Monetary Policy When Wages Are Downwardly Rigid: Friedman Meets Tobin[*]

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Abstract

In a monetary economy with downwardly rigid wages, the central banker should target a low, but strictly positive, inflation rate.

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1. Introduction

The idea that nominal wages are more downwardly rigid, than upwardly rigid, has a long history in economics. Earlier references include Keynes (1936), who discusses the role of downward nominal wage rigidity in business cycle fluctuations; Tobin (1972), who suggests that a positive rate of inflation may be socially beneficial in an economy where cutting nominal wages is privately costly; and Harris and Holmstrom (1982), who show that the optimal long-term contract has an insurance component whereby the (real) wage never falls in a setup where firms are risk-neutral and workers are risk-averse.

Furthermore, downward nominal wage rigidity has received ample empirical support from a large body of research based on micro data at the individual, firm and industry levels. Research on wage changes at the individual level finds that its distribution has a peak at zero, features few wage cuts, and is positively skewed. This is so even in countries, like Japan and Switzerland, where inflation is very low or even negative.[1] Surveys on attitudes towards nominal wage cuts show that both workers and firms dislike them, but for different reasons. Workers perceive nominal wage cuts as unfair (Kahneman, Knetsch and Thaler, 1986), while firms are generally concerned about the effect of wage cuts on morale and, in practice, only cut wages when facing bankruptcy (Bewley, 1995, and Campbell and Kamlani, 1997).

This paper is concerned with the macroeconomic implications of downward nominal wage rigidity, in particular for monetary policy. To that end we build a small-scale, dynamic stochastic general-equilibrium (DSGE) model where the cost of adjusting prices and wages may be asymmetric. We follow the Neo Keynesian literature in postulating a simple mechanism to model nominal frictions in the goods and labor markets, but relax the assumption that frictions are symmetric around the current price or wage.[2] In particular, we adopt an adjustment cost specification based on the linex function due to Varian (1974), which includes the quadratic function in Rotemberg (1982) as a special case. Hence in our model, adjustment costs depend not only of the size but also on the sign of the adjustment. For example, a nominal wage cut may involve a larger frictional cost that an increase of exactly the same magnitude. The nonlinear model based on a second-order

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[1] See, McLaughlin (1994), Akerlof, Dickens and Perry (1996), Card and Hyslop (1997), and Barattieri, Basu and Gottschalk (2009) for the United States; Farès and Lemieux (2001) for Canada, Kuroda and Yamamoto (2003) for Japan, Castellanos Castellanos, Garcia-Verdú and Kaplan (2004) for Mexico, and Fehr and Goette (2005) for Switzerland. The same characteristics are found by Holden and Wulfsberg (2008) in the distribution of wage changes at the industry level in various OECD countries.

[2] Two widely-used mechanisms for nominal frictions are due to Rotemberg (1982) and Calvo (1983). In the former, agents face a quadratic (and, hence, symmetric) cost for changing prices or wages. In the latter, only agents that receive an exogenous signal are allowed to re-optimize their price or wage. Solving a first-order approximation to a model with Calvo-type rigidity imposes symmetry by construction.

approximation is estimated by the Simulated Method of Moments (SMM) and a simple t test is used to evaluate whether the macro data supports the view that nominal wages are downwardly rigid.

This project builds on—but makes a distinct contribution from—our previous work; Kim and Ruge-Murcia (2009) carries out the analysis using a cashless economy and is primarily concerned with the optimal amount of "grease" inflation. In contrast, this paper studies the positive implications of downward wage rigidity—which are not examined in our earlier contribution—and does so in the context of a fully-fledged monetary economy. From the modeling perspective, this paper extends Kim and Ruge-Murcia (2009) by characterizing the role of money as a medium of exchange. Modeling money is important for the normative analysis of monetary policy. In the cashless environment of Kim and Ruge-Murcia (2009), downward wage rigidly trivially induces a positive optimal rate of inflation, as was anticipated by Tobin (1972). Thus, the object of interest in our previous paper is not the level of inflation *per se*, but rather the extra optimal inflation induced by asymmetric costs compared with symmetric costs (that is, "grease" inflation).

In a monetary economy, inflation—or even modest deflation as far as the nominal interest rate is positive—leads to the inefficient economizing in money balances. Thus, in the absence of nominal frictions, the optimal inflation rate is negative and equal to the Friedman's rule (Friedman, 1969). In many previous models with nominal frictions, optimal inflation rate is larger than the Friedman's rule but still negative (see, for example, Rotemberg and Woodford 1997). However, if nominal wages are downwardly rigid, the monetary authority faces a non-trivial trade-off. Explicit modeling of this trade-off is important because there is currently a discrepancy between economic theory and monetary policy in practice. The former prescribes a zero-to-negative optimal inflation rate while the latter targets low, but strictly positive, inflation rates. In a sense, our quantitative analysis has the flavor of a (friendly) match between two old long-standing views of optimal monetary policy, namely those of James Tobin and Milton Friedman.

The paper is organized as follows: Section 2 presents the model; Section 3 describes the data and method used to estimate the model, reports parameter estimates, and studies aggregate implications of downward nominal wage rigidly; Section 4 computes the optimal inflation rate and derives the optimal responses to shocks under the Ramsey policy that maximizes social welfare; Section 5 computes the optimal inflation target under a strict targeting policy; and Section 6 concludes.

2.   The Model

The economy consists of i) a continuum of infinitely-lived households with differentiated job skills, ii) a continuum of firms that produce differentiated goods using labor as sole input, and iii) a

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government that implements monetary policy using a Taylor-type rule. Households and firms interact in markets with frictions where adjusting nominal wages and prices involves convex and (possibly) asymmetric costs. The model is a monetary version of the one developed in Kim and Ruge-Murcia (2009) and we refer the reader to that article for a more detailed discussion about functional forms and modeling assumptions.

2.1   Households

Household $h \in [0,1]$ maximizes

$$E_s \sum_{t=s}^{\infty} \beta^{t-s} U(c_t^h, n_t^h), \tag{1}$$

where E_s denotes the expectation conditional on information available at time s, $\beta \in (0,1)$ is the discount factor, $U(\cdot)$ is the instantaneous utility function, c_t^h is consumption, and n_t^h is hours worked. Consumption is an aggregate of all differentiated goods available in the economy

$$c_t^h = \left(\int_0^1 (c_{j,t}^h)^{1/\mu} dj \right)^{\mu}, \tag{2}$$

where $\mu > 1$ is a parameter that determines the elasticity of substitution between goods. The price of this consumption bundle is

$$P_t = \left(\int_0^1 (P_{j,t})^{1/(1-\mu)} dj \right)^{1-\mu}, \tag{3}$$

where $P_{j,t}$ is the price of good j. P_t serves as the aggregate price index in our model economy and the gross rate of price inflation is then $\Pi_{t+1} = P_{t+1}/P_t$.

