What Explains the Varying Monetary Response to Technology Shocks in G-7 Countries?*

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Abstract

In a recent paper, Gali, Lopez-Salido, and Valles (2003) examined the Federal Reserve's response to VAR-identified technology shocks. They found that during the Martin-Burns-Miller era, the Fed responded to technology shocks by overstabilizing output, while in the Volcker-Greenspan era, the Fed adopted an inflation -argeting rule. We extend their analysis to countries of the G-7; moreover, we consider the factors that may contribute to differing monetary responses across countries. Specifically, we find a relationship between the volatility of capital investment, type of monetary policy rule, the responsiveness of the rule to output and inflation fluctuations, and the response to technology shocks. [JEL: C32, E2, E52]

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1 Introduction

A number of studies employ structural vector autoregressions (SVARs) to determine the roles of monetary policy shocks in generating cyclical fluctuations in the United States (e.g., Christiano, Eichenbaum, and Evans, 1999, and many others). Using both long- and short-run identifying restrictions, various authors have explored the empirical response of the economy to exogenous monetary innovations. While the majority of the studies of monetary policy have focused on the effect of exogenous money growth or interest rate shocks, recent research has begun to investigate the effect of endogenous monetary policy – that is, the central bank's reaction to non-monetary shocks. Many of these papers expand on the notion of a monetary policy rule introduced by Taylor (1993). Taylor conjectured that the central bank responds to fluctuations in inflation from a target and output from potential. Unfortunately, the vast majority of the empirical studies investigating the monetary policy rules are decidedly divorced from consideration of the forces driving these fluctuations.

One exogenous shock that many economists believe contributes to the business cycle fluctuations that feed into the Taylor rule is the *technology shock*.[1] In an effort to identify the empirical effects of technology shocks, Gali (1999) estimated two models: a bivariate model of productivity and hours and a five-variable model adding money, inflation, and interest rates. His identification estimates a decomposition of productivity and hours into innovations to technology and non-technology components by assuming that only the former can have long-run effects on labor productivity.[2,3]

[1] We will at times refer to the technology shock as a productivity – or more specifically, a labor productivity – shock.

[2] Both models produced results that seemed contradict the technology-driven real business cycle hypothesis; specifically, hours fell in response to a positive technology shock (i.e., a shock that raises labor productivity). Gali, therefore, concluded that technology shocks were not the driving force behind macroeconomic fluctuations and that his non-technology shocks better explained the cyclical movements in the data.

[3] Basu, Fernald, and Kimball (1998) reached similar conclusions using alternative methods to identify technology. They regressed the growth rate of output on the growth rate of inputs at a disaggregated level with proxies for capacity utilization. Francis and Ramey (2002, 2003) further confirmed the conculsions of Gali by examining the exogeneity and pre-War technology shocks, respectively. Christiano, Eichenbaum, and Viggfusson (2003) offered an alternative view, arguing against entering hours into the VAR in differences. Francis and Ramey (2003), however, find that labor entered in levels implies a series of implausibly (sizeable) positive technology shocks during the Great Depression and the technology shocks so identified are Granger-caused by government

Empirical identification of the technology shock was a key first step in developing a unified reduced-form framework with which to examine the role that monetary policy has played in smoothing economic fluctuations.[4] Along these lines, Gali (2002) and Gali, Lopez-Salido, and Valles (2003 – henceforth GLV) examined the endogenous response of monetary policy to identified technology shocks in the United States. GLV examine a four-variable structural VAR for the United States with labor productivity, labor hours, the real interest rate, and inflation. Using the Gali (1999) identification, they find that during the Volcker-Greenspan (VG) era the Fed's response to the technology shock is to raise the nominal interest rate, while during the Martin-Burns-Miller (MBM) era the Fed lowers the nominal rate. Moreover, they find that the inflation and hours responses in the two periods differ in sign.[5]

Our goal is to expand the scope of GLV to an international context to determine whether the effect of technology shocks is consistent across the major industrialized countries. In particular, we are interested in how the different central banks respond to technology shocks. We investigate the possibility that technology shocks in different countries produce fundamentally different inflation and employment responses and to what extent those effects alter the monetary response.

The remainder of the paper is organized as follows: Section 2 discusses the data we use for empirical investigation and outlines the econometric technique and the identification procedure. Section 3 reviews the econometric results. In particular, we analyze the responses to the identified technology shocks across countries and group the countries into three subgroups. Section 4 presents a model based on King and Wolman (1996) that provides a theoretical foundation for discussion of the empirical response of monetary policy to innovations in labor productivity. Section 5 offers a number of parameterizations of the theoretical model that highlight potential causes for variations in responses. Our goal will be to map the theoretical responses generated

spending, money, and prices.

[4] A number of papers have explored the role for monetary policy in a theoretical framework (see Rotemberg and Woodford, 1999, and King and Wolman, 1999).

[5] They find that during the BM era, hours and inflation fall persistently. On the other hand, during the VG era, hours rise after a short decline and inflation is virtually unchanged. They conclude that the empirical responses for the VG era match theoretical responses obtained from an inflation targeting rule. They further conclude that there exists evidence against the use of a money money targeting rule during the BM era.

from the model simulations to the empirical responses observed in the data. In section 6, we consider the merit of these theoretical explanations by offering some further empirical evidence. Section 7 offers concluding remarks.

2 Econometric Framework

To attribute cross-country differences to features of a theoretical model, we find it prudent to first present the empirical findings. We employ the method of Gali (1999) to identify the technology shocks. We discuss the specification and the results of the estimation below. We characterize three different country-subgroups to facilitate discussion.

2.1 Data

We estimate a four-variable vector autoregression. The data used in the model are a short-term nominal interest rate (either the 3-month T-bill rate or the short term money market rate) and the logarithms of real per capita GDP, the GDP deflator, and the employment index for the G-7 countries. We construct a labor productivity series by taking the difference between *log(real per capita GDP)* and *log(employment index)*.[6] The frequency of the data are quarterly. Unit root tests were conducted for all variables. The null hypothesis of no unit root was rejected for all countries' labor productivity series save Germany. Summary statistics for the variables used and results of the unit root tests are included in Table 1.

Table 1 about here

For the United States, there is significant evidence of a change in Federal Reserve policy during the Volcker disinflation.[7] In addition, the remainder of the countries in our sample

[6] Output does not enter explicitly into the model. Instead it can be imputed from the labor productivity and labor index responses. Similarly, the model is estimated with the real interest rate and the nominal interest rate response is imputed.

[7] The policy break literature is too vast for a comprehensive survey here. We direct the reader to two papers. Clarida, Gali, and Gertler (2000) provide evidence that the weight on inflation in the Fed's objective function

exhibit evidence of structural instability over the full sample. In order to ascertain a stable sample for analysis, we conduct Lagrange Multiplier tests for each country to determine the timing and significance of a single structural break in the coefficient matrix of the VAR.[8] The results of the structural break tests, including the break date, are included in Table 1. In most cases (the U.S. and U.K. are exceptions), data limitations force us to constrain estimation of post-break subsamples in circumstances in which breaks are significant. The break date for most countries occurs in the early 1970s. The dates correspond to a series of oil shocks (see Hamilton, 1983) and the break up of the Bretton Woods system. France is an exception. For the U.K. and the U.S., we follow GLV and estimate separately the pre- and post-Volcker disinflation samples.[9]

2.2 Identification

In order to evaluate the effects of technology shocks and the subsequent monetary responses, we specify a model in which we simultaneously identify both technology and monetary shocks. We specify a structural VAR with restrictions on both the contemporaneous and long-run impacts of monetary and technology shocks. Consider the MA representation of a four-variable structural VAR:

$$Y_t = C(L)\varepsilon_t, \tag{1}$$

where

was significantly different during VG than during BM. Boivin and Giannoni (2002) argue that the Fed's inflation target declined in the VG period.

[8] We acknowledge that a single structral break as an alternative hypothesis is limiting. Data availability for the G-7 countries, however, prevents us from estimating a more general model that we leave for future research.

