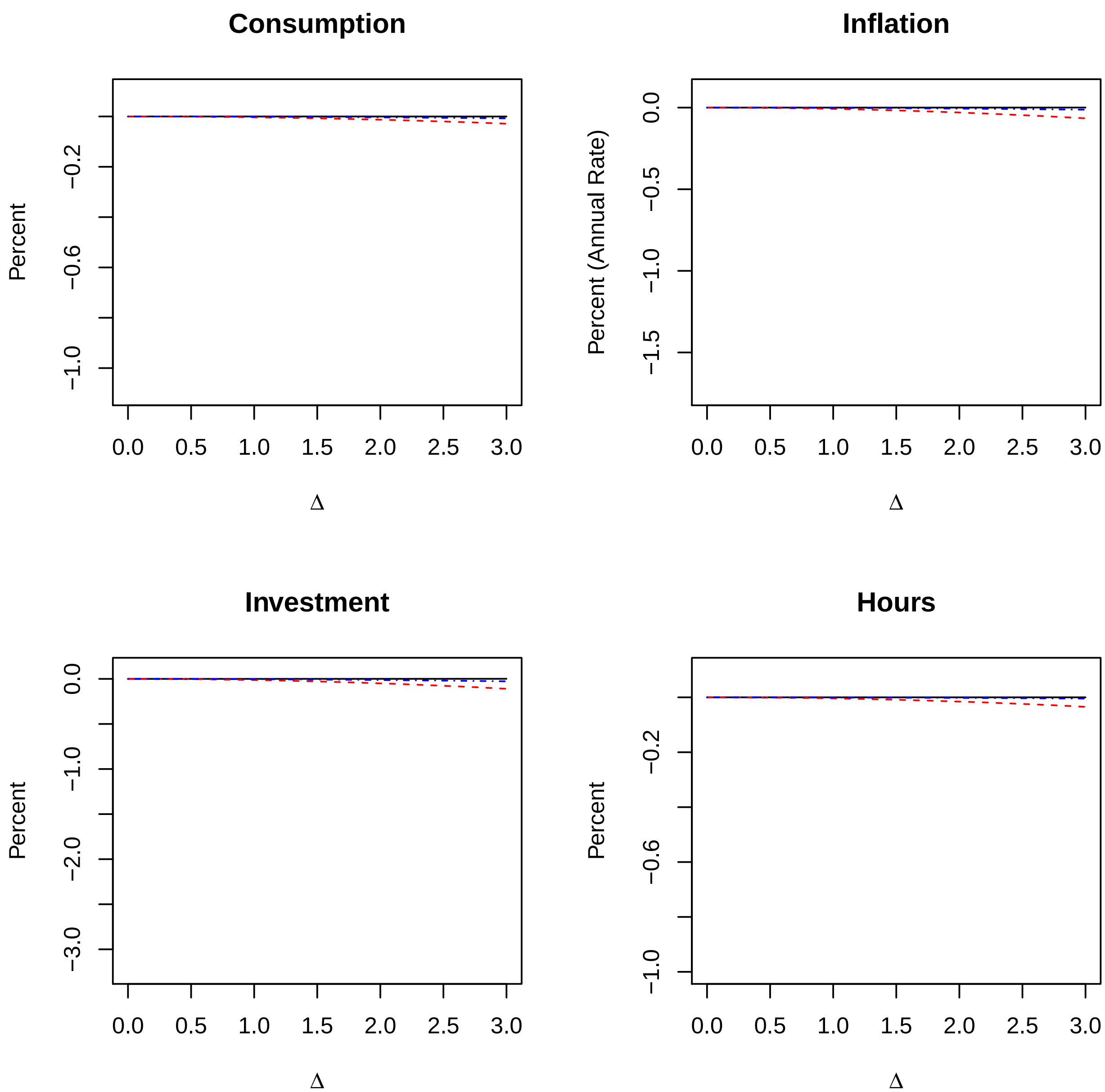
The horizontal axis is the spread in the distribution of G_2 (Δ) expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\mu_1 = 1$. The blue dashed-dotted line is the case when $\mu_1 = \underline{\underline{\mu}}$. The red dashed line is the case when $\mu_1 = \underline{\mu}$.