Households choose their nominal wage taking as given the firms' demand for their labor type and face a convex cost whenever they adjust its value. This cost is represented by the function (see Varian, 1974)

$$\Phi_t^h = \Phi(W_t^h/W_{t-1}^h) = \phi \left(\frac{\exp(-\psi \left(W_t^h/W_{t-1}^h - 1 \right)) + \psi \left(W_t^h/W_{t-1}^h - 1 \right) - 1}{\psi^2} \right), \tag{4}$$

where $\phi \geq 0$ and ψ are cost parameters. For the analysis below, it is important to keep in mind two special cases of this function. First, when $\psi \to 0$, (4) becomes a quadratic function. The symmetry of the quadratic form implies that nominal wage increases or decreases of the same magnitude are equally costly. Second, when $\psi > 0$, cutting nominal wages is generally more costly than raising them and so wages are downwardly rigid. These two cases are plotted in Figure 1.

Another special case that is nested in (4) is the "L" shape used by Benigno and Ricci (2008), which corresponds to the situation where $\psi \to \infty$ and implies that wage cuts are infinitely costly while wage increases are costless.

The household's budget constraint is

$$c_t^h(1+f(c_t^h, m_t^h)) + \frac{M_t^h - M_{t-1}^h}{P_t} + \frac{B_t^h - i_{t-1}B_{t-1}^h}{P_t} + \frac{Q_t A_t^h - A_{t-1}^h}{P_t} = \left(\frac{W_t^h n_t^h}{P_t}\right)\left(1 - \Phi_t^h\right) + \frac{T_t^h}{P_t} + \frac{D_t^h}{P_t},$$

where $m_t^h = M_t^h/P_t$ is real money balances, M_t^h is nominal money balances, B_t^h is nominal bonds, i_t is the gross nominal interest rate, A_t^h is complete portfolio of state-contingent securities, Q_t is a vector of prices, T_t^h is a lump-sum transfer, D_t^h is dividends, and $f(c_t^h, m_t^h)$ is a transaction cost function that captures the idea that money facilitates consumption purchases and motivates money demand on the part of households. Since markets are complete, there is no loss of generality in assuming that wage adjustment costs are paid by the household.

For the rest of the paper, we assume the following functional forms for the instantaneous utility and the transaction cost

$$U(c_t^h, n_t^h) = \frac{\left(c_t^h\right)^{1-\eta}}{1-\eta} - n_t^h, \tag{5}$$

$$f(c_t^h, m_t^h) = a\left(\frac{c_t^h}{m_t^h}\right) + b\left(\frac{m_t^h}{c_t^h}\right) - 2\sqrt{ab}, \tag{6}$$

where η, a and b are positive parameters and c_t^h/m_t^h is the consumption velocity of money. The linear representation of the household's disutility of labor is based on the indivisible-labor model due to Hansen (1985). The form of the transaction cost function is due to Schmitt-Grohé and Uribe (2004a) and implies a money demand elasticity with respect to consumption equal to unity.

Utility maximization implies an optimal consumption demand for good j of the form

$$c_{j,t}^h = \left(\frac{P_{j,t}}{P_t}\right)^{-\mu/(\mu-1)} c_t^h, \tag{7}$$

where $\mu/(\mu-1)$ is the elasticity of demand with respect to the relative price of good j. Optimal money demand is implicitly defined by

$$\Lambda_t\left(1 + b - a\left(\frac{c_t^h}{m_t^h}\right)^2\right) = \beta E_t\left(\frac{\Lambda_{t+1}}{\Pi_{t+1}}\right), \tag{8}$$

where Λ_t is the household's marginal utility. The term $b - a(c_t^h/m_t^h)^2$ corresponds to $c_t^h \partial f(c_t^h, m_t^h)/\partial m_t^h$ and would equal to zero if households were satiated with money, as they would be under the Friedman's rule.

2.2 Firms

Firm $j \in [0,1]$ produces a differentiated good using the technology

$$y_{j,t} = x_t n_{j,t}^{1-\alpha}, \tag{9}$$

where $y_{j,t}$ is output of good j, $n_{j,t}$ is labor input, x_t is an aggregate productivity shock, and $\alpha \in (0,1)$ is a constant parameter. The productivity shock follows the process

$$\ln(x_t) = (1-\rho)\ln(x) + \rho \ln(x_{t-1}) + u_t, \tag{10}$$

where $\rho \in (-1,1)$ and u_t is a disturbance term. The disturbance is independently and identically distributed ($i.i.d.$) with mean zero and standard deviation σ_u.

The labor input is an aggregate of differentiated labor supplied by households. The aggregator takes the form

$$n_{j,t} = \left(\int_0^1 (n_{j,t}^h)^{1/\theta} dh \right)^\theta, \tag{11}$$

where $\theta > 1$ is a parameter that determines the elasticity of substitution between labor types. The price of the labor input is

$$W_{j,t} = \left(\int_0^1 (W_t^h)^{1/(1-\theta)} dh \right)^{1-\theta}, \tag{12}$$

where W_t^h is the nominal wage demanded by the supplier of labor type h.

Firms choose their nominal price taking as given the consumption demand for their good and subject to a convex cost for price changes. The real per-unit cost of a price change is

$$\Gamma_t^j = \Gamma(P_{j,t}/P_{j,t-1}) = \gamma \left(\frac{\exp(-\varsigma \left(P_{j,t}/P_{j,t-1} - 1 \right)) + \varsigma \left(P_{j,t}/P_{j,t-1} - 1 \right) - 1}{\varsigma^2} \right), \tag{13}$$

where $P_{j,t}$ is the nominal price of good j at time t, and $\gamma \geq 0$ and ς are cost parameters. For the rest of the analysis, we focus on the case where $\varsigma \to 0$ meaning that price adjustment costs are quadratic, as in Rotemberg (1982).

Firm j maximizes

$$E_s \sum_{t=s}^\infty \beta^{t-s} \left(\frac{\Lambda_t}{\Lambda_s} \right) \left(\frac{D_{j,t}}{P_t} \right),$$

where

$$D_{j,t} = P_{j,t}(1 - \Gamma_t^j)c_{j,t} - \int_0^1 (W_t^h n_t^h) dh \tag{14}$$

is nominal profits, which are transferred to households in the form of dividends. In the definition (14), $c_{j,t}$ denotes the total consumption demand for good j, which is simply the integral over the individual households' demands. That is, $c_{j,t} = \int_0^1 c_{j,t}^h dh$. Profit maximization implies the optimal labor demand schedule

$$n_t^h = \left(\frac{W_t^h}{W_t}\right)^{-\theta/(\theta-1)} n_t, \tag{15}$$

where $\theta/(\theta-1)$ is the elasticity of demand with respect to the relative price of labor of type h.

2.3 Government

The government sets monetary policy using the interest rate rule

$$\ln(i_t/i) = \lambda_1 \log(i_{t-1}/i) + \lambda_2 \log(\Pi_t/\Pi) + \lambda_3 \log(y_t/y) + v_t, \tag{16}$$

where $\lambda_1 \in (0,1)$, λ_2 and λ_3 are constant parameters, variables without time subscript denote steady-state values, and v_t is an *i.i.d.* disturbance with mean zero and standard deviation σ_v.