[9] A number of studies of U.K. monetary history suggest a similarity between the U.S. and U.K. break dates (we refer the reader to Nelson and Nikolov (2002) for a study examining the policies of the Bank of England during the 1970s and 80s.). Our initial tests identified a break date of 1974:1, which we found was attributable to mandated reductions in employment in response to energy shocks. We, therefore, include a dummy variable for that quarter.

$$Y_t = \begin{bmatrix} \Delta x_t \\ \Delta n_t \\ \Delta p_t \\ r_t - \Delta p_t \end{bmatrix} \quad \text{and} \quad \varepsilon = \begin{bmatrix} \varepsilon^x \\ \varepsilon^n \\ \varepsilon^p \\ \varepsilon^r \end{bmatrix}.$$

$C(L)$ is a polynomial matrix in the lag operator, x_t denotes the log of labor productivity, n_t is the the log of employment index, p_t is the the log of GDP deflator, and r_t is the three-month treasury bill rate.[10] We use four quarterly lags of each of the variables in the VARs. As per Table 1, we tested and failed to reject unit roots for productivity, employment, and prices; therefore, these variables enter the VAR in first differences.[11] Inflation and the real interest rate enter the VAR in annualized rates.[12]

The long-run restrictions that identify the technology shock, ε^x, imply $C^{1j}(1) = 0$, $j > 1$, restricting the unit root in productivity to originate solely from the technology shock. In addition, we impose short-run exclusion restrictions that allow us to identify the monetary shock, ε^r.[13] This shock is identified from a contemporaneous impact matrix which imposes a Cholesky ordering on the model variables. The assumptions identifying monetary innovation is that it does not have contemporaneous effects and that the monetary authority takes all other variables in the VAR into consideration when setting policy.[14]

[10] The treasury bill rate is assumed to respresent the monetary policy instrument. We use the T-bill rate as it is the only short term interest rate common to all countries. Results using the T-bill rate were found to be consistent with those replacing the T-bill with the federal funds rate for U.S. data.

[11] The exception here is Germany's employment series, which is entered in detrended levels.

[12] We also considered a seven-variable VECM that included consumption, investment and velocity. Results for the four variables of interest were unchanged.

[13] Note we can potentially identify all the shocks in the system since the C(0) matrix is fully recursive.

[14] The model as it stands is overidentified. A just identified model would require 6 additional identifying assumptions. Our specification delivers 9 such restrictions, 3 from the long run assumptions and 6 from the $C(0)$ matrix. We experimented with relaxing some of these restrictions and allow more coefficients in $C(0)$ to be free parameters. Our results remained robust across these alterations.

3 Empirical Results

Based on the identifying assumptions outlined in the previous section, we could potentially generate impulse responses to both technology and monetary shocks in the four-variable model. However, we concentrate our efforts on the responses to technology shocks and the responses of monetary instruments to such shocks.[15] We note here that productivity and, hence, output for each country respond as expected yielding permanent increases in each variable.[16]

Figure 1 about here

To ease comparison of the results across studies, we first present the response to a one standard deviation technology shock for the post-Volcker–disinflation United States in Figure 1. The estimated technology shock induces a short, statistically-significant decline in employment. After a few quarters, employment rises persistently. Moreover, the technology shock is deflationary, leading to a two-year period in which prices permanently decline. Although the shock is deflationary, the Fed increases the nominal interest rate leading to a short-run rise in the real rate.

These results, consistent with GLV, might suggest that during the Volcker-Greenspan era, the Fed employs an optimal monetary rule. In this case, the Fed may be responding to the productivity shock by raising the nominal rate–and, thus, the real rate–in order to suppress inflationary expectations. The Fed achieves, according to the empirical evidence, long-run price stability but does not completely damp out all of the short-run price effects.

[15] We consider the monetary shock to determine whether restrictions identifying the technology shocks aversely affect the response of the monetary shock. We find that the responses to the monetary shock have the expected shape (see Bernanke and Mihov, 1998) and, thus, we are reassured that monetary shock is robust to the identication of the technology shock using Gali's (1999) method. For brevity, we refer the reader to the usual literature in exogenous monetary shocks (see Christiano, Eichenbaum, and Evans, 1999; Bernanke and Mihov, 1998; and Leeper, Sims, and Zha, 1996).

[16] The difference in the U.S. and U.K. inflation and interest rate responses before and after the breaks lead us to analyze the two subperiods for each country separately. We will refer to the pre- and post-break subsamples explcitly.

Figure 2 about here

In order to facilitate further discussion, we collect the remaining countries (including the pre-Volcker U.S.) into three subgroups based on the response of their central banks to the technology shock and the attributes of the shock itself (i.e., its impact on prices and employment). The point estimates for the impulse responses of both real and nominal interest rates, inflation, and employment to a one standard deviation technology shock for the first country grouping (France, Japan, and the post-break U.K.) are depicted in Figure 2. Employment for these countries, while declining in the short-run, rises overall.[17]

For this first grouping, the central bank raises the real interest rate in response to a technology shock. The real interest rate for three of the four countries declines in the short-run. However, for all four countries, it rises within a few quarters and remains either positive or statistically negligible.[18] Long-run stabilization of the real rate is accomplished through a rise in the nominal interest rate in response to an increase in prices and employment. The real rate falls in the short-run in three countries because of the immediate increase in inflation. The central bank's response occurs at a lag, leaving the nominal interest rate unchanged in the short-run.

Figure 3 about here

The impulse responses to the technology shock for the second country group–consisting of Canada, Germany, the pre-break U.K., and the United States (MBM)–are reported in Figure 3.[19] This group is characterized by a decline in the nominal rate and relatively persistent declines in employment (usually more than 17 quarters) and inflation. This persistent reduction in employment is theoretically consistent with a job destructive technology shock (see Caballero

[17] France's labor response is slightly different. It rises in the short to medium run but turns negative after 15 quarters.

[18] The slow in the response of the real interest rate may be interpreted as central bank reaction time or monetary policy lags.

[19] It is important to reiterate that we could not reject the null hypothesis of no unit root in Germany's productivity series and that the model was estimated with detrended employment.

and Hammour, 1994).

A cursory examination of the monetary response for this group, characterized by a decrease in the nominal interest rate, might indicate a difference in the behavior of monetary policy from the first country grouping. The monetary authority appears to be accommodating the technology shock, lowering nominal rates in the face of falling employment. The third panel of Figure 3, however, shows that countries in this group either raise or hold real interest rates constant in the long-run in response to the shock. Since these countries experience deflationary technology shocks, the central bank maintains the real interest rate via a reduction in the nominal interest rates.

Figure 4 about here

The final country to be considered is Italy, whose impulse responses are shown in Figure 4. Italy is characterized by a technology shock that induces a negative comovement between inflation and employment. Here, the response of employment to the technology shock is a persistent reduction in labor, consistent with the responses of the countries in group 2. However, in contrast to the countries in group 2, prices rise in response to the technological innovation. The monetary authority responds to the technology shock by increasing the nominal interest rate. The net effect is to counterbalance rising inflation's effect on the real interest rate. The Bank of Italy, thus, initially accommodates the decline in employment but eventually raises real interest rates in response to inflation.

It comes as no surprise that the central banks in our sample respond differently to technology shocks. This is especially true given that the labor and price response varies considerably across countries. However, in each case, the central bank acts to increase the real interest rate in response to the shock, regardless of the direction of the inflation response.[20] In order to explain this cross-country variation, we propose a representative agent model in the following section.

[20] In some cases, the central bank is not entirely successful in increasing or maintaining the real interest rate. We, however, focus on the comovement between inflation and the nominal interest rate. In all cases, the comovement is positive.

4 Model

The model we present is adapted from King and Wolman (1996) and incorporates both a technology shock and a monetary policy reaction function. The model examines the optimization problems of firms and workers and the dynamic responses to idiosyncratic technology shocks under differing monetary policy rules. The nature of the impulse responses to a technology shock will hinge on whether the policy of the central bank is money supply growth targeting or employing a Taylor rule.

Our model is a representative agent model with a central bank. The household maximizes lifetime utility subject to time and budget constraints. Additionally, households experience a time cost of acquiring consumption goods–a shopping time. Firms maximize profits under a Calvo (1983) pricing scheme. Finally, the central bank can adopt either a Taylor rule or money supply growth targeting rule.