Figure 3: Uncertain Investment Tax Rate



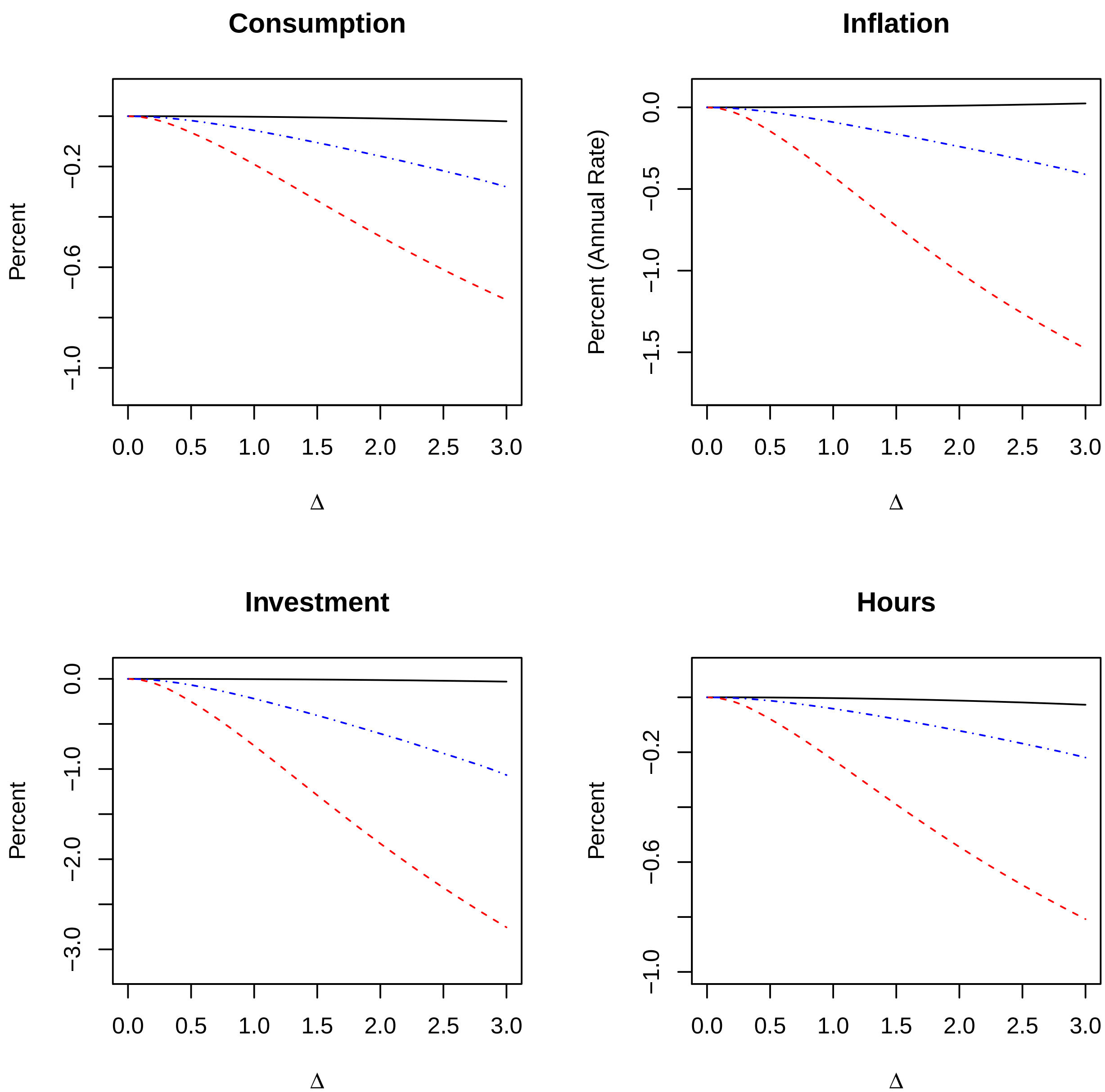
The horizontal axis is the spread in the distribution of $\tau_{I,t}$ (Δ) expressed as percentage points. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\mu_1 = 1$. The blue dashed-dotted line is the case when $\mu_1 = \underline{\underline{\mu}}$. The red dashed line is the case when $\mu_1 = \underline{\mu}$.

Figure 4: Uncertain Capital Income Tax Rate



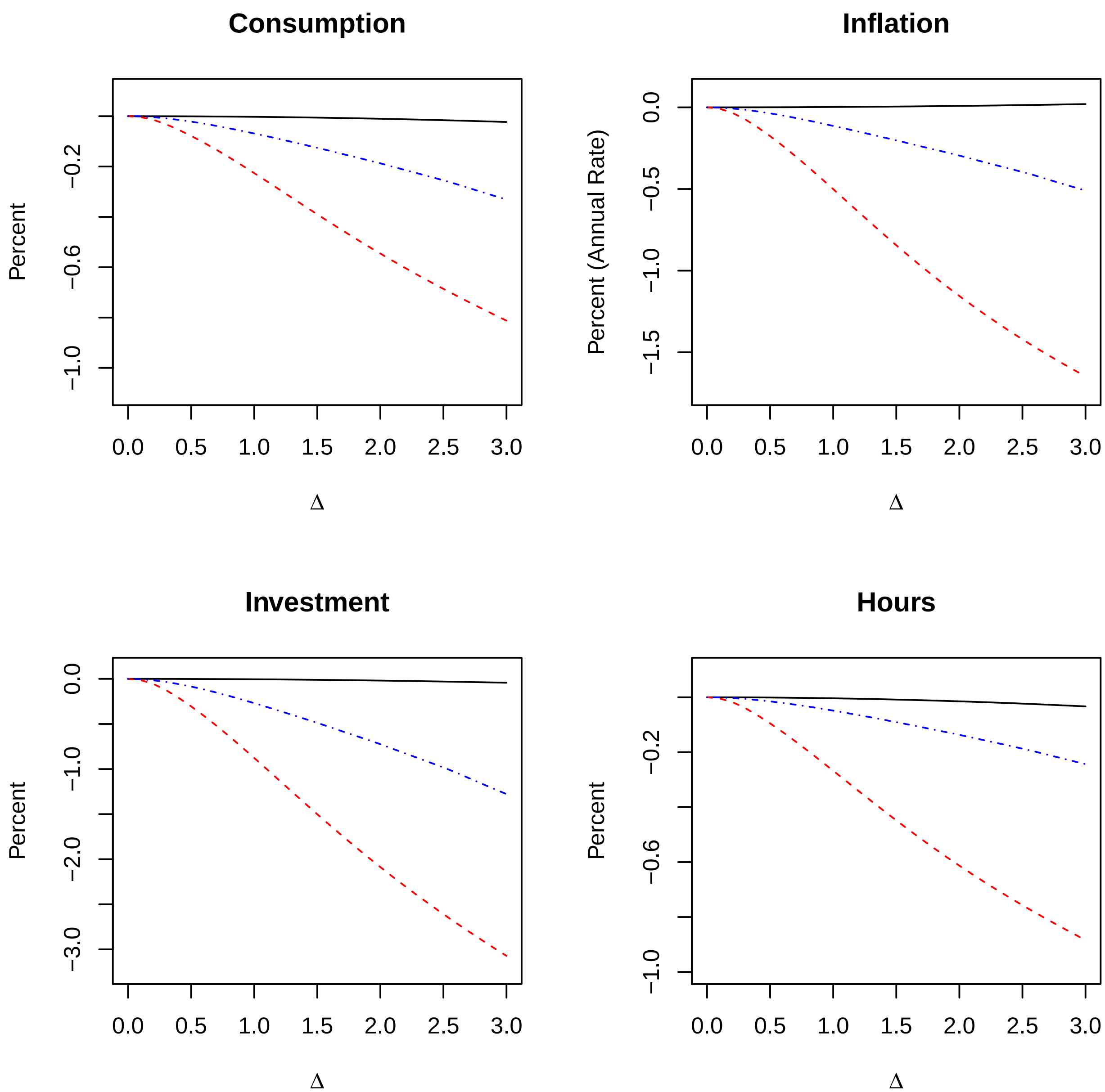
The horizontal axis is the spread in the distribution of $\tau_{K,2}$ (Δ) expressed as percentage points. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\mu_1 = 1$. The blue dashed-dotted line is the case when $\mu_1 = \underline{\underline{\mu}}$. The red dashed line is the case when $\mu_1 = \underline{\mu}$.

