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

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In a recent paper, Galí, López-Salido, and Vallés (2003) examined the Federal Reserve's response to VAR-identified technology shocks. They found that during the Martin-Burns-Miller era, the Federal Reserve responded to technology shocks by overstabilizing output, while in the Volcker-Greenspan era, the Federal Reserve adopted an inflation-targeting 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, the type of monetary policy rule, the responsiveness of the rule to output and inflation fluctuations, and the response to technology shocks.

JEL Codes: C32, E2, E52.

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,

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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 exogenous money-growth or interest-rate shocks, recent research has begun to investigate endogenous monetary policy—that is, the central bank's reaction to nonmonetary 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 such force that many economists believe contributes to the business cycle fluctuations that feed into the Taylor rule is exogenous technological innovation. In an effort to identify the empirical effects of *technology shocks*, Galí (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 nontechnology components by assuming that only the former can have long-run effects on labor productivity.[1]

Empirical identification of the technology shock was a step in developing a unified reduced-form framework to examine the role that endogenous monetary policy plays in smoothing economic fluctuations.[2] Along these lines, Galí (2002) and Galí, López-Salido, and Vallés (2003—henceforth GLV) examined the endogenous response of monetary policy to identified technology shocks in the United States. GLV estimated a four-variable long-run restricted SVAR for the United States with labor productivity, hours worked, the real interest rate, and inflation. They find that during the Volcker-Greenspan

[1] Galí (1999) concluded that technology shocks do not drive business cycle fluctuations, in part, because hours decline in response to a positive technology shock. However, variation in the impact response of hours to technology shocks is observed depending on whether that series is differenced, detrended, or entered in levels (see Francis and Ramey [2004]; Christiano, Eichenbaum, and Vigfusson [2003]; and Uhlig [2003]). Our contribution is not to this debate, and the tenor of our results does not depend on how hours enter the system.

[2] 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]).

(VG) era, the Federal Reserve responded to technology shocks by raising the nominal interest rate, while during the Martin-Burns-Miller (MBM) era, the Federal Reserve lowered the rate. Further, during the VG era, hours rose after a short decline and inflation was virtually unchanged, while during the MBM era, hours and inflation fell persistently. GLV conclude that the empirical responses for the VG era match theoretical responses obtained from an inflation-targeting rule but that there exists evidence against the use of a money-targeting rule during the MBM era.

Our contribution is to expand the scope of GLV to an international context to determine whether the effect of technology shocks is substantively different across the major industrialized countries. In particular, we are interested in how the different central banks respond to technology shocks. We investigate cross-country variation in the inflation and employment responses to technology shocks and whether these cross-sectional differences alter the central bank's response. Further, we examine possible causes for these differences in the context of a theoretical model.

The remainder of the paper is organized as follows: Section 1 discusses the data we use for empirical investigation and outlines the procedure to achieve identification. Section 2 reviews the econometric results. In particular, we analyze the responses to the identified technology shocks across countries and divide the countries into three subgroups. Section 3 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 4 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 from the model simulations to the empirical responses observed in the data. In section 5, we consider the merit of these theoretical explanations by offering some further empirical evidence. Section 6 offers concluding remarks.

1. 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 Galí (1999) to identify the technology shocks.

The specification and the results of the estimation are discussed below. To facilitate discussion, we identify three country subgroups based on similarities in their responses to the technology shock.

1.1 Data

The model we estimate is a quarterly five-variable VAR with four lags. The data used in the model are inflation, a short-term nominal interest rate (either the three-month Treasury-bill rate or the short-term money market rate), and the logs of real per capita GDP, money, and the employment index for each of the G-7 countries.[3] The inflation rate is taken to be the annualized growth rate of the GDP deflator. Data were taken from the Organisation for Economic Co-Operation and Development (OECD) and the International Monetary Fund (IMF), with the exception of U.S. GDP and inflation (Bureau of Economic Analysis), population (Bureau of Labor Statistics), and interest rates (Federal Reserve Board). Labor productivity is constructed from the difference of *log(real per capita GDP)* and *log(employment index)*. Unit root pretests were conducted for all variables. The null hypothesis of no unit root was rejected for all countries' labor productivity series except for Germany and Canada. Summary statistics for the variables used and results of the unit root tests are included in tables 1a–1c.