The government supplies the money balances that households demand at this interest rate using lump-sum transfers or taxes to adjusts the money stock. Hence,

$$\frac{T_t}{P_t} = \frac{M_t - M_{t-1}}{P_t}.$$

where the right-hand side is seigniorage revenue.

2.4 Equilibrium

We focus on a symmetric equilibrium where all households and firms are identical *ex-post* and so Arrow-Debreu securities and bonds are not held by any household. Substituting the government budget constraint and the profits of the (now) representative firm into the budget constraint of the (now) representative household delivers the economy-wide resource constraint

$$c_t(1 + f(c_t, m_t)) = y_t(1 - \Gamma_t) - (W_t n_t/P_t)\Phi_t. \tag{17}$$

This equation shows that price and wage adjustment cost are deadweight losses that reduce the quantity of output available for consumption. Since the losses are minimized when inflation is zero, many models with sticky prices prescribe zero inflation as a criterion for good policy.

3. Solution and Estimation

The model is solved by taking a second-order expansion of the optimality conditions, the resource constraint, and the monetary policy rule, around the model's deterministic steady state.[3] The solution method is explained in detail by Jin and Judd (2002), Schmitt-Grohé and Uribe (2004b), and Kim, Kim, Schaumburg and Sims (2008). The rest of this section explains the issues regarding estimation of the second-order approximate solution.

3.1 Data

The data used to estimate the model are quarterly observations of hours worked, real consumption per capita, real money balances per capita, the price inflation rate, the wage inflation rate, and the nominal interest rate between 1964Q2 to 2006Q2. The raw data were taken from the FRED database available at the Federal Reserve Bank of St. Louis web site (*www.stls.frb.org*). The rates of price and wage inflation are measured by the percentage change in the consumer price index (CPI) and the average hourly earnings for private industries, respectively; real money balances is M2 per capita divided by the CPI; real consumption is personal consumption expenditures per capita divided by the CPI; population is the quarterly average of the mid-month U.S. population estimated by the Bureau of Economic Analysis (BEA); hours worked are measured by the aggregate weekly hours index for total private industries produced by the Bureau of Labor Statistics (BLS); and the nominal interest rate is the effective federal funds rate. The original interest rate series, which is quoted as a net annual rate, was transformed into a gross quarterly rate. Except for the nominal interest rate, all data are seasonally adjusted at the source. All series were logged and linearly detrended prior to the estimation of the model.

3.2 SMM Estimation

The second-order approximate solution of our nonlinear DSGE model is estimated using the Simulated Method of Moments (SMM). Ruge-Murcia (2009) explains in detail the application of SMM to the estimation of higher-order DSGE models and reports Monte-Carlo evidence on their small-sample properties. Intuitively, SMM involves the minimization of the weighted distance between

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[3]Since money is not superneutral in the deterministic steady state, the levels consumption, labor input and real balances must be jointly found from the numerical solution of a system of three nonlinear equations. For the estimation of the model, this approach is computationally demanding because this system must be solved in each iteration of the optimization routine that minimizes the statistical objective function (see Section 3.2). Thus, we follow the simpler approach of solving analytically for steady-state consumption and labor input treating money as superneutral, and then computing the real balances demanded at that level of consumption. The steady state values computed in this manner differ only after the fifth decimal place from those obtained by numerically solving the system of nonlinear equations.

the unconditional moments predicted by the model and those computed from the data, where the former are obtained by means of stochastic simulation. In this application, the weighting matrix is the diagonal of the inverse of the matrix with the long-run variance of the moments, which was computed using the Newey-West estimator. The number of simulated observations is ten times larger than the sample size with innovations drawn from the normal distribution.[4] The dynamic simulations of the nonlinear model are based on the pruned version of the solution, as suggested by Kim, Kim, Schaumburg and Sims (2008). The moments used in the estimation are the six variances, fifteen covariances, and the first- to fourth-order autocovariances of our data series.

We estimate twelve structural parameters. The parameters are those of the price and wage adjustment cost functions (γ, ϕ and ψ), the transaction cost function (a and b), the monetary policy rule (λ_1, λ_2, λ_3 and σ_v), the productivity shock process (ρ and σ_u), and the consumption curvature in the utility function (η). Additional information is used to fix the values of four parameters to economically plausible numbers during the estimation routine. These parameters are the curvature of the production function, the discount factor, and the elasticities of substitution between goods and between labor types (μ and θ, respectively). Data from the U.S. National Income and Product Accounts (NIPA) shows that the share of labor in total income is approximately 2/3 and, hence, a plausible value for α is 1/3. The discount rate is set to 0.997, which is the inverse the average gross real interest rate during the sample period. Finally, the elasticities of substitution between goods and between labor types are fixed to $\mu = 1.1$ and $\theta = 1.4$, respectively, which are standard values in the literature.

In addition to the model with asymmetric wage adjustment costs, we also estimate the restricted model with quadratic costs that corresponds to the case where $\psi = 0$. The restricted model provides a useful benchmark to evaluate the implications of downward nominal wage rigidity.

3.3 Parameter Estimates

SMM estimates of the model parameters are reported in the first column of Table 1. The size of relative risk aversion in consumption is $\eta = 1.746$ (0.401). (The number in parenthesis is the standard error.) This estimate is larger than, but not statistically different from, unity that corresponds to the case of logarithmic preferences. Estimates of the transaction cost function are $a = 0.009$ and $b = 0.133$, which are similar to the values 0.011 and 0.075 as reported by Schmitt-Grohé and Uribe (2004a). This result is interesting because the estimation approaches followed

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[4]We use an antithetic accelerator in the simulation of the artificial data. The idea is to increase the efficiency of the finite sample estimator of the moments by using (antithetic) variates that are deliberately induced to have a negative correlation. In practice, this means that the simulated sample consists of two subsamples of equal length: one based on a given draw of random innovations and another based on the negative values of the same draw. This strategy delivers the smallest possible correlation of -1 (see, Ripley, 1987).

in these two papers are rather different: We structurally estimate a full nonlinear DGSE model, while Schmitt-Grohé and Uribe compute their estimates from a reduced-form ordinary least squares (OLS) regression of consumption velocity on a constant and the nominal interest rate.

Both prices and wages are rigid in the sense that the null hypotheses $\gamma = 0$ and $\phi = 0$ can be rejected at the one percent significance level.[5] The wage asymmetry parameter is $\psi = 7146.3$ (1840.4), which is positive and statistically different from zero.[6] Based on this result, we conclude that nominal wages are downwardly rigid. This finding is important because, as we will show below, downward wage rigidity modifies previous conclusions regarding the relative importance of price *versus* wage rigidity, the effects of monetary policy shocks, and the optimal rate of inflation.

Consider the restricted version of our model where $\psi = 0$ so that adjustment costs are quadratic and, hence, symmetric. Parameter estimates for this model are reported in the second column of Table 1. In this case, ϕ (γ) fully captures the degree of nominal wage (price) rigidity. Since ϕ is much larger than γ (711.3 and 42.0, respectively), one is tempted to conclude that wages are generally more rigid than prices. In contrast, in the model with asymmetric adjustment costs, nominal rigidity depends on the asymmetry parameter as well. Since ϕ is quantitatively close to γ but the wage asymmetry parameter is positive and large, we conclude instead that prices and wages are similarly upwardly rigid but that wages are more downwardly rigid than prices. This is more that a semantic refinement because, as we will show below, the effects of monetary shocks are very different in the models with quadratic and asymmetric adjustment costs.