Figure 5: Uncertain Consumption Tax Rate



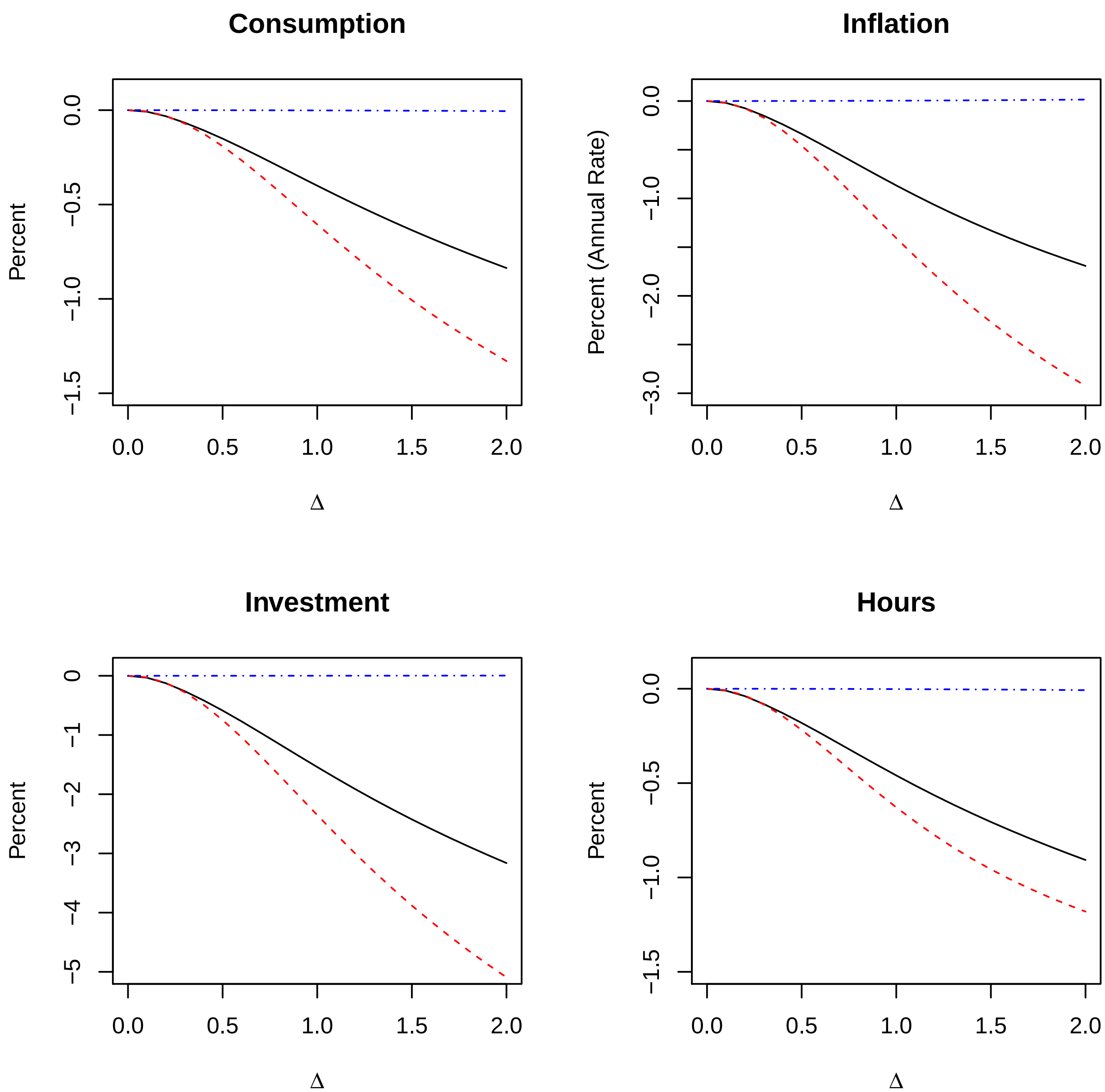
The horizontal axis is the spread in the distribution of $\tau_{C,2}$ (Δ) expressed as percentage points. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\mu_1 = 1$. The blue dashed-dotted line is the case when $\mu_1 = \underline{\underline{\mu}}$. The red dashed line is the case when $\mu_1 = \underline{\mu}$.