For the United States, there is significant evidence of a change in Federal Reserve policy during the Volcker disinflation.[4] In addition, the remainder of the countries in our sample exhibit evidence of structural instability over the full sample (e.g., European monetary unification). To ascertain a stable sample for analysis, we conduct Lagrange multiplier tests for each country to determine the timing and significance of a structural break in the coefficient matrix of the

[3]The Treasury-bill rate represents 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 it with the federal funds rate for U.S. data.

For most countries, the money stock is M2. Exceptions are the United Kingdom, for which we use M0, and Japan, for which we use M2 plus CDs.

[4]The policy break literature is too vast for a comprehensive survey here. We direct the reader to two papers. Clarida, Galí, and Gertler (2000) provide evidence that the weight on inflation in the Federal Reserve's objective function was significantly different during VG than during MBM. Boivin and Giannoni (2002) argue that the Federal Reserve's inflation target declined in the VG period.

Table 1a. Sample Periods, Break Dates, and Lagrange Multiplier Stats

Country	Full Sample	Break Date	LM Stat	Estimated Period
Canada	1970:1–2002:2	1976:3	125.7	1976:3–2002:2
France	1978:1–1998:4	1983:1	130.4	1983:1–1998:4
Germany	1970:1–1998:4	1974:4	134.7	1974:4–1998:4
Italy	1971:1–1998:4	1976:2	199.6	1976:2–1998:4
Japan	1970:1–2002:2	1975:1	172.2	1975:1–2002:2
UK	1960:1–2002:2	1974:1	154.3	
UK-pre				1960:1–1979:2
UK-post				1982:3–2002:2
US	1960:1–2002:3	1981:1	128.0	
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.

VAR. The results of the structural break tests, including the break date, are included in table 1a. Additional tests of the subsamples revealed no breaks. We constrain the samples for France, Germany, and Italy to the pre-EU period. In most cases (the United States and United Kingdom are exceptions), data limitations force us to constrain estimation of postbreak subsamples in circumstances in which breaks are significant. For the United Kingdom and the United States, we follow GLV and estimate separately the pre- and post-Volcker–disinflation samples.[5]

[5]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 (2004) 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.

Table 1b. Descriptive Statistics

	Productivity†		Employment†		Inflation†		Interest Rate‡		Money†	
Country	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Canada	−0.03	0.33	0.19	0.24	−0.02	1.14	8.33	3.68	0.66	0.44
France	−0.22	2.93	0.07	0.12	−0.04	0.73	7.32	3.10	0.55	0.71
Germany	0.06	1.00	0.03	0.24	−0.03	2.47	5.55	2.33	1.21	1.18
Italy	0.18	0.37	0.05	0.27	−0.06	1.38	11.76	4.88	1.81	1.56
Japan	0.18	0.40	0.08	0.15	−0.06	1.08	4.43	3.20	0.54	0.35
UK-pre	0.29	0.47	0.02	0.21	0.10	2.50	5.93	1.62	0.86	0.62
UK-post	0.13	0.37	0.05	0.22	−0.07	1.95	9.18	3.19	0.56	0.21
US-pre	−0.01	0.43	0.22	0.22	0.05	0.58	5.49	2.41	1.26	0.45
US-post	0.05	0.37	0.17	0.18	−0.03	0.41	6.59	2.77	0.70	0.44