Finally, the coefficients of the Taylor-type rule are in line with previous estimates reported elsewhere in the literature (for example, Taylor, 1999, and the references therein).

3.4 Impulse Responses

We now study the implications of downward nominal wage rigidity for the economy's response to a monetary policy shock.[7] Since the responses of nonlinear dynamic systems typically depend on the sign, size and timing of the shock (see Gallant, Rossi and Tauchen, 1993, and Koop, Pesaran and Potter, 1996), our experiments involve shocks of different signs and sizes. More precisely, we consider innovations to the interest rate rule of $+2$, $+1$, -1 and -2 standard deviations. A positive shock leads to an increase in the nominal interest rate and is therefore contractionary,

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[5]Since the null lays at the boundary of the parameter space, the distribution of the t statistic is not standard (see, Andrews, 2001). Hence, this result needs to be interpreted with caution and is best taken as indicative only.

[6]Though bigger, this estimate is not statistically different from 3844.4 as reported in our previous work (Kim and Ruge-Murcia, 2009). In particular, our previous estimate is contained in the ninety-five percent confidence interval around the estimate reported in this paper.

[7]In preliminary work, we also examined the effects of productivity shocks. These results are not reported here in order to save space, but they are available from the corresponding author upon request.

while a negative shock is expansionary. In all cases, we assume that a shock take place when the system is at its stochastic steady state. That is, when all variables are equal to their unconditional mean.

Figure 2 plots the responses of consumption, output, price inflation, wage inflation, real wage, nominal interest, real interest, and real money balances in the economy where wages are downwardly rigid. In all panels, the stochastic steady state is represented by the horizontal line, and the vertical axis is the percentage deviation of each variable from its deterministic steady state. Hence, the distance between this horizontal line and zero reflects the model's departure from certainty equivalence. For instance, uncertainty induces lower average levels of consumption and output than the deterministic steady state as a result of the precautionary savings motive on the part of households. In the figure, the rates of price inflation, wage inflation, nominal interest and real interest are annualized.

The most obvious observation in Figure 2 is that, when wages are downwardly rigid, the effects of monetary policy shocks are asymmetric. For example, a contractionary shock produces a quantitatively larger and more persistent movement in consumption and output than an expansionary shock of the same magnitude. Starting at the unconditional mean, the contractionary shock of size +2 standard deviations yields an initial decrease of 1.73 percent in consumption and 0.85 percent in output, while the expansionary shock of size −2 yields increases of 1.03 and 0.53, respectively. Also, the quantitative effects of the larger shock (say +2 standard deviations) are more than twice those of the smaller one (that is, +1 standard deviation). The finding that contractionary monetary policy shocks produce larger real effects than expansionary ones is line with evidence reported by Cover (1992). Cover performs OLS regressions of output on a constant, measures of positive and negative money supply shocks, and other controls, and he finds that contractionary shocks have a larger effect on output than expansionary shocks. Furthermore, he rejects the hypothesis that contractionary and expansionary shocks induce output changes of the same magnitude.

Monetary shocks also have an asymmetric effect on price and wage inflation. The contractionary shock of size +2 induces an initial decrease of 0.37 percent in price inflation, while the expansionary shock of the same magnitude induces an initial increase of 1.26 percent. The economy returns to the stochastic steady state faster in the former than in the latter case. Since price rigidity is symmetric, the asymmetric response of price inflation is entirely due to the downward rigidity of nominal wages through general equilibrium effects. Also, in this case, the quantitative effects of the large negative shock are more than twice those of the smaller one, but the converse is true for positive shocks.

The asymmetry is especially pronounced in the case of wage inflation. In all experiments, a

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monetary shock delivers an increases in wage inflation. Positive shocks induce larger responses than negative shocks of the same magnitude, and feature almost no overshooting. These responses on the part of price and wage inflation imply that real wages rise after a monetary shock regardless of whether the shock is expansionary or contractionary.[8] In this sense, real wages are downwardly rigid with respect to monetary policy shocks. The fact that the real wage may rise following an expansionary monetary shock moderates the expected increase in output and consumption and explains the asymmetric effect of monetary shocks on these two variables.

Finally, there is also asymmetry in the responses of the nominal interest rate, the real interest rate, and the real balance. For example, in the case of the real interest rate, contractionary shocks produce generally smaller responses than expansionary shocks of the same magnitude, with the former generally more persistent than the latter.

It is useful to compare these responses with the ones implied by the model with the quadratic adjustment costs. These responses are plotted in Figure 3 and show that an expansionary shock induces an increase in consumption, output, price inflation, wage inflation and real money balances and a decrease in the real wage and the rates of real and nominal interest. The contractionary shock induces the converse effects. Responses are approximately symmetric meaning that positive and negative monetary shocks generate dynamics that are almost mirror images of each other. Comparing Figures 2 and 3 shows substantial differences in the magnitude and persistence of responses for most variables. In particular, there are large quantitative and qualitative differences in the responses of wage inflation and the real wage. The response of wage inflation to either an expansionary or a contractionary shock are relatively small under the quadratic model as a result of the large estimate of the wage rigidity parameter. Instead, under the asymmetric model, the response to an expansionary shock is very large, while the response to a contractionary shock is relatively muted as a result of downward nominal wage rigidity. The responses of the real wage are also very different under both models, especially for expansionary monetary policy shocks.

4. Optimal Monetary Policy

In this section, we study optimal policy in a monetary economy where wages are downwardly rigid. In particular, we consider the problem of a government that follows the Ramsey policy of maximizing the representative household's welfare subject to the aggregate resource constraint and the optimality conditions for firms and households. The government is assumed to use the same discount factor as households in evaluating future utilities and to credibly commit to implementing

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[8]This result, however, is not general. For small contractionary shocks, say of size 0.5 standard deviations, wage inflation and the real wage fall a little and approach their steady state from below.

the optimal policy. We again approximate the model to the second order, and the resulting decision rules are used to compute the optimal average inflation rate and the optimal responses to productivity shocks.

4.1 Optimal Inflation Target

The optimal average rate of gross inflation is defined as the level at the stochastic steady state under the Ramsey policy. Recall that, by definition, the unconditional mean of all variables is their stochastic steady state. We compute these means from the decision rules using the parameter values reported in the left column of Table 1. Results indicate that mean gross inflation is 1.0040, meaning that optimal net inflation is 0.40 percent per year. In contrast to earlier literature on optimal monetary policy,[9] the optimal (net) inflation rate is positive. That is, for an economy with downwardly rigid wages, the benefits of positive inflation conjectured by Tobin (1972) overcome Friedman's (1969) general prescription of negative inflation. As in the cashless economy in Kim and Ruge-Murcia (2009), this result is driven by prudence: The Ramsey planner prefers to incur the systematic, but small, price and wage adjustment costs associated with positive inflation rate rather than taking the chance of having to pay the large adjustment costs required to implement nominal wage decreases. However, in contrast to Kim and Ruge-Murcia (2009), this is so even after taking into account the benefits of negative inflation as pointed out by Friedman.