Figure 6: Uncertain Wage Tax Rate



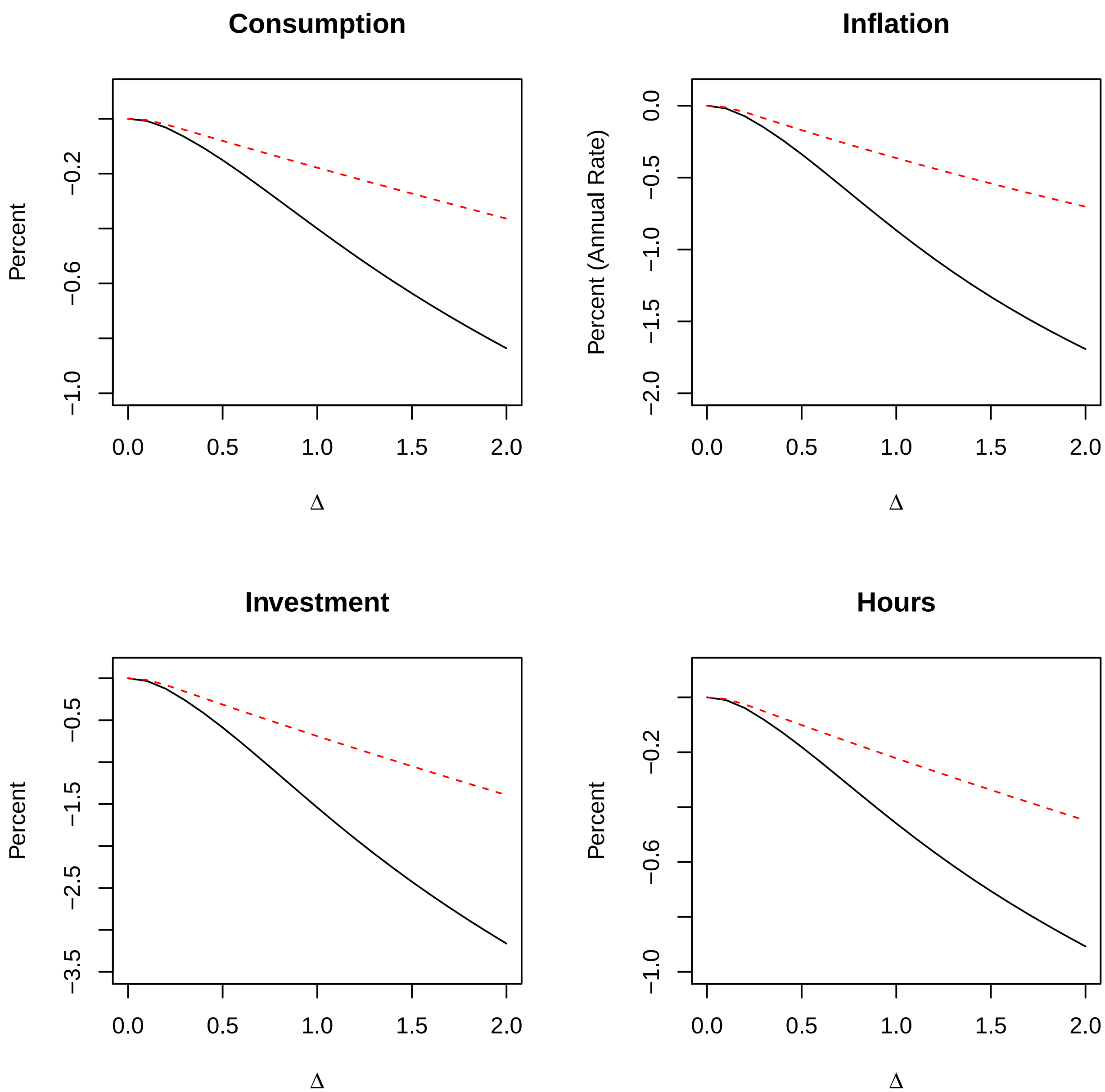
The horizontal axis is the spread in the distribution of $\tau_{H,2}$ (Δ) expressed as percentage points. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\mu_1 = 1$. The blue dashed-dotted line is the case when $\mu_1 = \underline{\underline{\mu}}$. The red dashed line is the case when $\mu_1 = \underline{\mu}$.

Figure 7: Timing of Fiscal Policy Uncertainty



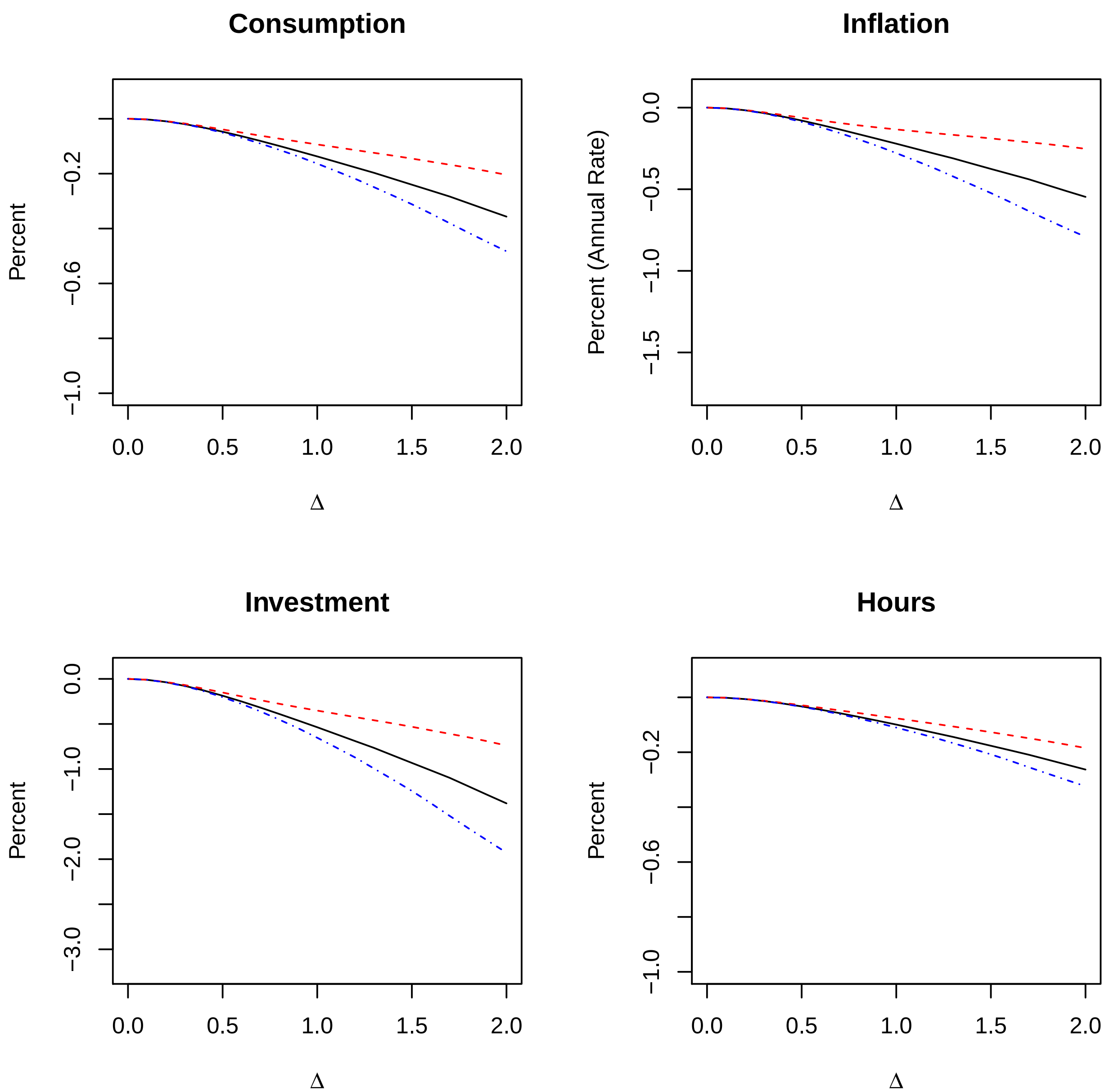
Government spending is uncertain and $\mu_1 = \underline{\mu}$. The horizontal axis is the spread in the distribution, Δ, expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when G_2 is uncertain. The red dashed line is the case when G_5 is uncertain. The blue dashed-dotted line is the case when G_t is uncertain after $\mu_t = 1$.