4.1 The Household's Problem

The household's current period utility depends on its level of consumption and leisure:

$$U_t = \ln c_t + \phi \ln l_t,$$

where c_t is consumption, l_t is leisure, and ϕ is a weighting factor. The household's problem is to maximize expected lifetime utility

$$\max \left\{ E_t \sum_{j=0}^{\infty} \beta^j U_{t+j} \right\}$$

subject to a budget constraint

$$E_t \sum_{j=0}^{\infty} \Delta_{t,j} P_{t+j} c_{t+j} \leq E_t \sum_{j=0}^{\infty} \Delta_{t,j} P_{t+j} \left[w_{t+j} n_{t+j} - \frac{R_{t+j}}{1+R_{t+j}} m_{t+j} \right] + \text{ other wealth}$$

and a normalized working day

$$n_{t+j} + l_{t+j} + h_{t+j} = 1.$$

Here, β and Δ are discount factors; m_t is real money balances; P_t is the price level; w_t is the real wage; R_t is the nominal interest rate; n_t and l_t are labor and leisure, respectively; and h_t is shopping time. Shopping time captures the fact that it is costly, in terms of time, to undertake real consumption activity. The form of the shopping time technology is,

$$h_t = h\left(\frac{m_t}{c_t}\right) = \alpha + \kappa(\frac{m_t}{c_t}) - \frac{\upsilon}{\upsilon - 1}\zeta^{1/\upsilon}(\frac{m_t}{c_t})^{\frac{\upsilon-1}{\upsilon}}$$

with $h'(.) < 0$.

4.2 The Firm's Problem

We assume firms are monopolistic competitors. A firm's decision depends on its current capital stock k_t and the expectation of the future consumption good price P_{t+j} and real wage w_{t+j}. Firms choose the output level, employment, and investment to maximize the expected value of future profits

$$E_t\Pi = E_t \sum_{j=0}^{\infty} \Delta_{t,j}[P_{t+j}y_{t+j} - P_{t+j}w_{t+j}n_{t+j} - P_{t+j}i_{t+j}]$$

subject to a constant returns to scale production technology

$$y_{t+j} = A_{t+j}f\left(n_{t+j}, k_{t+j}\right) \tag{2}$$

and an investment constraint

$$k_{t+j+1} - k_{t+j} = \Phi\left(\frac{i_{t+j}}{k_{t+j}}\right)k_{t+j} - \delta k_{t+j},$$

where δ is the capital depreciation rate. $\Phi\left(\frac{i}{k}\right)$ is a positive, increasing, and concave function that represents the increasing cost of augmenting capital too rapidly.

Firms set prices according to the staggered price setting scheme of Calvo (1983), with probability η firms do not adjust prices and with probability $1-\eta$ they do. This implies that the fraction of firms that last adjusted price j periods ago is given by,

$$\theta_j = (1-\eta)\eta^j.$$

The aggregate price level is, then, assumed to follow

$$P_t = \left[\sum_{j=0}^{\infty} \theta_j (P_{t-j}^*)^{1-\varepsilon}\right]^{1/1-\varepsilon},$$

where P_{t-j}^* is the price chosen by firms who adjusted their price j periods ago.

The coefficient A_{t+j} in (2) is a productivity shifter which we will identify as the level of technology. Shocks to A_{t+j} will be interpreted as shocks to technology; we model these shocks as random walk processes, thus, introducing some persistence into the model. Our primary interest is to determine the central bank's reaction and the subsequent dynamic response of model variables to innovations in A_{t+j} under alternate policy rules.

4.3 Monetary Policy Rules and First-Order Conditions

In addition to the behavior of the agents, the rule followed by the monetary authority will influence the responses of the economy to a technology shock. We assume that the monetary authority can adopt one of two policy rules:

1. Taylor Rule: The central bank manipulates interest rates each period to achieve a given annualized inflation rate target π^*. The policy rule would be of the form:

$$R_t = R_{t-1} + a\left(y_t - y^*\right) + b\left(\pi_t - \pi^*\right)$$

where y^* is potential output.

2. Money Supply Targeting: The central bank targets the rate of growth of money supply. That is, money growth is held constant.

$$\log(m_t) - \log(m_{t-1}) = \varphi$$

where m_t is the quantity of money.

The endogenous reaction of monetary policy to the technology shock will depend on which of the two policy rules the monetary authority chooses to adopt. Given the set up of the model, the following first order conditions obtain:

$$\frac{1}{c_t} = -\lambda_t P_t [1 - \kappa \frac{w_t}{c_t}\frac{m_t}{c_t} + \frac{w_t}{c_t}\left(\frac{m_t}{c_t}\right)^{\frac{\upsilon-1}{\upsilon}} \zeta^{\frac{1}{\upsilon}}] \qquad \text{MU of Consumption,}$$

$$\frac{\phi}{l_t} = -\lambda_t P_t w_t \qquad \text{Labor Supply,}$$

$$-\frac{w_t}{c_t}\left[\kappa - (\frac{m_t}{c_t})^{\frac{-1}{\upsilon}} \zeta^{\frac{1}{\upsilon}}\right] = \frac{R_t}{1+R_t} \qquad \text{Cash Balance Holding,}$$

$$\gamma_t \alpha A_t n_t^{\alpha-1} k_t^{1-\alpha} = P_t w_t \qquad \text{Labor Demand,}$$

and

$$\gamma_t (1-\alpha) A_t n_t^{\alpha} k_t^{-\alpha} = Z_t \qquad \text{Capital Decision,}$$

where Z_t is the rental price of capital, γ_t and λ_t are shadow prices and α is the share of labor in the production function. These first-order conditions allow us to simulate the model and determine the policy reaction and subsequent theoretical responses to innovations to technology.

5 Simulations

The model that we have presented above consists of a few key parameters that can affect the shapes–and more importantly, the signs–of the theoretical impulse responses to technology shocks. In particular, we explore differences induced by the two policy rules (Taylor rule or money growth targeting) and by changes in the cost of capital adjustment.[21] In Table 2, we offer four model parameterizations that characterize a variety of alternative responses to a positive technology shock. The differences in the price responses underlies variations in the employment response to technological innovations.

Table 2 about here

Figure 5 about here

Figure 5 plots the theoretical impulse responses of selected variables to a one percent positive shock to technology under the Taylor rule for the first parameterization, which we henceforth term a *creative* technology shock.[22] The theoretical technology shock causes a level shift in output that in turn requires, from the first-order conditions, that the capital-labor ratio increase. Since the cost of adjusting capital is sufficiently low, when labor increases due to the rise in average productivity, capital responds positively to the shock. Thus, a productivity shock causes an increase in output that exceeds the shift in potential and, thus, leads to an increase in prices. The central bank, with a stable Taylor rule (in the sense of Clarida, Gali, and Gertler, 2000), responds by raising both the nominal and real interest rates to counteract rising prices.

[21] We considered but do not report changes in the agents' relative valuation of leisure to consumption, the time cost of purchasing consumption goods, and the rate at which firms can change prices. We found that these parameters are not key to explaining cross-country differences in the monetary response to technology shocks. They may, however, be valuable in explaining other business cycle variables including, for example, the effect of technology on consumption. We leave this for future research.

[22] This parameterization in this simulation has 25 percent of firms adjusting their prices, a relatively low cost of adjusting investment, and a feedback coefficient on inflation relative to output greater than 1 in the Taylor rule equation.

Figure 6 about here

The second and third parameterizations are presented together in Figure 6. These parameterizations exemplify how both a monetary targeting rule and a Taylor rule can produce similar theoretical responses.[23] One major difference between these two specifications is how the decline in employment is generated. When the policymaker employs a Taylor rule in this parametrization, high adjustment costs cause a rigidity in the capital market. The shift in the level of output again indicates an increase in the capital-labor ratio that can only be achieved by a short-run reduction in employment. This decline in employment endures until firms can adjust their capital stock. Sufficiently rigid capital markets can therefore produce persistent employment reductions. Since the central bank's Taylor rule in this parameterization places a relatively high weight on output, the level shift in output causes the policymaker to underestimate the necessary reduction in the nominal interest rate. The change in the real interest rate is positive and prices fall. We henceforth term this parameterization a *destructive* technology shock.[24]

In the case of the money growth targeting, the level shift in output forces the consumer to spend more time shopping. In the previous parameterization, the central bank injects liquidity by dropping the interest rate, thereby decreasing the shopping time cost. Here, the central bank holds the money growth rate constant. Thus, agents switch out of leisure and labor into purchase of consumption goods. In this case, the decline in employment obtains not from a rigidity in the capital market but from a rigidity induced by the central bank's policy rule. The relative tightness in money also produces the decline in prices.