We now examine how the optimal inflation rate varies with the volatility of the productivity shock. Figure 4 plots optimal inflation as a function of the standard deviation of the productivity innovation. The range of the standard deviation is [0, 0.025]. Notice that when there is no uncertainty, meaning that $\sigma_u = 0$, optimal inflation is 0.9994. Thus, without a precautionary motive, optimal inflation falls between Friedman's rule and zero. As volatility increases, optimal inflation increases in σ_u. The relation is quadratic because the decision rules are linear in the conditional variance of productivity and, hence, quadratic in its standard deviation. The value for optimal average inflation reported above, namely 1.0040, corresponds to the SMM estimate of σ_u at 0.011.

Finally, it is interesting to compute optimal grease inflation for this monetary economy. Following Kim and Ruge-Murcia (2009), we measure optimal grease inflation as the extra amount of inflation implied by asymmetric costs compared with symmetric costs. As we reported above, for the case where $\psi = 7146.3$ and wages are, therefore, downwardly rigid, optimal inflation is 1.0040. For the where $\psi = 0$ and wage adjustment costs are quadratic, optimal inflation is 0.9989. Notice

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[9]See, for example, Rotemberg and Woodford (1997), Chari and Kehoe (1999), Teles (2003), Khan, King and Wolman (2003), Kim and Henderson (2005), and Schmitt-Grohe and Uribe (2006).

that in this case we recover the result reported in earlier literature. That is, in a monetary economy with sticky prices and wages, optimal (net) inflation lies between Friedman's rule and zero. Optimal grease inflation is simply $1.0040 - 0.9989 = 0.0051$, that is 0.51 percent per year. This value is roughly similar to the one of 0.35 reported in our previous work. This result implies that the amount of grease inflation originally computed in Kim and Ruge-Murcia (2009) for a cashless economy is robust to modeling money as a medium of exchange.

4.2 Optimal Responses

The optimal responses to a productivity shock are reported in Figure 5. Following a positive productivity shock, consumption and output increase before returning to their stochastic steady state. An exogenous productivity increase permits a larger output with the same inputs and this creates a wealth effect that allows consumption to rise today and in the future. A negative productivity shock has the converse effects. There is some asymmetry between positive and negative shocks, with the latter inducing larger adjustments than the former.

Positive (negative) shocks induce an initial decrease (increase) in price inflation. There is some asymmetry with respect to the shock size and the dynamics involve inflation overshooting its long-run value. The real wage increases following a positive shock and decreases following a negative one, with the responses proportionally larger in the former case. In this sense, real wages are downwardly rigid with respect to productivity shocks under the optimal policy.

There is considerable asymmetry in the responses of wage inflation, the nominal and real interest rates and real money balances to productivity shocks. In the case of wage inflation, all shocks induce an increase in wage inflation. In particular, following a negative productivity shock and in order to avoid incurring the large costs associated with nominal wage cuts, the Ramsey policy involves wage increases throughout and instead the decrease in the real wage is implemented *via* an increase in the price level. This result illustrates Tobin's proposition that a positive rate of price inflation may be socially beneficial in an economy with downwardly rigid wages.

Real money balances decrease (increase) after negative (positive) shocks. Responses are asymmetric in that the effects of a negative shock are larger than those of a positive shock of the same magnitude. Since, by construction, the money stock is held fixed in this experiment, this asymmetry is due to the asymmetric responses to productivity shocks on the part of consumption and the price level.

The optimal policy involves an increase in the nominal interest rate after a negative technology shock and a decrease after a positive shock. The initial responses of the real interest rate are the opposite: The real interest rate falls after a negative shock and rises after a positive one. However,

after the second period the real interest rate responses are reversed and, therefore, equivalent to those of the nominal rate. Note that responses are asymmetric. For example, the shock of size -2 induces an increase in nominal rate of 1.21 percent while the positive shock of the same size induces a decrease of 0.58. The very asymmetric response in the nominal interest rate under the optimal policy allows a smoother, less asymmetric response on the part of consumption, output and real balances to productivity shocks.[10]

5.   Optimized Simple Policy

In order to study the normative implications of downward nominal wage rigidity under a policy more realistic than the unconstrained Ramsey optimal policy, we now compute the inflation rate that delivers the highest (unconditional) welfare when the monetary authority follows a simple policy rule that strictly hits an inflation target regardless the state of the economy. Figure 6 plots unconditional welfare, expressed in consumption equivalents, for different values of the target. The benchmark policy is Friedman's rule, whereby the target is the discount rate, that is, $(0.997)^4 = 0.9881$ at the annual rate. Notice in Figure 6 that a policy that targets deflation (that is, a gross inflation rate less than 1) or strict price stability (that is, a gross inflation rate equal to 1), deliver a welfare loss compared with Friedman's rule. On the other hand, targeting gross inflation rates a bit larger than 1 (that is, positive rates of net inflation) lead to significant welfare gains compared with Friedman's rule. The optimal inflation target is 1.007, that is, 0.7 percent per year and involves a welfare increase of 0.276 percent of consumption. This target is about twice as large as that of the Ramsey policy. The reason is that positive inflation in a model with downward wage rigidity is driven by prudence. With limited knowledge and less flexibility with respect to shocks, the inflation targeting government needs a larger buffer above zero inflation to eschew paying the costs associated with nominal wage cuts. Inflation targets larger than the optimal one are still superior to Friedman's rule and, since welfare decreases very slowly as the inflation target rises, they are only minimally less desirable. Thus, in a monetary economy with downwardly rigid prices, a central banker should target a low, but strictly positive, inflation rate.

6.   Conclusion

This paper characterizes the positive and normative implications of downward nominal wage rigidity for the conduct of monetary policy. The analysis is carried out using a simple DSGE model where

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[10]Optimal asymmetric responses are also reported by Carlsson and Westermark (2008) and Kim and Ruge-Murcia (2009) for more restrictive cashless economies. Our result here show that the asymmetries survive the inclusion of an additional asset (money) that serves not only as a unit of account but can be used as a medium of exchange.

money serves a medium of exchange and the cost of nominal wage changes may depend on both sign and magnitude of the adjustment. The second-order approximation of the model is estimated using quarterly aggregate U.S. data. The macro data supports the notion of downward nominal wage rigidity in that the wage asymmetry parameter is larger than, and statistically different from, zero.

From the positive perspective, results show that monetary policy shocks have asymmetric effects that are in line with empirical evidence (see Cover, 1992). For example, contractionary shocks induce larger changes in output and consumption than expansionary shocks of the same magnitude.

From the normative perspective, the Ramsey policy that maximizes social welfare involves an average inflation rate of about 0.4 percent per year. Hence, for an economy with downwardly rigid wages, the benefits of positive inflation conjectured by Tobin (1972) may overcome Friedman's (1969) general prescription of negative inflation. In the more realistic case of a central banker that follows a simple targeting policy, the optimal inflation target is about 0.7 percent per year. Since welfare decreases slowly as inflation rises beyond the optimal target, actual inflation ranges like one used in Canada from 1 to 3 percent deliver higher welfare than Friedman's rule and strict price stability (*i.e.*, a net inflation rate equal to zero). We view this result as providing support for the low, but strictly positive, inflation targets used in many countries.