Figure 8: The Effects of the Persistence of the Change in Fiscal Policy



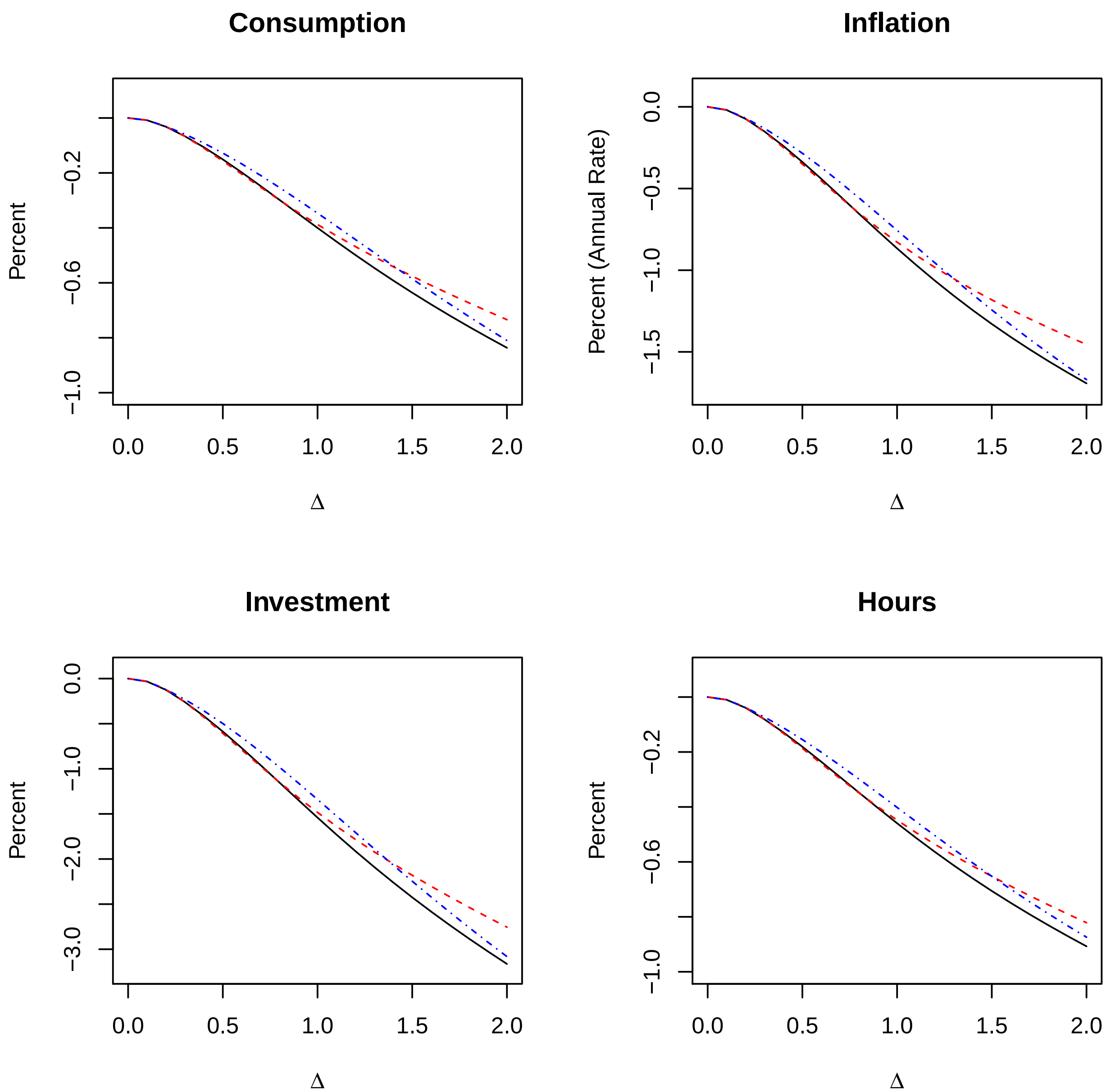
Government spending is uncertain and $\mu_1 = \underline{\mu}$. The horizontal axis is the spread in the distribution of G_2 (Δ) expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\rho_G = 0.75$. The red dashed line is the case when $\rho_G = 0.5$.