Figure 7 about here

[23] Later, we will consider empirical methods of distinguishing between the two types of policy rules.

[24] A negative employment response also may reflect the possibility that a dominant *wealth effect* drives down employment and causes the technology shock to be deflationary. After a positive productivity shock, firms' markups rise, increasing the wedge between the marginal productivity of labor and the real wage. Because this wedge is expected to diminish over time, expected real wages rise and agents reduce their short-run labor supplied due to the intertemporal substitution effect.

Finally, we present a fourth parameterization that reflects a policymaker with Taylor rule with an low (and unstable) weight on inflation but an even lower weight on output.[25] As in the second parameterization, a high capital adjustment cost makes employment decline. In this case, the central bank does not respond to output but instead responds to the upward pressure on prices by raising the nominal interest rate. However, since the coefficient on inflation in the policymaker's Taylor rule is less than unity, the magnitude of the response is insufficient to fully balance the pressure on prices and inflation rises.

6 Explaining Cross-Country Differences

In the previous section, we show that differences in the theoretical responses to the technology shock can be attributed to either differences in the monetary authority's rule (i.e., stable/unstable Taylor rule or money growth targeting) or the degree of rigidity in the adjustment of the capital stock. We have shown the empirical impulse responses from section 3 differ across countries. Here, we consider whether variation in the parameters that spur differences in the theoretical model can be possible explanations for these empirical cross-country differences.

Apart from the U.S. (VG) responses, the remaining countries (including the U.S. (MBM) period) seem to be well characterized by differences in the three key elements: the variable targeted by the central bank, the parameters of the policy rule, and capital market rigidities.[26] However, before we conclude that these differences in the impulse responses can truly be attributed to these the country characteristics, we explore further evidence. We conduct these tests in this section.

[25] This parameterization produces a near random walk in interest rates.

[26] We note here that GLV concluded that the U.S. (VG) period can be characterized by an optimal monetary policy rule. We refrain from further discussion of this period and, instead, focus on the nature of remaining cross-country variation.

6.1 Tests of Monetary Targeting

For the four countries in group 2, we are unable to distinguish theoretically between the responses of a country with a money growth rule with flexible capital markets and a country with an unstable Taylor rule with rigid capital markets. Empirically, we can test whether the central bank appears to be conducting policy as though it were targeting a money growth rate. Thus, we reestimate the model including a monetary aggregate in the monetary policy block. Results for the four countries in group 2 are presented in figure 8.

Figure 8 about here

During the sample periods, the responses of the money growth rate in Canada and Germany are statistically negligible. This suggests that these countries, indeed, seem to behave as though they target a money growth rate. On the other hand, the U.S. (MBM) period results are consistent with GLV. The response of money to the technology shock for the United States (MBM) is wildly varying and not suggestive of the Fed targeting a money growth rate. For the pre-break U.K., a technology shock causes a long-run increase in the money growth rate, providing some evidence against money targeting by the Bank of England. However, unlike GLV, our theoretical model allows us to make a further test of money targeting by considering the rigidity of capital markets.

6.2 Tests of Capital Adjustment

Under the Taylor rule specification, the direction of the theoretical response of employment depends on the cost of adjusting capital. While a direct measure of the cost is unavailable, we consider a proxy of the capital market rigidity in the volatility of quarterly investment. We posit that a higher the capital adjustment cost implies a greater the rigidity in the capital market and, thus, lower the investment volatility. The first column of Table 3 shows the detrended investment volatility for each country.[27]

Table 3 about here

The theoretical model predicts that all the countries in group 1 (France, Japan, and the post-break U.K.) and the potential money growth targeting countries in group 2 (Canada and Germany) have low capital adjustment costs and, thus, more volatile investment. On the other hand, the pre-break U.K., the U.S. (MBM), and Italy should have high capital adjustment costs and, thus, less volatile investment. Although only suggestive, the ordinal ranking of the investment volatilities does bear close resemblance to the prediction. Only Germany has investment volatility below countries inconsistent with the predicted result.[28]

6.3 Taylor Rule Coefficients

A final theoretical implication of the model is that, in order to match the empirical responses, the degree of output and inflation sensitivity in the policymaker's Taylor rule must vary. In order to uncouple the price and employment response for Italy, the Taylor rule implied by the empirical model must be unresponsive to output and inflation. While the empirical model does not explicitly generate estimates for the policymaker's Taylor rule, because the policy block is ordered last in the VAR, the coefficients in the interest rate equation can be taken to approximate the total responsiveness to output and inflation. To reveal whether the empirical results are consistent with our theoretical interpretation, we compare some benchmark Taylor rule coefficients from the literature. The results are shown in Table 3.[29] Since, these studies explicitly set out to model

[27] Further research might examine more disaggregated measures of investment or capital stock volatility.

[28] This may suggest that Germany and the pre-break U.K., although appearing to target the money growth rate in Figure 8, are actually Taylor rule countries. Also, the model does not suggest a particular cutoff for the investment volatility. Again, we emphasize that results in this section are merely suggestive.

[29] Note there are features of the model, such as capital adjustment cost and shopping time, not captured in the empirical section which negates any direct comparison of the policy reaction functions - theoretical and empirical. However, we proceed with the comparison under the assumption that either these factors do not affect (contemporaneous) output and employment found in the Taylor rule or their influence is not sufficient to render the comparison useless.

and estimate monetary policy reaction functions, in this regard, they provide more accurate coefficients than our empirical estimates.

Three key results are suggested from the Taylor Rule equations obtained from the literature. First, the Taylor rule for each of the group 1 countries has an inflation coefficient statistically equal to or greater than 1 and an output coefficient less than 0.5. This is consistent with the parameterization from our theoretical model and the relatively high investment volatility discussed in the previous section. Second, the pre-break Bank of England appears relatively too responsive to fluctuations in output versus inflation. This, coupled with the U.K.'s relatively low investment volatility, supports the hypothesis that the pre-break U.K. is, in fact, an "unstable" Taylor rule country rather than a money growth targeting country. Germany, on the other hand, appears to have a stable Taylor rule, which is inconsistent with theory. This leads us to believe that Germany is, indeed, money growth targeting, a results consistent with previous literature (Bernanke, Laubach, Mishkin, and Posen, 1998). Third, the Bank of Italy appears relatively unresponsive (compared to model predictions) to fluctuations in inflation. In combination with its relatively low investment volatility, Italy's responses are consistent with our theoretical model that includes high capital adjustment costs and an unstable Taylor rule.

7 Conclusion

In this paper, we extend the empirical analysis of Gali (1999) and Gali, Lopez-Salido, and Valles (2003) to an international context. We find considerable cross-country variation in the response to the identified technology shock. In particular, we identify three subgroups consisting of countries whose responses are similar in shape and direction. The two elements that characterize these differences are the direction of the price/employment/interest rate response and the comovement between employment and prices. One finding of particular interest is that the identified responses during the Volcker-Greenspan era are not replicated in any other G-7 country during any time period.[30]

Using a theoretical model adapted from King and Wolman (1996), we find that the empirical responses can be matched with theoretical responses. Differences in these theoretical responses can be attributed to alternative policy rules and changes in the cost of capital adjustment. Further tests verify that these country characteristics could, indeed, have some explanatory power. While our results are by no means conclusive, they do suggest a number of theoretically consistent similarities across countries in each subgroup. While we believe more investigation into these cross-country comparisons is warranted, the initial indication is that the manner in which monetary policy is conducted and the degree of rigidity in capital markets may be determining factors in a country's response to technology shocks.

[30] We find this of interest since GLV conclude the conduct of the Fed during this period can be construed as theoretically optimal.