Table 1. SMM Estimates

Description	Symbol	Wage Adjustment Costs	
		Asymmetric	Quadratic
Consumption curvature	η	1.746*	1.292*
		(0.401)	(0.388)
Parameter of transaction function	a	0.009	0.008
		(0.121)	(0.097)
Parameter of transaction function	b	0.133*	0.147*
		(0.022)	(0.027)
Wage adjustment cost	ϕ	215.9*	711.3*
		(39.5)	(168.6)
Price adjustment cost	γ	77.5*	42.0*
		(18.4)	(23.4)
Wage asymmetry	ψ	7146.3*	0
		(1840.4)	
Interest-rate smoothing	λ_1	0.986*	0.986†
		(0.274)	(0.514)
Inflation coefficient in policy rule	λ_2	0.717†	1.286
		(0.368)	(1.008)
Output coefficient in policy rule	λ_3	0.058	0.126
		(0.074)	(0.172)
Standard deviation	σ_v	0.0025*	0.0034*
		(0.0004)	(0.0004)
AR coefficient of productivity	ρ	0.956*	0.971*
		(0.009)	(0.009)
Standard deviation	σ_u	0.0135*	0.0111*
		(0.0016)	(0.0021)

Notes: The figures in parenthesis are standard errors. The superscripts $*$ and $\dagger$ denote statistical significance at the five and ten percent level, respectively.

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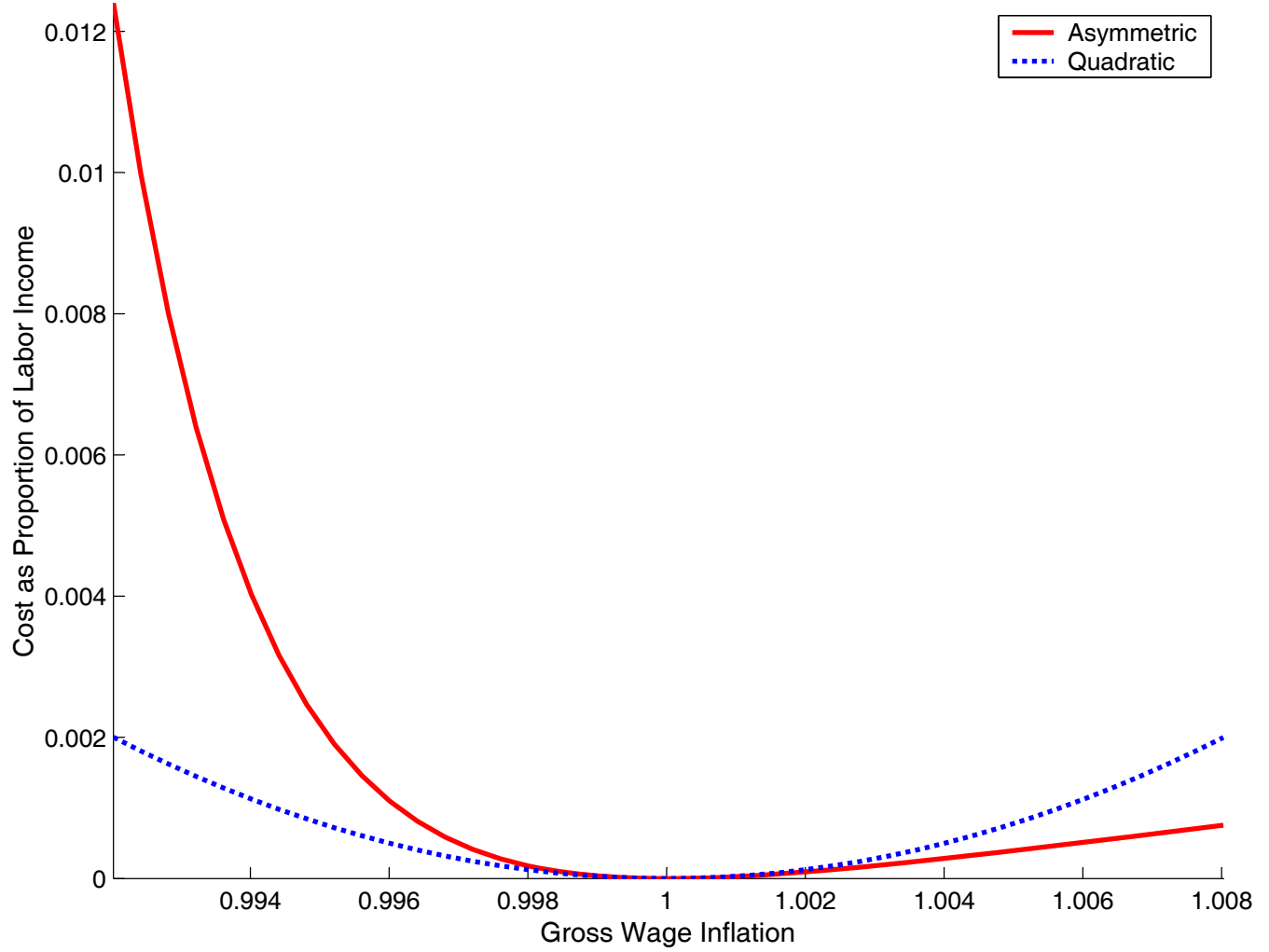
Figure 1: Adjustment Cost Functions