†computed from the log change
‡computed from the annualized rate

Table 1c. T-Stats for Unit Root Tests

Country	Dickey-Fuller					Phillips-Perron				
	Prod	**Emp**	**Infl**	**Rate**	**M2**	**Prod**	**Emp**	**Infl**	**Rate**	**M2**
Canada	**−3.12**	−0.83	−1.61	−1.59	−1.71	**−2.78**	−0.82	**−3.62**	−1.64	−1.78
France	−0.64	−0.42	**−2.95**	−1.86	−2.02	−1.42	1.50	**−4.68**	−1.67	−1.66
Germany	**−2.75**	−1.94	**−3.14**	**−2.60**	−0.74	**−3.10**	−0.75	**−9.76**	−2.28	−0.77
Italy	−1.52	−1.18	−1.54	−0.94	−2.26	−1.08	−1.39	**−3.85**	−1.01	−2.49
Japan	−1.32	−1.93	−2.51	−1.44	−1.32	−1.77	**−2.96**	**−4.46**	−2.45	−1.17
UK-pre	0.21	−1.62	−1.07	−0.90	−2.08	0.88	−1.96	**−7.26**	−0.40	0.88
UK-post	−1.03	−1.06	**−3.58**	−1.74	0.59	−1.04	0.12	**−3.72**	−1.92	0.66
US-pre	−1.23	−0.08	−1.01	−1.17	−2.00	−0.84	0.70	−1.45	0.15	−1.45
US-post	−1.79	−2.14	**−2.90**	**−3.44**	−2.13	−0.88	−1.19	**−5.33**	−2.55	−2.26

Notes: Values significant at the 10 percent level are in bold.
The variables were tested for unit roots in levels.
Though a unit root in productivity is marginally rejected for Canada and Germany, the VAR was estimated in first differences.
Results using H-P filtered levels were qualitatively similar.

1.2 Identification

In order to evaluate the effects of technology shocks and the subsequent monetary responses, we specify a model in which we identify technology using both long-run restrictions. The MA representation of our structural VAR is

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

where $Y_t = \left[\Delta x_t \; \Delta n_t \; \pi_t \; r_t - \pi_t \; \Delta m_t\right]'$ and $\varepsilon = \left[\varepsilon^x \; \varepsilon^n \; \varepsilon^p \; \varepsilon^r \; \varepsilon^m\right]'$. $C(L)$ is a polynomial matrix in the lag operator, x_t denotes the log of labor productivity, n_t is the log of employment index, π_t is the annualized inflation rate computed from the GDP deflator, r_t is the short-term real T-bill rate, and Δm_t is the growth rate of money.[6]

As per table 1, we tested and failed to reject unit roots for productivity and employment; therefore, these variables enter the VAR in first differences.[7] Inflation and the real interest rate enter the VAR in annualized rates.[8] 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.

There exist some alternative schemes for identifying technology shocks. Uhlig (1999) shows that sign restrictions on the impulse responses can be used to identify monetary policy shocks. Uhlig (2003) identifies a technology shock as that which generates a fixed forecast-error variance taken from a calibrated theoretical model at the designated horizon. In this case, though, the calibrated model determines the identification and no inference can be drawn from the cross-sectional variance. Finally, Francis, Owyang, and Roush (2005) identify technology as that which maximizes the forecast-error variance

[6]Output does not enter explicitly into the model. Instead, the output response is 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 unit root tests fail to reject the presence of a stochastic trend in employment. To check the robustness of the results, we also detrended employment using the H-P filter and reestimated the model using employment in levels. These results are consistent with employment entering in first differences.

[8]In addition to these data, we estimated a five-variable model that included a trade-weighted exchange rate and a seven-variable VECM that included consumption, investment, and velocity. Results were unchanged. We forgo formal discussion of these alternative models here, as it introduces additional complexity into the theoretical model and obfuscates comparisons.

of labor productivity. They show that the resulting impulse responses for the United States are qualitatively similar to those obtained from the long-run restriction identification.

2. Empirical Results

To ease comparison of the results across studies, in figure 1 we first present the response to a one-standard-deviation technology shock for the post-Volcker disinflation in the United States. We note here that productivity and, hence, output for each country respond as expected, yielding permanent increases in each variable.[9] The estimated technology shock induces a brief 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. The Federal Reserve responds to lower inflation by decreasing the nominal interest rate; the relative decline in the nominal rate and inflation is such that there is a brief rise in the real rate.