Figure 9: The Effects of Asymmetric Uncertainty



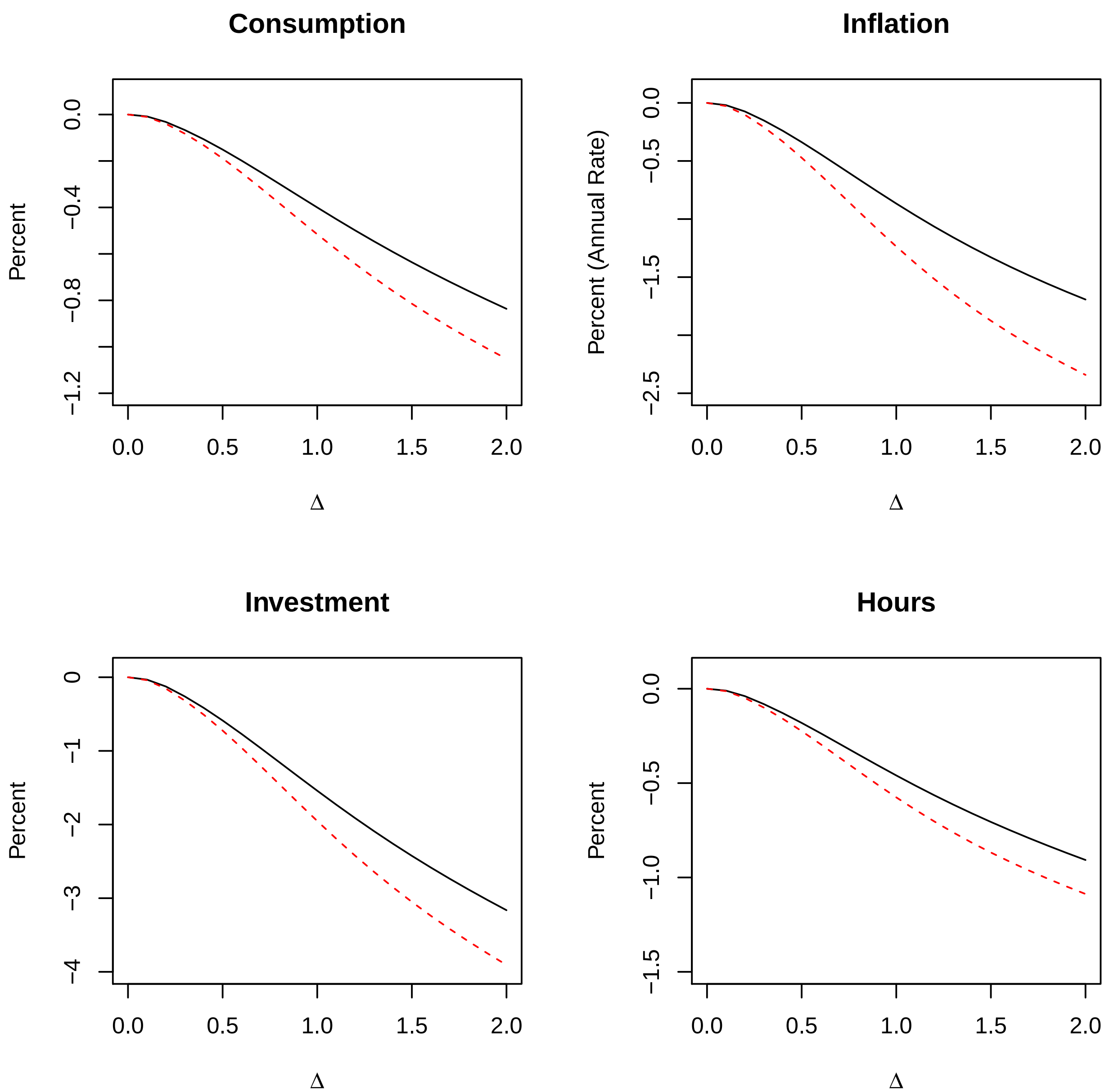
Government spending is uncertain and $\mu_1 = \underline{\underline{\mu}}$. The horizontal axis is the spread in the distribution, Δ, expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when the distribution is symmetric. The red dashed line is the case when the distribution is skew down. The blue dashed-doted line is the case when the distribution is skew up.

Figure 10: The Effects of Asymmetric Uncertainty (Cusp of ZLB)



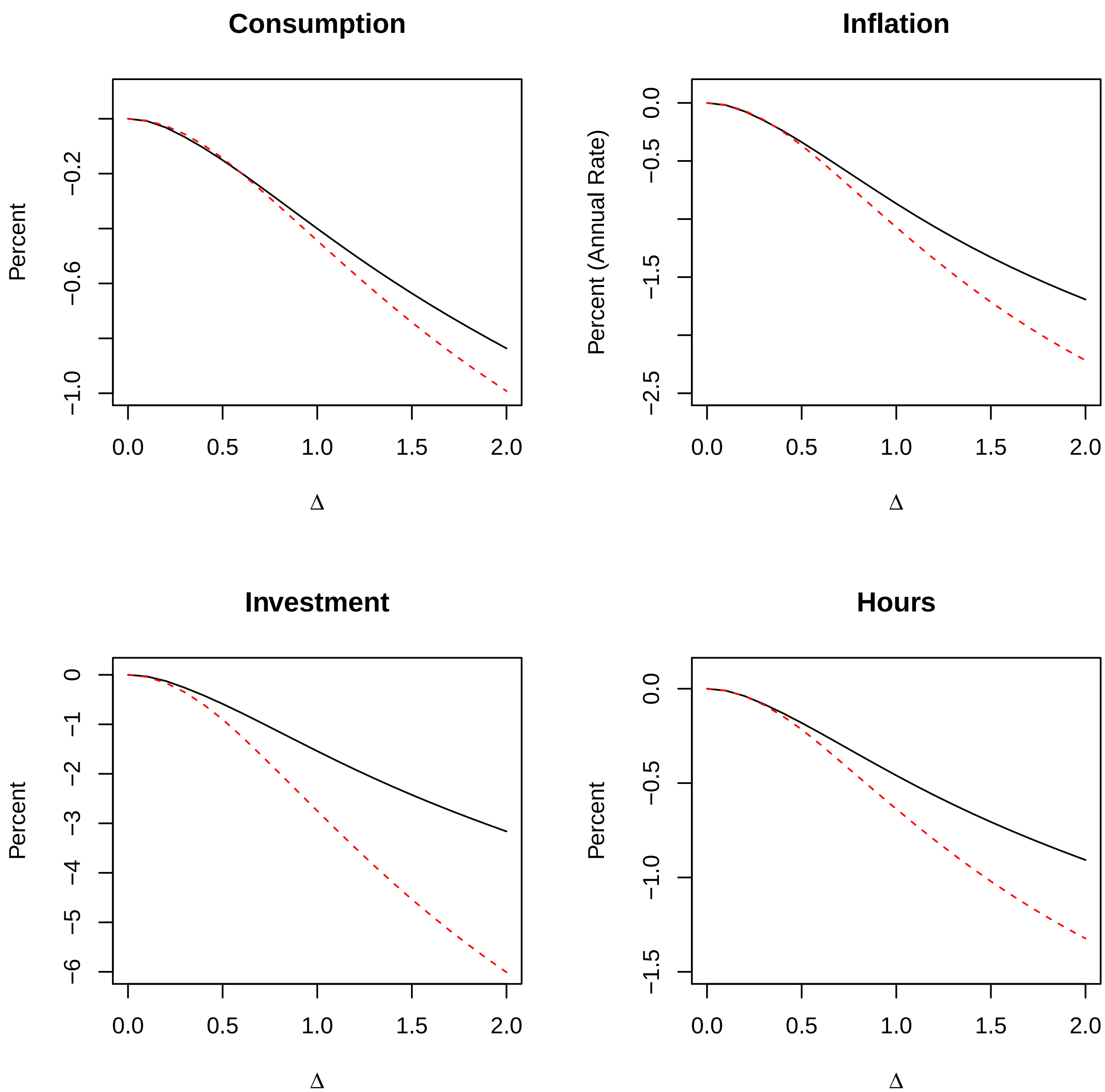
Government spending is uncertain and $\mu_1 = \underline{\mu}$. The horizontal axis is the spread in the distribution, Δ, expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when the distribution is symmetric. The red dashed line is the case when the distribution is skew down. The blue dashed-doted line is the case when the distribution is skew up.