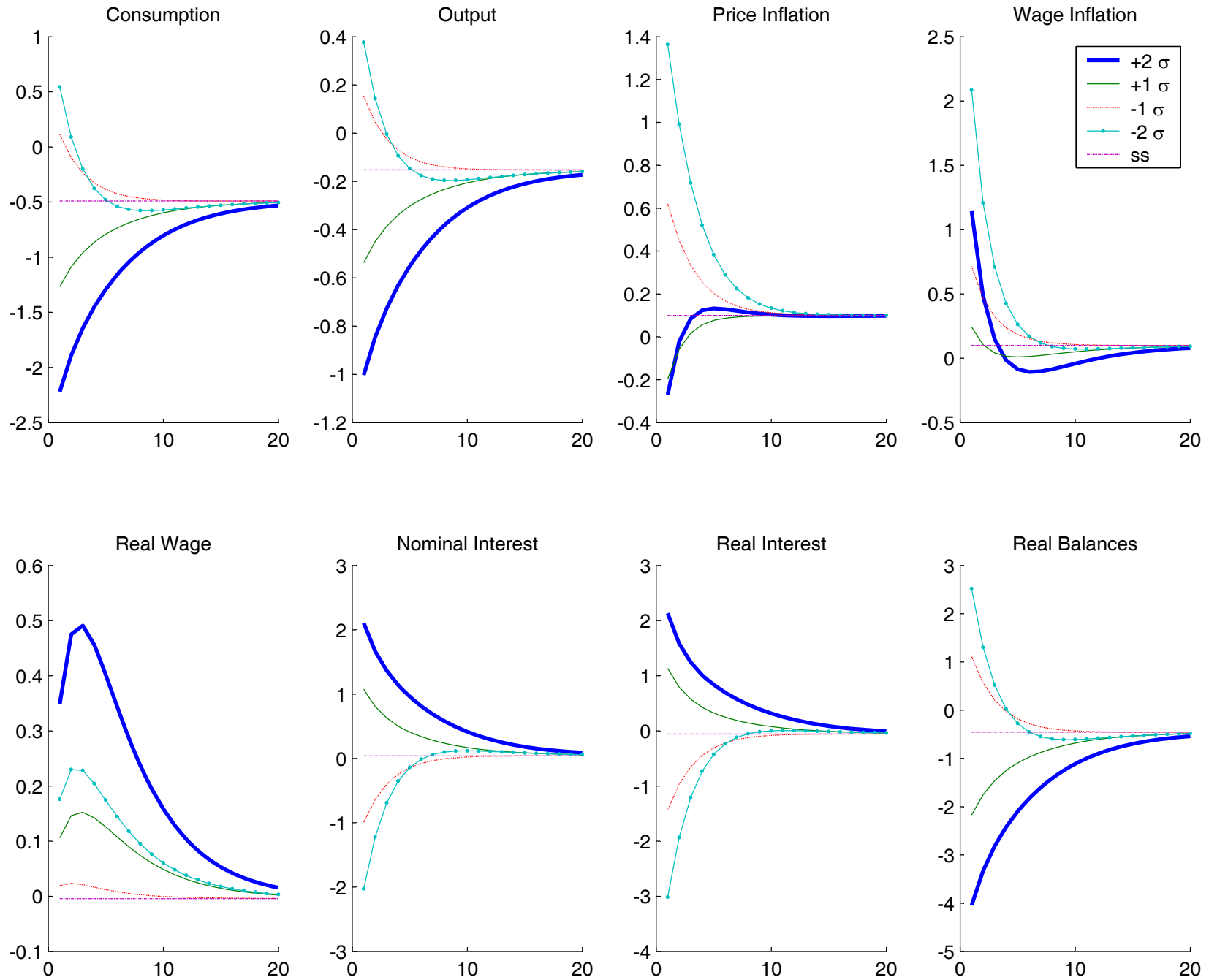Figure 2: Responses to Monetary Policy Shocks. Asymmetric Costs

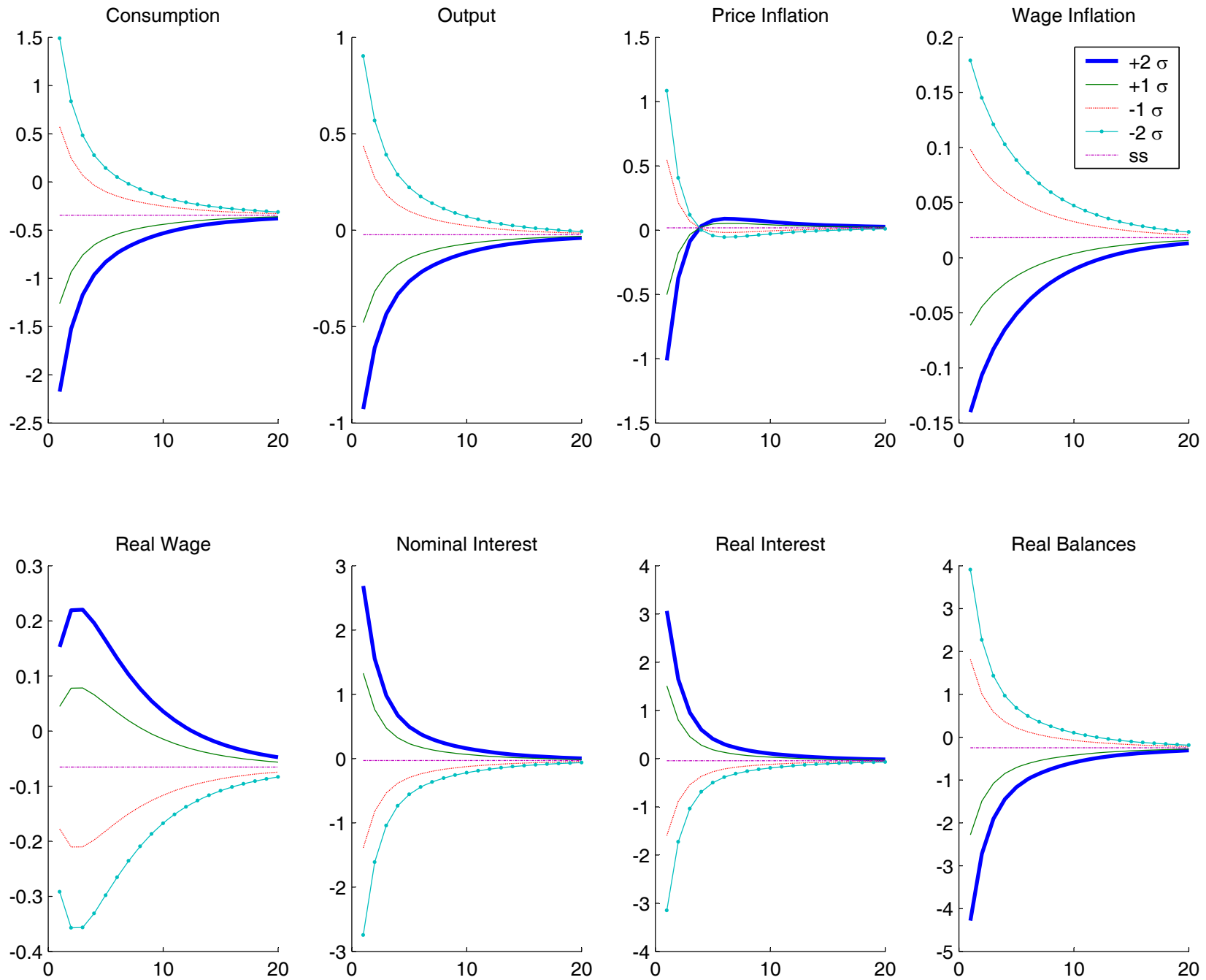Figure 3: Responses to Monetary Policy Shocks. Quadratic Costs
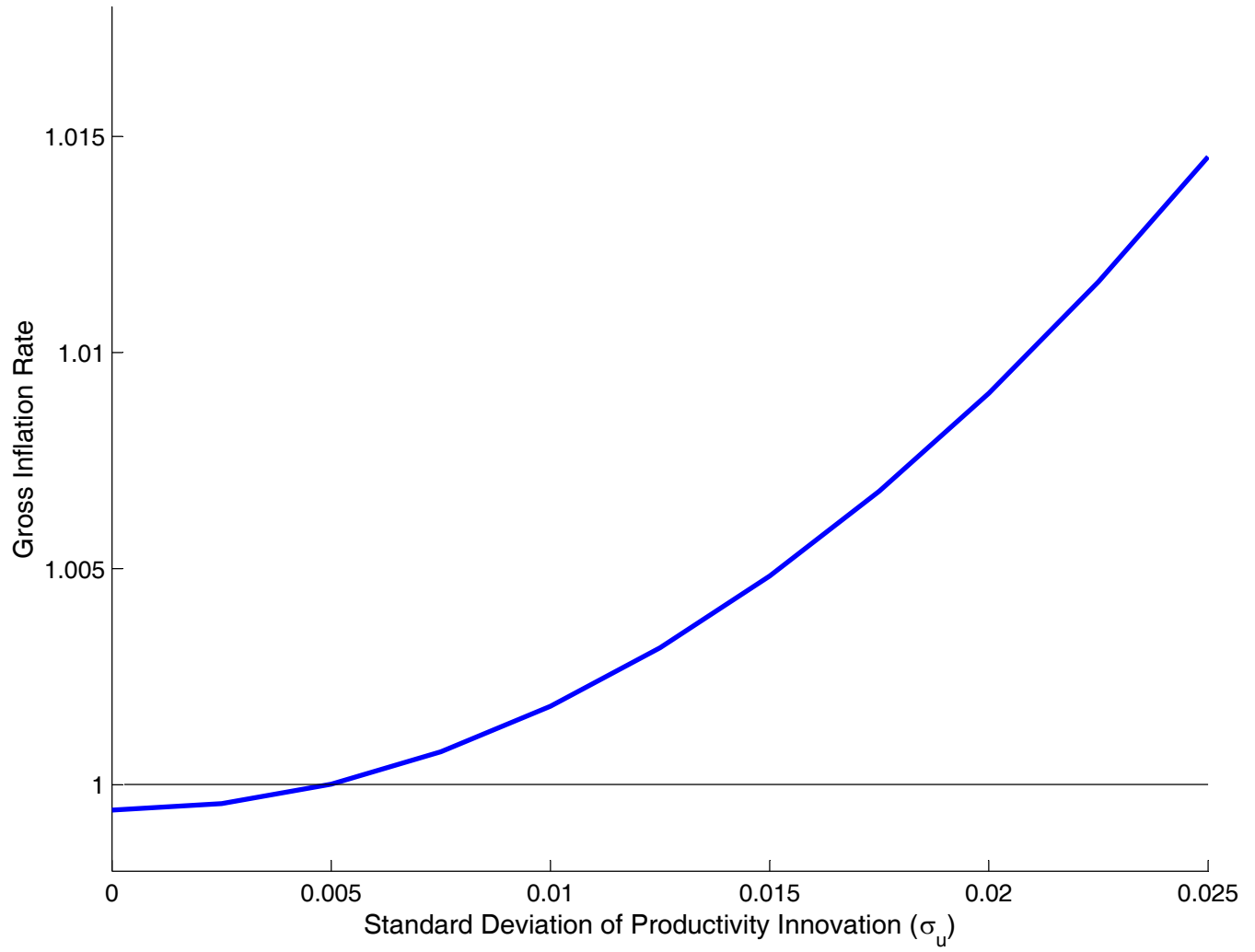
Figure 4: Optimal Inflation and Volatility