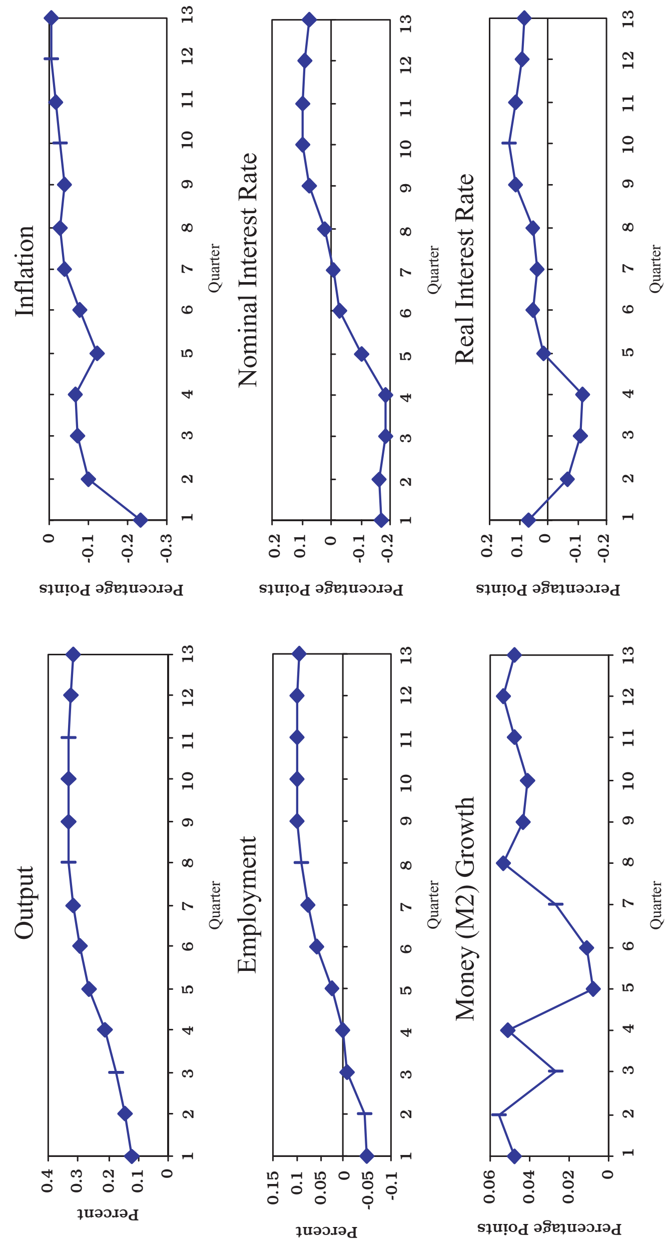
These results, somewhat consistent with GLV, might suggest that during the Volcker-Greenspan era, the Federal Reserve employs an optimal monetary rule. In GLV the technology shock is inflationary, so the Federal Reserve's optimal response is to raise the nominal rate. In our case, the Federal Reserve responds by injecting money and lowering the nominal rate in order to combat lower inflation.[10] The Federal Reserve achieves, according to the empirical evidence, long-run price stability, but does not completely damp out all of the short-run price effects.

In order to facilitate further discussion, we collect the remaining countries (including the pre-Volcker United States) 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

[9] Because we will discuss multiple countries simultaneously, we present only the point estimates for the impulse responses for select variables. The full sample of impulse responses with their associated 68 percent bootstrapped error bands are supplied in an appendix. We include the responses of both money growth and the log level of money, as well as the labor productivity response.

[10] The difference between our impulse responses and those of GLV stems from the inclusion of money growth in our baseline VAR. Our results are identical to GLV when we exclude money growth.

Figure 1. Empirical Responses for US (VG)



responses of both real and nominal interest rates, inflation, money, and employment to a one-standard-deviation technology shock for the first country grouping (France, Japan, and the postbreak United Kingdom) are depicted in figure 2. Employment for these countries, while declining in the short run, rises overall.[11]

For this first grouping, the central bank raises the nominal interest rate in response to a technology shock, although Japan's response is somewhat delayed. The real interest rate for two of the three countries declines in the short run. However, for all three countries, it rises within a few quarters and remains either positive or statistically negligible. Long-run stabilization of the real rate is accomplished through a rise in the nominal interest rate in response to an increase in prices. The short-run fall in the real rate in France and Japan is due to the sizable increase in inflation on impact in both countries.