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Table 1

Panel A: Sample Periods, Structural Break Dates, and LM Stats

	Full Sample Period	Structural Break Date	LM Stat at Break Date	Estimated Period
CANADA	1970:1 - 2002:2	1976:3	125.72	1976:3 - 2002:2
FRANCE	1978:1 - 1998:4	1983:1	130.41	1983:1 - 1998:4
GERMANY	1970:1 - 1998:4	1974:4	134.66	1974:4 - 1998:4
ITALY	1971:1 - 1998:4	1976:2	199.59	1976:2 - 1998:4
JAPAN	1970:1 - 2002:2	1975:1	172.20	1975:1 - 2002:2
UK	1960:1 - 2002:2	1974:1	154.31	
UK-pre				1960:1 - 1979:2
UK-post				1982:3 - 2002:3
US	1960:1 - 2002:3	1981:1	128.00	
US-pre				1960:1 - 1979:2
US-post				1982:3 - 2002:3

Note: Structural break dates were determined based on the subsample stability of the coefficient matrix with productivity and employment in differences, and inflation and the interest rate in levels.

Panel B: Descriptive Statistics of the Growth Rates Over the Estimated Periods

	Productivity		Employment		Inflation		Interest Rate	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**
CANADA	-0.03	0.33	0.19	0.24	-0.02	1.14	8.33	3.68
FRANCE	-0.22	2.93	0.07	0.12	-0.04	0.73	7.32	3.10
GERMANY	0.06	1.00	0.03	0.24	-0.03	2.47	5.55	2.33
ITALY	0.18	0.37	0.05	0.27	-0.06	1.38	11.76	4.88
JAPAN	0.18	0.40	0.08	0.15	-0.06	1.08	4.43	3.20
UK								
UK-pre	0.29	0.47	0.02	0.21	0.10	2.50	5.93	1.62
UK-post	0.13	0.37	0.05	0.22	-0.07	1.95	9.18	3.19
US								
US-pre	-0.01	0.43	0.22	0.22	0.05	0.58	5.49	2.41
US-post	0.05	0.37	0.17	0.18	-0.03	0.41	6.59	2.77

Panel C: T-stats From Unit Root Tests

	DICKEY-FULLER				PHILLIPS-PERRON			
	PROD	**EMPL**	**INFL**	**RATE**	**PROD**	**EMPL**	**INFL**	**RATE**
CANADA	**-3.12**	-0.83	-1.61	-1.59	**-2.78**	-0.82	**-3.62**	-1.64
FRANCE	-0.64	-0.42	**-2.95**	-1.86	-1.42	1.50	**-4.68**	-1.67
GERMANY	**-2.75**	-1.94	**-3.14**	**-2.60**	**-3.10**	-0.75	**-9.76**	-2.28
ITALY	-1.52	-1.18	-1.54	-0.94	-1.08	-1.39	**-3.85**	-1.01
JAPAN	-1.32	-1.93	-2.51	-1.44	-1.77	**-2.96**	**-4.46**	-2.45
UK-pre	0.21	-1.62	-1.07	-0.90	0.49	-1.96	**-7.26**	-0.40
UK-post	-1.03	-1.06	**-3.58**	-1.74	-1.04	0.12	**-3.72**	-1.92
US-pre	-1.23	-0.08	-1.01	-1.17	-1.08	0.70	-1.45	0.15
US-post	-1.79	-2.14	**-2.90**	**-3.44**	-0.88	-1.19	**-5.33**	-2.55

Values significant at the 10% level are bolded.
Note: The variables were tested for unit root in levels.
Note: Germany was estimated with a linearly detrended productivity variable in levels.

Table 2: Model Parametrization

	Group 1	Group 2		Group 3
	Taylor Rule	Money Target	Taylor Rule	Taylor Rule
Parameterization Number	**1**	**2**	**3**	**4**
Own price elasticity (ε)	4.33	4.33	4.33	4.33
Probability firm does not adjust price (η)	0.90	0.75	0.75	0.75
Multiplicative term on h() function (ζ)	0.0116	0.0116	0.0116	0.0116
Curvature of h() function (υ)	0.8004	0.8004	0.8004	0.8004
Shift term in h() function (κ)	0.0011	0.0011	0.0011	0.0011
Labor share (α)	2/3	2/3	2/3	2/3
Quarterly depreciation rate (δ)	0.025	0.025	0.025	0.025
Quarterly inflation rate (5% annually) (π)	0.0122	0.0122	0.0122	0.0122
Investment adjustμεντ cost parameter (ξ)	0.5	0.5	20	20
Utility discount factor (β)	0.9917	0.9917	0.9917	0.9917
Inflation Coefficient in Taylor Rule	1.5	n/a	0.5	0.2
Output Coefficient in Taylor Rule	0.5	n/a	1.0	0.001

Table 3: Cross Country Differences

	Detrended Investment Volatility*	Taylor Rule	
		Inflation	Output
Group 1			
France	7.49	1.33[a]	0.27**
Japan	20.70	2.04[a]	0.08
UK - post	13.76	0.98[a]	0.19
Group 2			
Canada	12.71	2.25[d,***]	0.92***
Germany	2.85	1.31[a]	0.25
UK - pre	4.72	0.315[c]	0.52
US - pre	7.35	0.86[b]	0.39
Group 3			
Italy	6.14	0.91[a]	0.10**

* Gross Fixed Capital Formation

** Includes coefficient on relative price of domestic currency to an EU area bundle of prices.

*** Coefficients estimated with the assumption of a forward-looking Taylor Rule, and a backward-looking inflation target rule.

**** Since Germany was estimated with a linearly detrended labor coefficient, its output coefficient is not directly comparable to that of the other countries.

Taylor Rule Coefficients Extracted From:

a Clarida, Gali, and Gertler (2000)
b Clarida, Gali, and Gertler (1998)
c Nelson and Nikolov (2002)
d Fougere (2001)

Figure 1: Empirical Responses for US (VG)

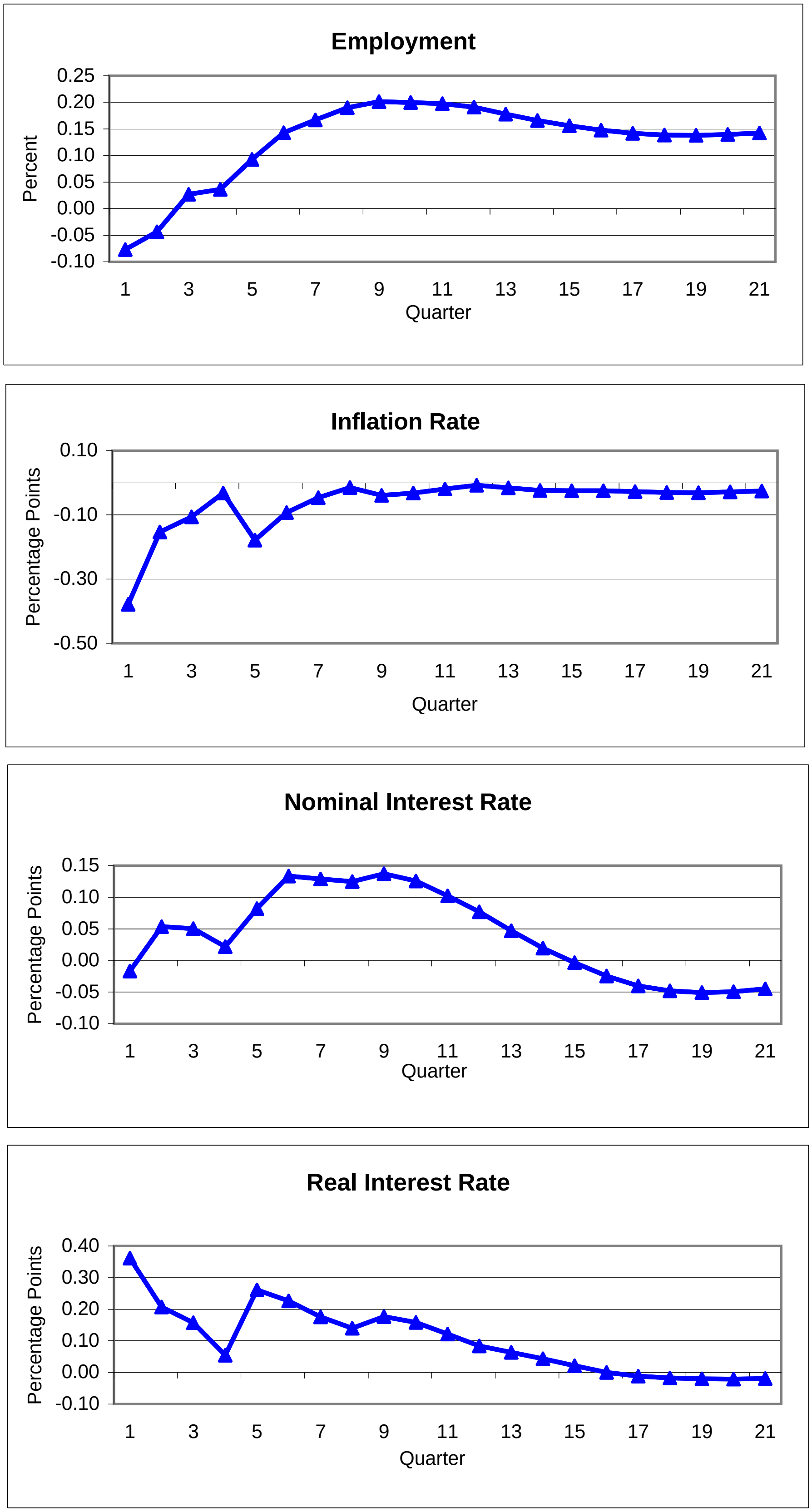

Figure 2: Empirical Responses for Group 1 (UK-Post, France, Japan)