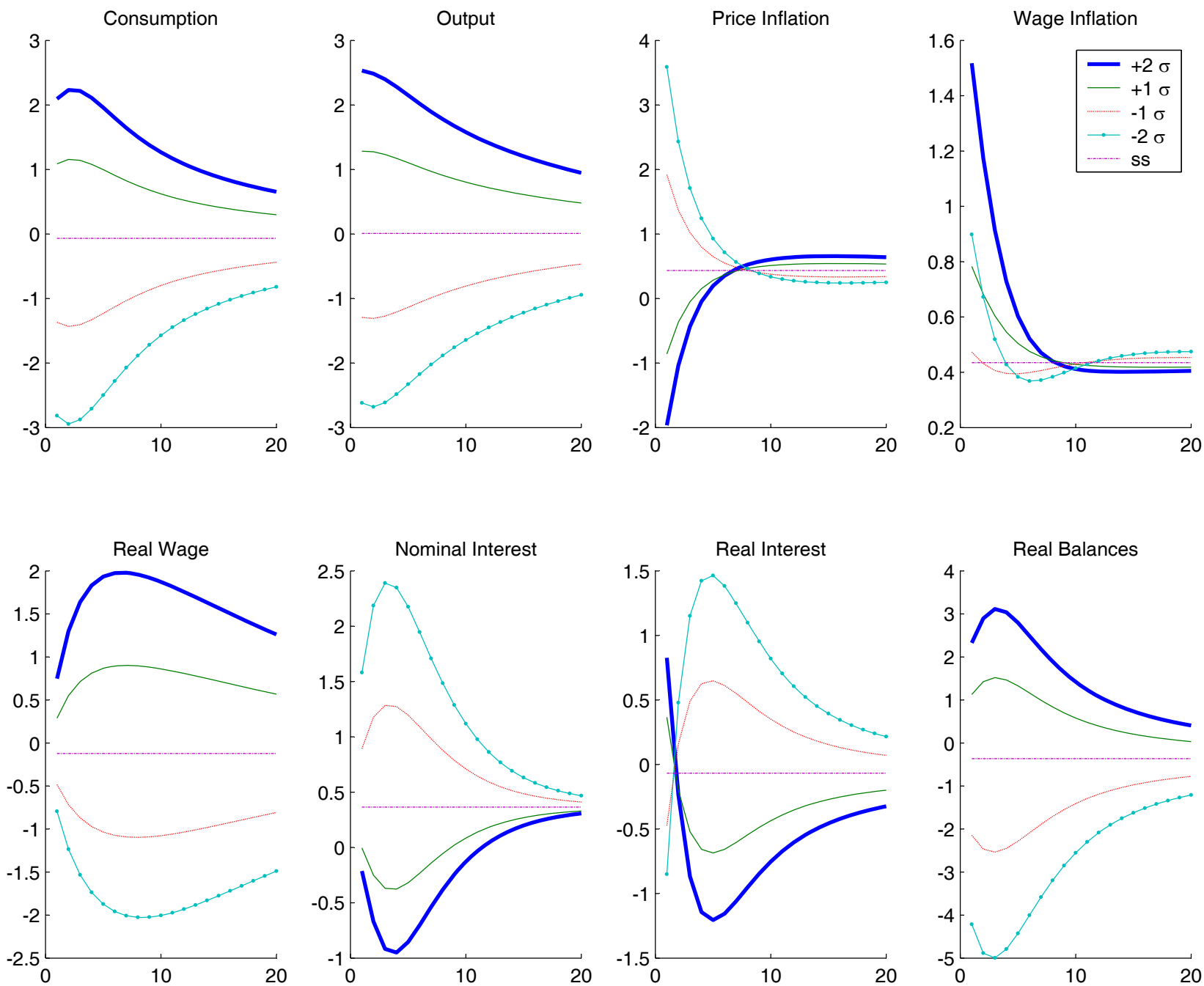# Figure 5: Optimal Responses to Productivity Shocks. Asymmetric Cotst

Figure 6: Welfare