The point estimates for the impulse responses to the technology shock for the second country group—consisting of Canada, Germany, the prebreak United Kingdom, and the United States (MBM)—are reported in figure 3. This group is characterized by an overall decline in the nominal rate and relatively persistent declines in employment (usually more than seventeen quarters) and inflation. This persistent reduction in employment is theoretically consistent with a job-destructive technology shock (see Caballero 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.[12] Since these countries experience deflationary technology shocks, the central bank maintains the real interest rate via a reduction in the nominal interest rates and, for most countries, a reduction in the rate of money growth.

[11] France's employment response is slightly different. It rises in the short to medium run but turns negative after fifteen quarters.

[12] Canada's real rate rises in the short run but is persistently negative after five quarters, while the U.S. prebreak rate is negative on impact but is close to zero in the long run.

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

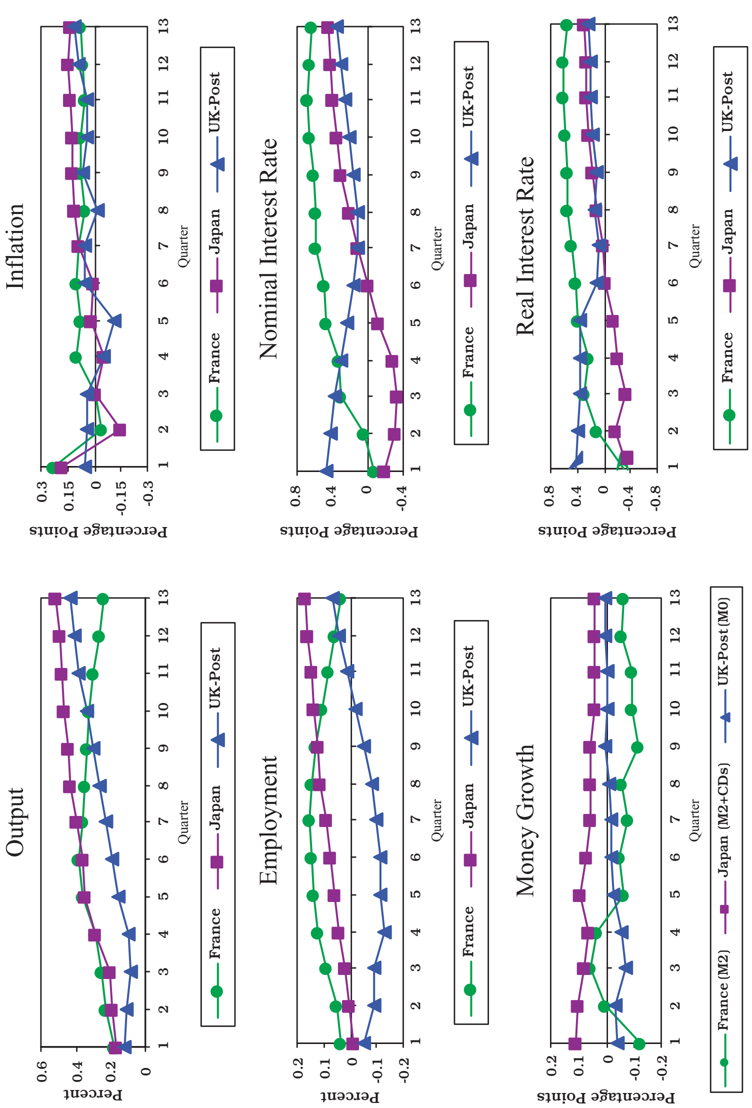
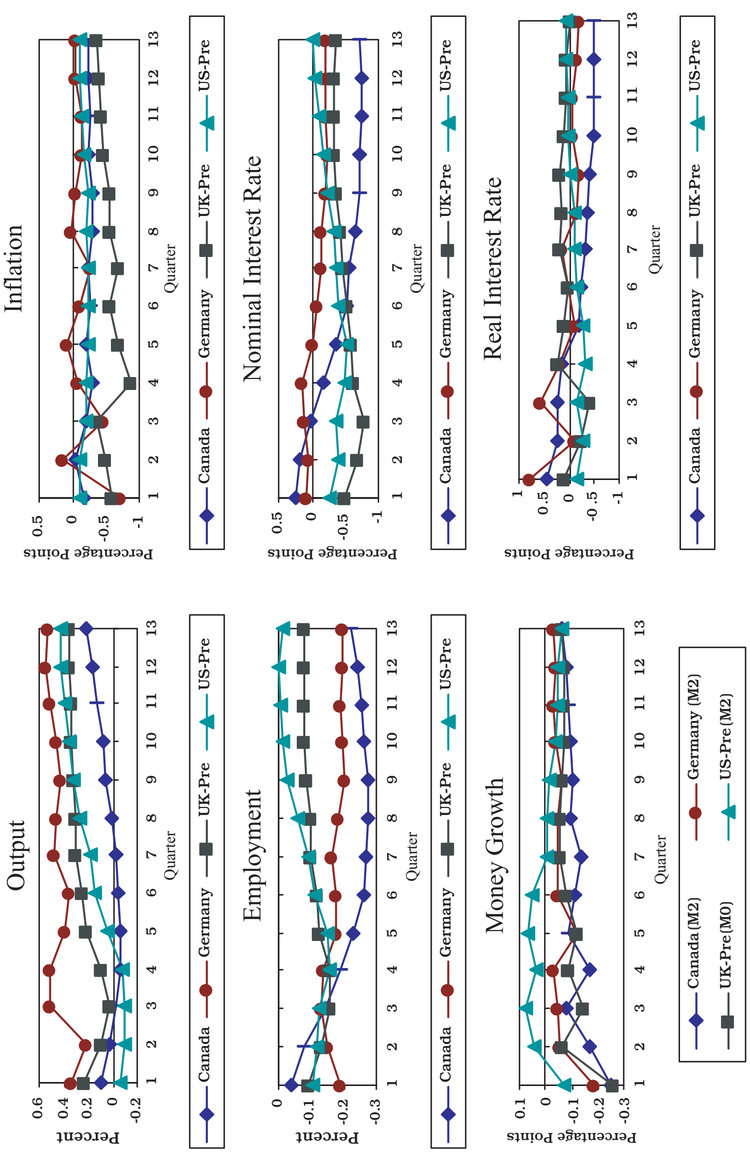