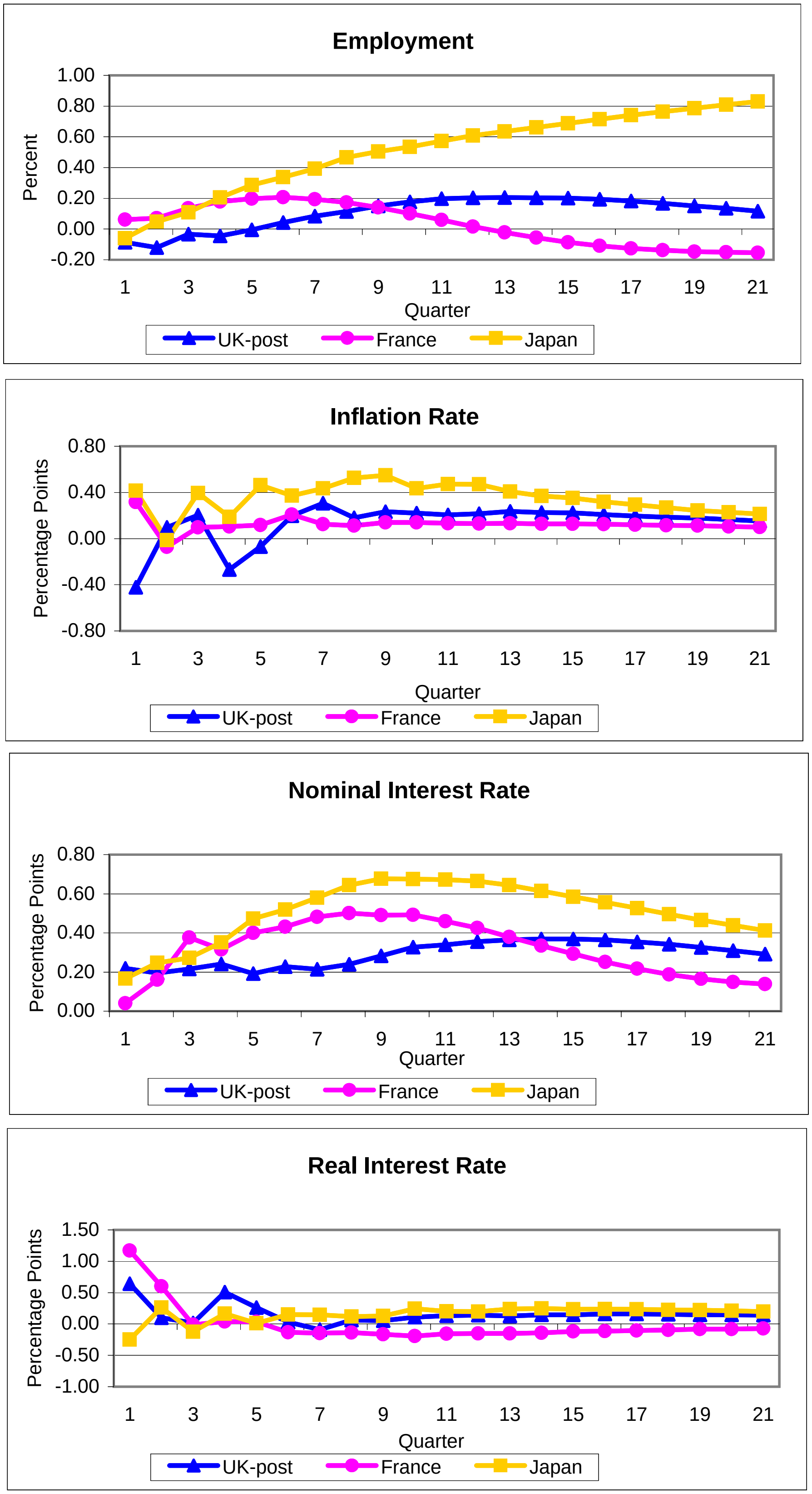

Figure 3: Empirical Responses for Group 2 (Canada, Germany, US(MBM), and UK-Pre)

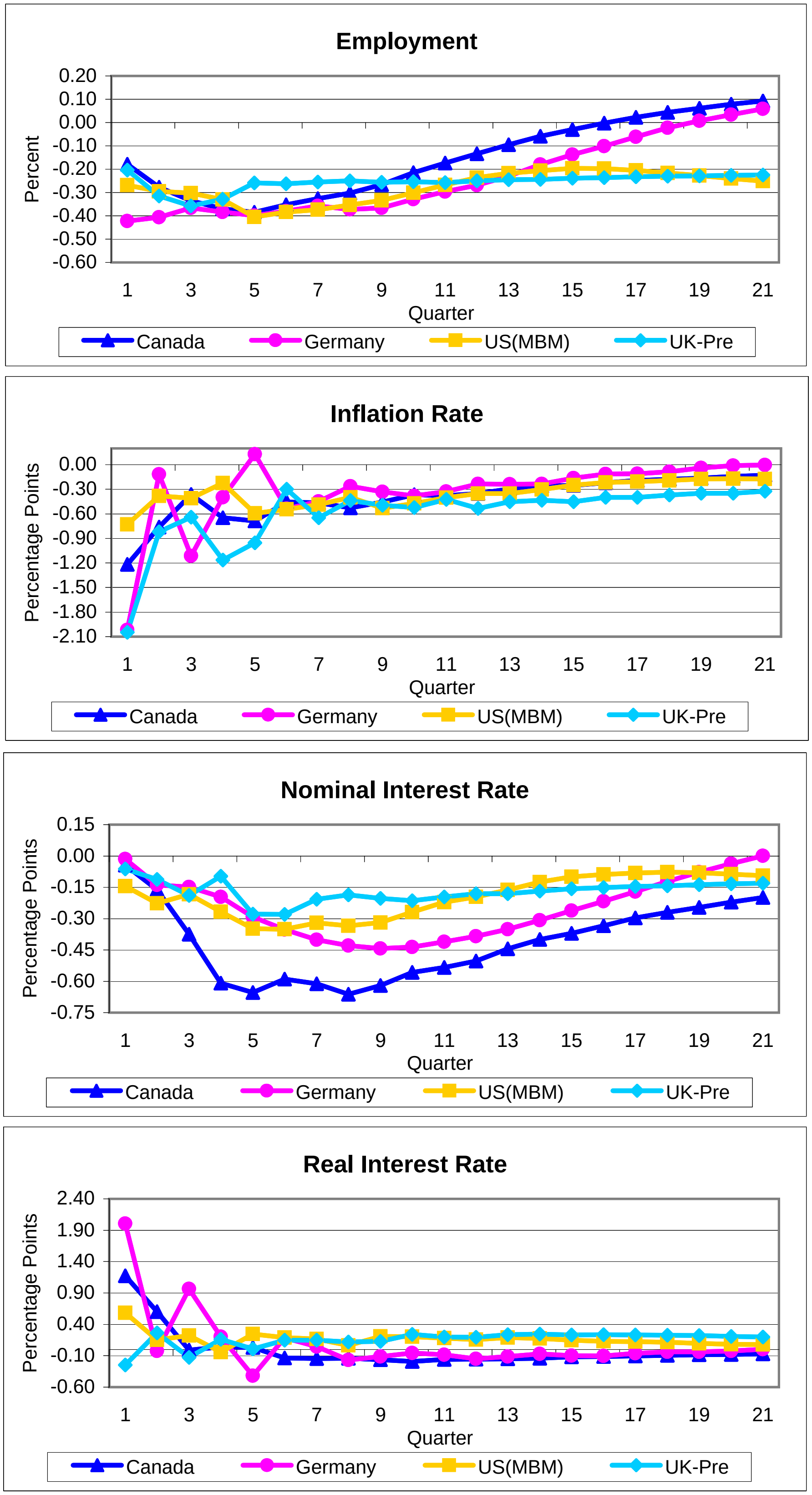

Figure 4: Empirical Responses for Group 3 (Italy)