Figure 11: The Effects of Price Adjustment Costs



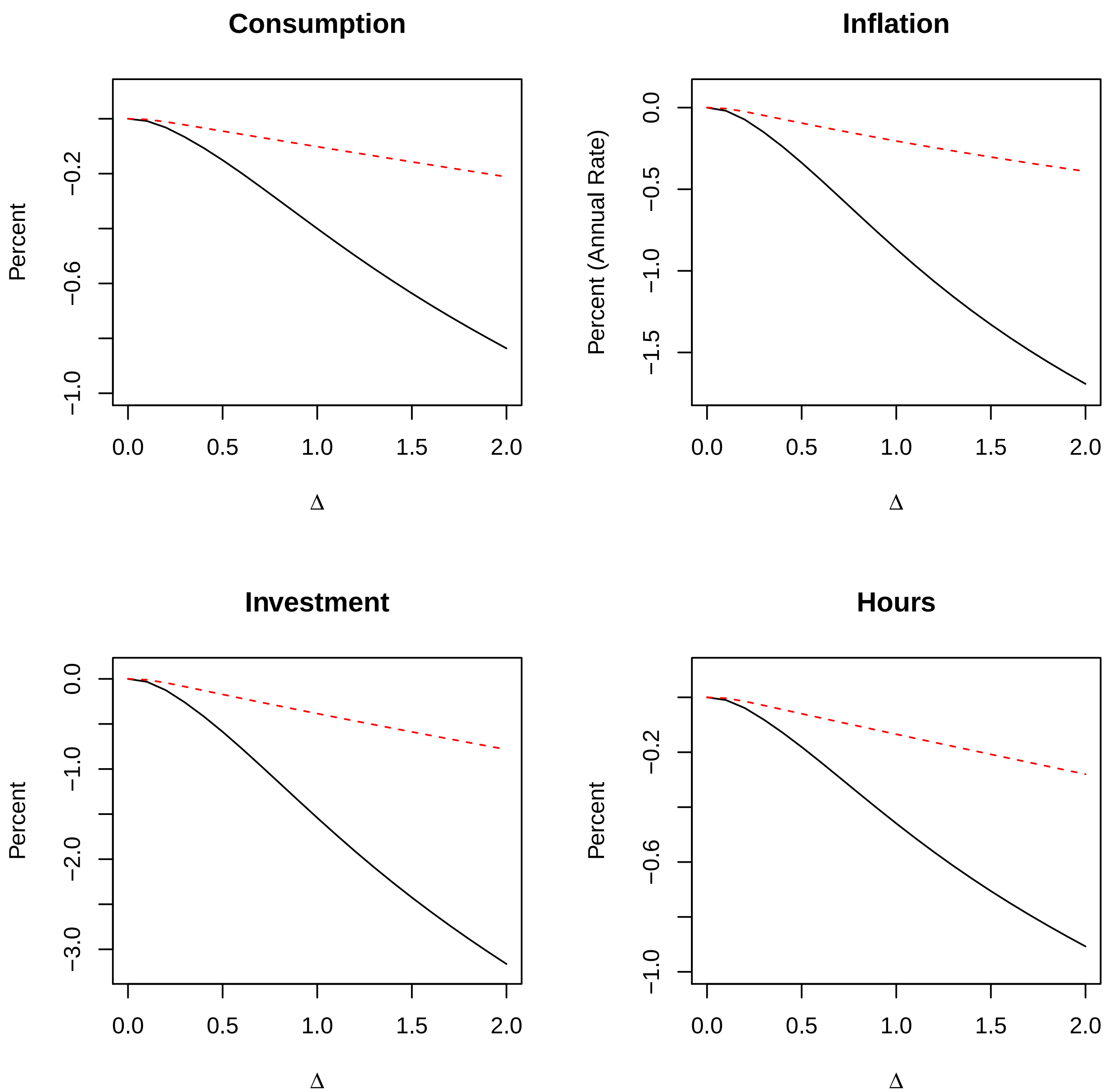
Government spending is uncertain and μ_1 is set so that the nominal interest rate is on the cusp of the ZLB in each case. The horizontal axis is the spread in the distribution, Δ, expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\phi_\pi = 116$. The red dashed line is the case when $\phi_\pi = 100$.

Figure 12: The Effects of Capital Adjustment Costs



Government spending is uncertain and μ_1 is set so that the nominal interest rate is on the cusp of the ZLB in each case. The horizontal axis is the spread in the distribution, Δ, expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\phi_K = 17$. The red dashed line is the case when $\phi_K = 10$.

Figure 13: The Effects of the Persistence of the Change in μ_t



Government spending is uncertain and μ_1 is set so that the nominal interest rate is on the cusp of the ZLB in each case. The horizontal axis is the spread in the distribution of G_2 (Δ) expressed as a percentage of steady state GDP. The vertical axis is the percent change due to the spread in the distribution as compared to the case when $\Delta = 0$. The black solid line is the case when $\rho_\mu = 0.75$. The red dashed line is the case when $\rho_\mu = 0.5$.

B Equilibrium Conditions

The following equations, along with the monetary policy rule an the stochastic processes for μ_t and the fiscal instruments determine equilibrium. Per-period utility is given by

$$U(C,H) = \frac{C^{1-\sigma}}{1-\sigma} - \frac{\chi}{1+\gamma}H^{1+\gamma}$$

Households take prices as given. Define

$$\lambda_t \equiv \frac{U_C(C_t,H_t)}{P_t(1+\tau_{C,t})}$$

This is the first-order optimality condition of the household problem with respect to C_t. The optimality condition with respect to H_t is

$$-U_H(C_t,H_t) = \lambda_t P_t W_t (1-\tau_{H,t})$$

The bond-saving decision is determined by

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} R_t$$

and the capital saving decision is determined by

$$\begin{aligned}(1+\tau_{I,t})/\mu_t + \phi_K\left(\frac{K_{t+1}}{K_t}-1\right) =& \beta E_t \frac{\lambda_{t+1}P_{t+1}}{\lambda_t P_t}\left(r_{t+1}\left(1-\tau_{K,t+1}\right) + (1-\delta)\left(1+\tau_{I,t+1}\right)/\mu_{t+1}\right) \\ &+ \beta E_t \frac{\lambda_{t+1}P_{t+1}}{\lambda_t P_t}\left(\phi_K\left(\frac{K_{t+2}}{K_{t+1}}-1\right)\frac{K_{t+2}}{K_{t+1}} - \frac{\phi_K}{2}\left(\frac{K_{t+2}}{K_{t+1}}-1\right)^2\right)\end{aligned}$$