Figure 3. Empirical Responses for Group 2 (Canada, Germany, UK-Pre, US-Pre)



The final country to be considered is Italy, whose impulse responses are shown in figure 4. 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, there is a significant rise in prices between two and five quarters after the initial shock. The monetary authority responds to the technology shock with a (large) increase in the nominal interest rate, leading to a rise in the real interest rate.

Figures 1 through 4 report point estimates and, hence, do not reflect that the impulse responses are computed with uncertainty, which could affect our country groupings. In an effort to gauge this uncertainty, we conducted Monte Carlo experiments to determine the percentage of draws of the joint impulse responses for each country that satisfies our grouping restrictions. Results from these experiments are reported in table 2. Evident from these experiments is that, except for the postbreak U.K. sample, the majority of draws satisfy our grouping restrictions.[13] Grouping countries based on statistically significant responses yields results similar to those presented here.

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 responses vary 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.[14] In order to explain this cross-country variation, we propose a representative agent model in the following section.

3. Model

The model we present is a modified version of the model proposed in King and Wolman (1996) and incorporates both a technology shock

[13]Although the postbreak U.K. sample impulse responses meet the joint group 2 restrictions in less than half of the draws, the sample qualifies for other groups even more infrequently. Thus, we have chosen to categorize the postbreak U.K. sample based on the restrictions its responses meet most often.

[14]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 most cases, the comovement is positive.