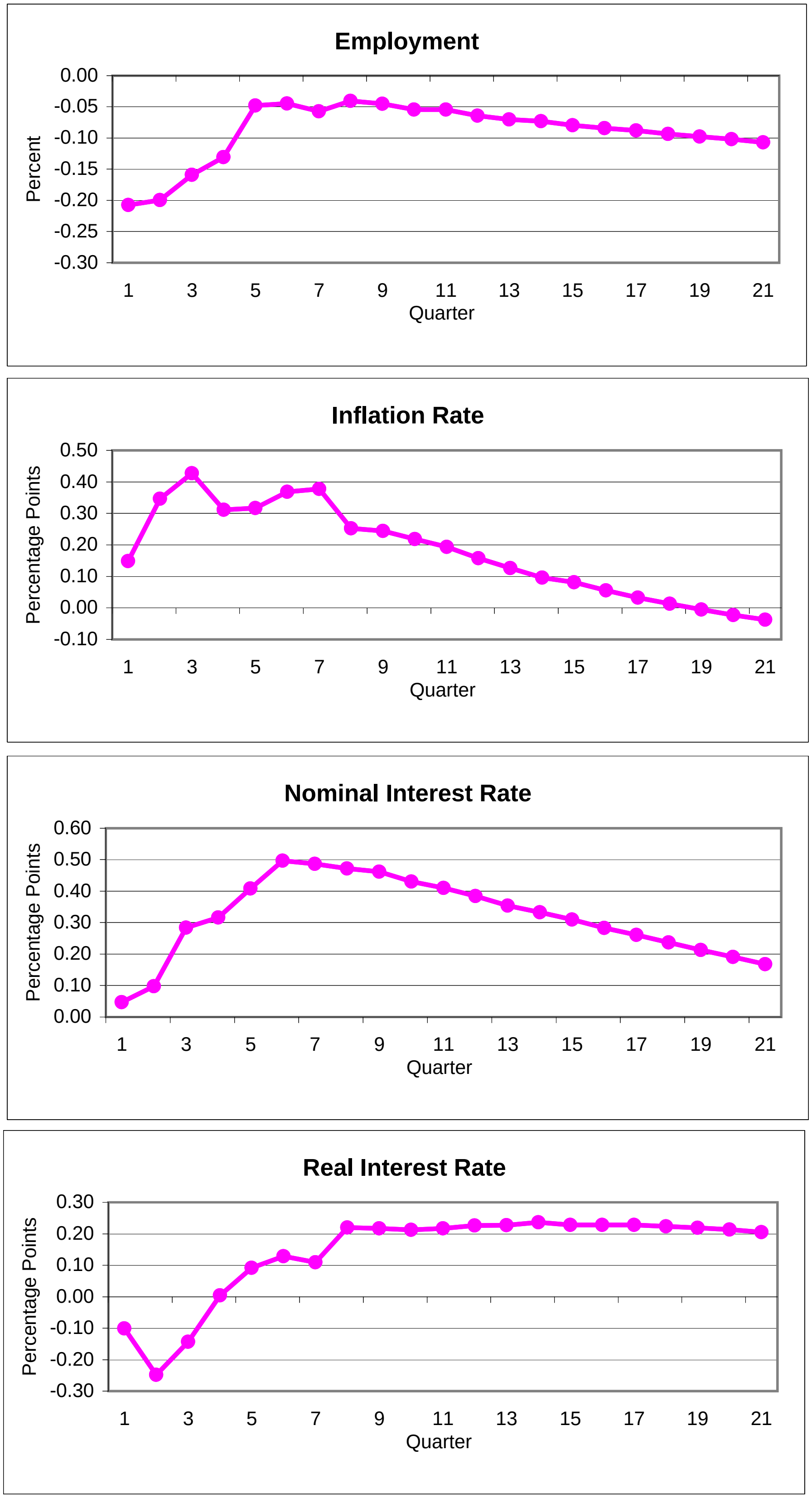

Figure 5: Theoretical Responses Parameterization 1

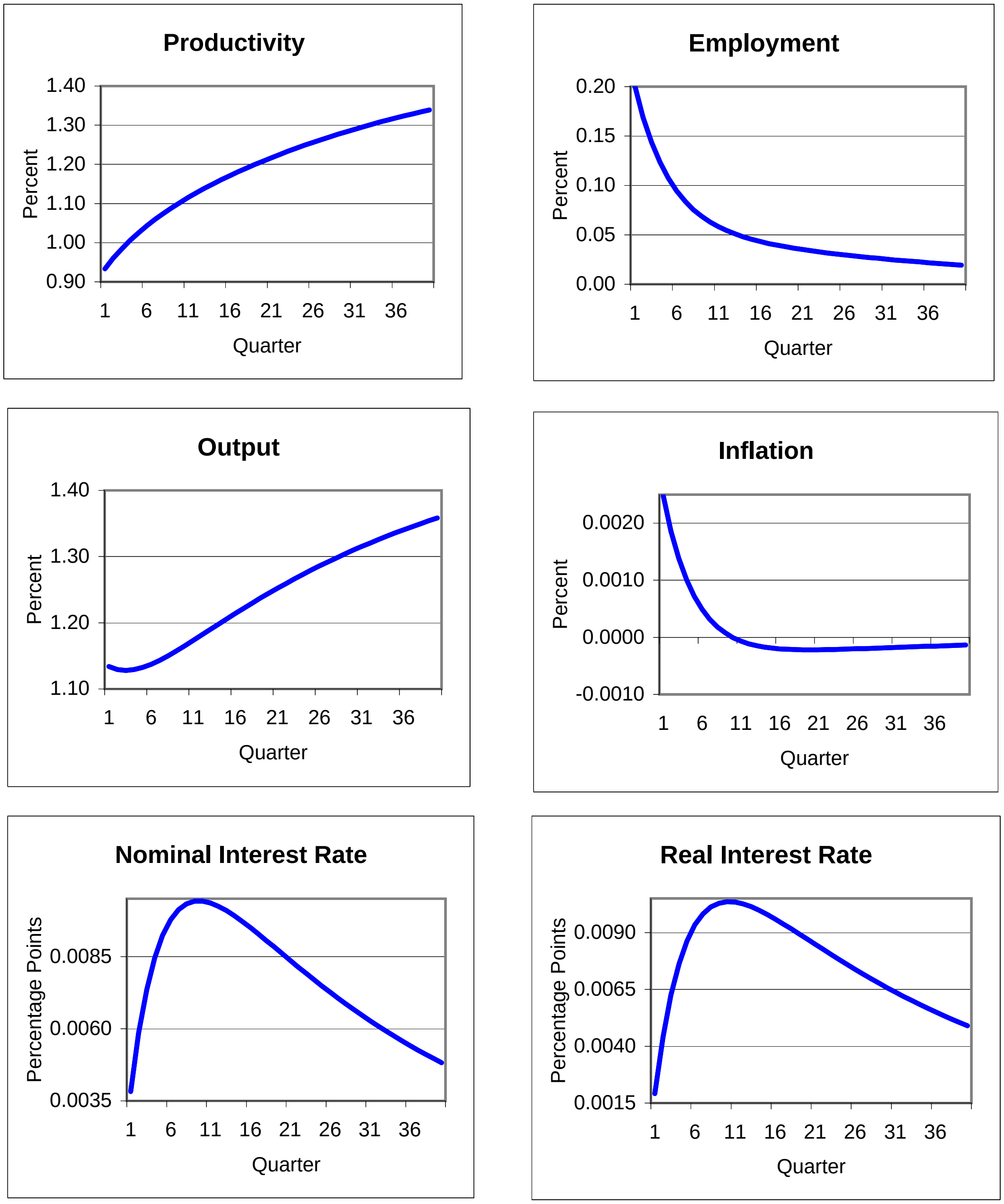

Figure 6: Theoretical Responses Parameterization 2 & 3

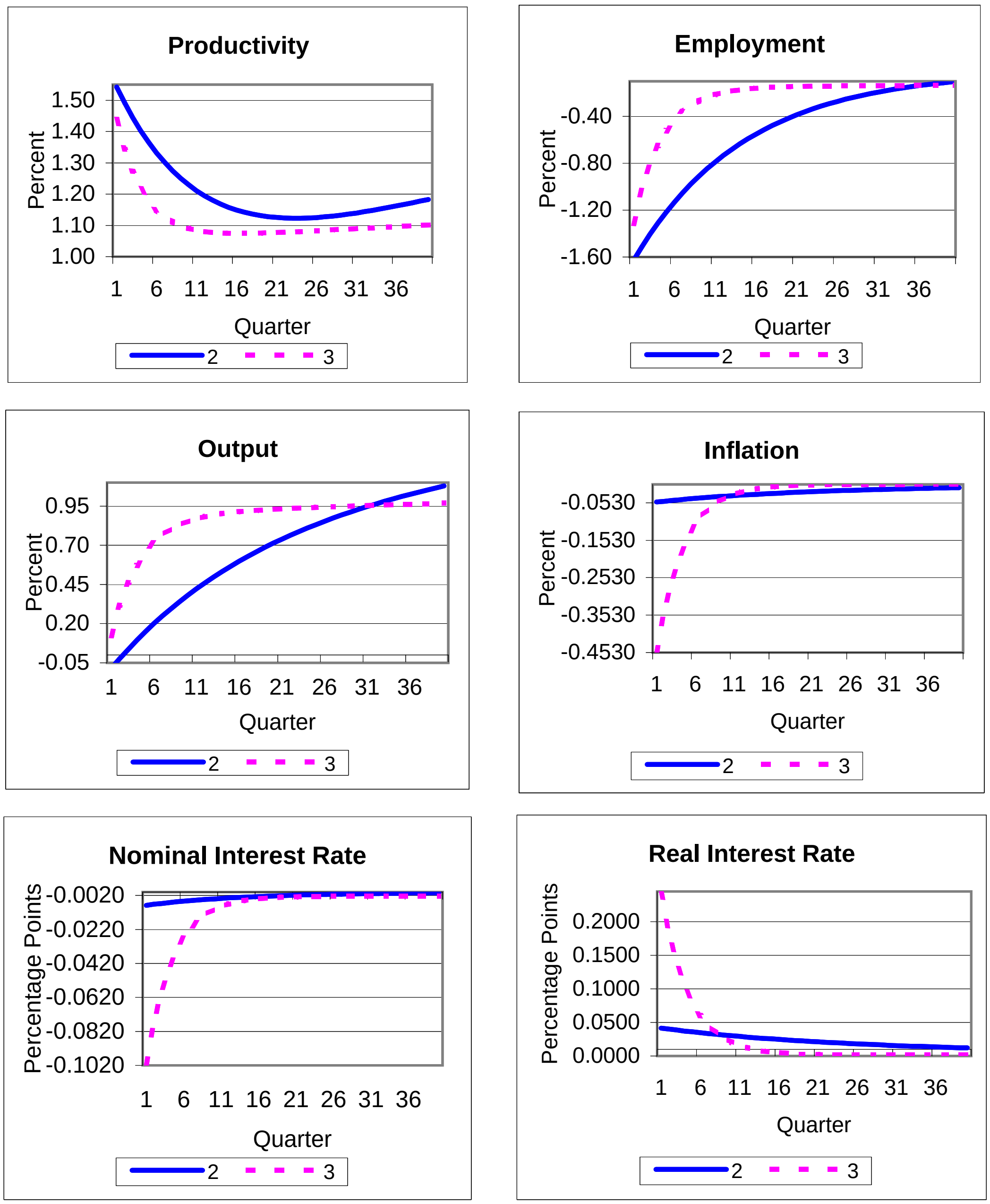