Firms take wages and the rental rate of capital as given and choose quantities so that

$$K_t r_t = \frac{\alpha_y}{1-\alpha_y} W_t H_t$$

They set their price (and hence their quantities, since they are monopolistically competitive) according to the following equation

$$(1+s)(\epsilon-1)Y_t = W_t \frac{\epsilon}{1-\alpha_y} H_t - \phi_\pi \left(\frac{\pi_t}{\pi^*}-1\right)\frac{\pi_t}{\pi^*} Y_t + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\phi_\pi \left(\frac{\pi_{t+1}}{\pi^*}-1\right)\frac{\pi_{t+1}^2}{\pi^*} Y_{t+1}$$

Total output in the economy is given by

$$Y_t = C_t + G_t + I_t + \frac{\phi_\pi}{2}\left(\frac{\pi_t}{\pi^*}-1\right)^2 Y_t + \frac{\phi_K}{2}\left(\frac{K_{t+1}}{K_t}-1\right)^2 K_t$$

and is created using the following technology

$$Y_t = K_t^{\alpha_y} H_t^{1-\alpha_y}$$

C Solution Method

The solution method I use involves time iteration on the Euler equations that define the equilibrium. The method is outlined in chapter 17 of Judd (1998). It has been implemented in Coleman (1991) as well as in Bi et al. (2012), among others.

Consider a constant set of tax rates, τ, and government spending, G, and set $\mu_t = 1$ forever. Nothing is random in the model and the only state variable is capital. Assume that we have equilibrium consumption, investment, and inflation as a function of the capital stock. From the resource constraint we can recover output, which also gives us hours worked. The nominal interest rate can be computed from the monetary policy equation and the wage rate can be computed from the intra-temporal Euler equation of the household. Three equilibrium conditions remain unused: the first-order condition for price setting of the intermediate goods firms, the inter-temporal Euler equation from the household, and the first-order condition for investment from the household. These three equations define a set of nonlinear equations, Ψ, so that

$$\Psi(K, C(K), I(K), \pi(K)) = 0.$$

A set of functions $C(\cdot)$, $I(\cdot)$, and $\pi(\cdot)$ that satisfy these conditions constitute an equilibrium. If we conjecture a set of such functions for the following period and call them $\{C^+(\cdot), I^+(\cdot), \pi^+(\cdot)\}$ we can read the equilibrium conditions instead as a set of restrictions on on functions for the current period, denoted $\{C(\cdot), I(\cdot), \pi(\cdot)\}$. That is, equilibrium requires that

$$\Psi(K, C(K), I(K), \pi(K), C^+(K), I^+(K), \pi^+(K)) = 0.$$

Conditional on the capital stock, the above restrictions require simply the solution to a system of nonlinear equations to determine the values $\{C(K), I(K), \pi(K)\}$. We can then set $\{C^+(\cdot), I^+(\cdot), \pi^+(\cdot)\} = \{C(\cdot), I(\cdot), \pi(\cdot)\}$ and check to see if the functions have changed. If they are unchanged, we have an equilibrium. If they have changed, we can continue to iterate in this fashion.

To make the procedure operational, I define an equally spaced grid of 4848 points over the interval $[\log(0.7K_{ss}), \log(1.3K_{ss})]$, where K_{ss} is the non-stochastic steady state level of capital of the baseline parameterization of the model. I specify the functions C, I, and π to be piecewise linear functions, where the value of the function at a grid point is a parameter and the value of the function between two grid points is a linear interpolation between them. The number of grid points was chosen as what seemed like a reasonable trade-off between accuracy and computational time. I have experimented with as many as 10000 and as few as 300 grid points, and the choice does not effect the qualitative conclusions of the paper. To determine if the functions have converged, I check to see if the values of the functions at any each grid point have changed by more than 1×10^{-9}.

Given the above method for solving the model with constant fiscal instruments, the same methodology can be adapted to the experiments I consider in the body of the paper, except with a distribution over μ_t and a different decision rule for each state of μ_t and fiscal instrument. My chosen stochastic processes for μ_t and the fiscal instruments imply that the randomness in the model follows a finite Markov process. For each state, s_t, the Euler equations that determine equilibrium define a system of equations that must hold in expectation

$$E_t \Psi(K_t, C(K;s), I(K;s), \pi(K;s), s_t, s_{t+1}) = 0.$$

where the expectation is taken with respect to the distribution of the state in the next period. I assume that each state has its own set of piecewise linear decision rules that are a function of the capital stock. I find these decision rules in a similar way to the above methodology. That is, I posit that a conjectured set of decision rules is operative in the next period and compute the solution to the system of equations at each point in the grid for the current period. I check to see if the solutions match the conjectured decision rules, and iterate until they converge. I use the same number of grid points and the same convergence criterion as defined above.

D Stationary Version of the Model

To make the model have a stationary distribution, I specify the process for government spending so that whenever G_t is equal to its mean value (G), households and firms learn that fiscal policy is uncertain in the next period with probability 0.05. If government spending might change in the next period, it has distribution

$$G_{t+1} = \begin{cases} G + \Delta & \text{with probability } \frac{1}{3} \\ G & \text{with probability } \frac{1}{3} \\ G - \Delta & \text{with probability } \frac{1}{3} \end{cases}$$

where Δ is fixed. The value of G_t reverts back to G with probability 0.25. I assume that μ_t takes two values, 1 and $\underline{\mu}$. If $\mu_t = 1$, it remains at that value with probability 0.99. If $\mu_t = \underline{\mu}$, it remains at that value with probability 0.75. This parameterization is meant to imply that that events where μ_t is low are rare events. As in the experiments above, I find that the effects of fiscal policy uncertainty are larger when the ZLB binds than when it does not and largest when the economy would otherwise be at the cusp of the ZLB.