Figure 7: Theoretical Responses Parameterization 4

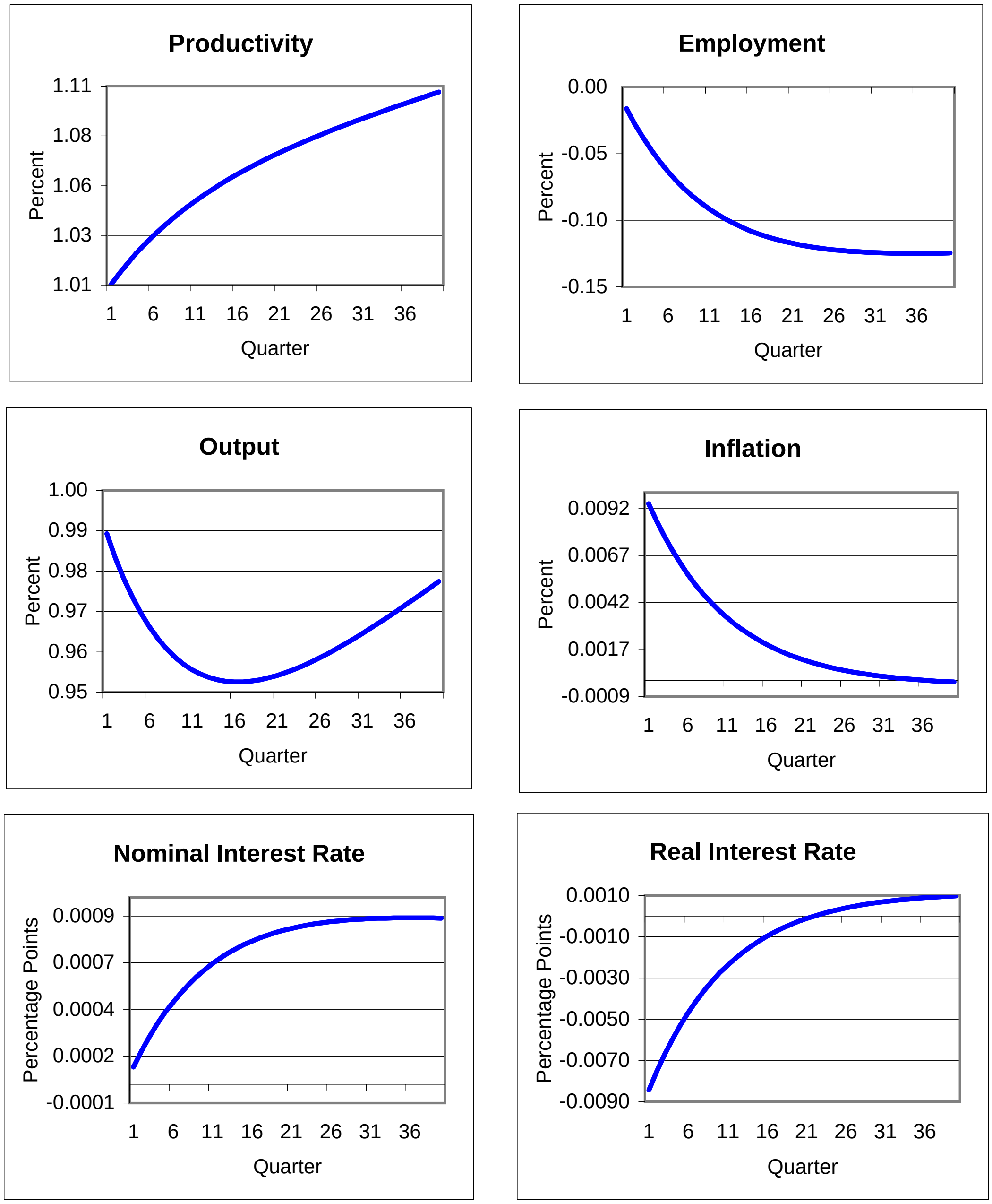

Figure 8: Empirical Response of Monetary Aggregates to a Technology Shock for Canada, Germany, US(MBM), and UK-Pre