Figure 4. Empirical Responses for Group 3 (Italy)

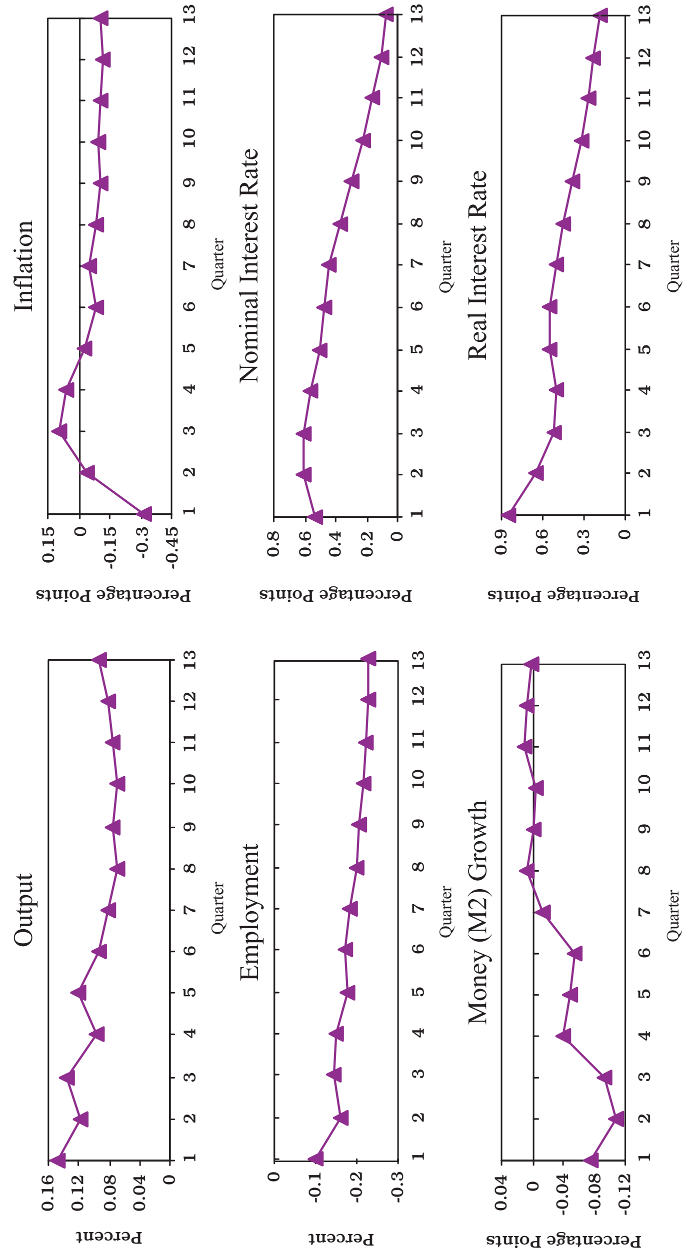


Table 2. Uncertainty

Country	Percentage of Runs Meeting Restrictions*
Canada	60%
France	68%
Germany	89%
Italy	71%
Japan	75%
UK-pre	61%
UK-post	47%
US-pre	73%
US-post	58%

*5,000 Monte Carlo draws from the posterior distribution for the impulse response.

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 targeting money growth 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 face capital adjustment costs and maximize profits under a Calvo (1983) pricing scheme. Finally, the central bank can adopt either a Taylor rule or a money-growth-targeting rule.

We could incorporate additional model features to enhance realism at the expense of expositional efficacy. That is, increasing the number of model features—even those with well-known implications—can introduce enough cross-sectional variation in responses that it becomes impossible to isolate the source. We attempt to avoid this problem by incorporating only features that are both possible causes of cross-country differences and yield potential, testable explanations. Our goal is to write the most parsimonious model possible that still may generate sufficient cross-sectional variation to explain our empirical results.[15] Our model follows.

3.1 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

[15] Sticky wages (Smets and Wouters 2005), for example, deliver more persistence than sticky prices but yield nearly equivalent aggregate results for technology shocks. Habit formation in consumption (Boldrin, Christiano, and Fisher [2001] and Francis and Ramey [forthcoming]) is used in conjunction with investment adjustment costs to match empirical movements in stock prices and generate a decline in short-run employment. However, we viewed testing for cross-country variation in habit formation as problematic.

undertake real consumption activity. The form of the shopping time technology is

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

with $h'(\cdot) < 0$.

3.2 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,

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

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 and $\Phi\left(\frac{i}{k}\right)$ 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 that firms do not adjust prices and with probability $1 - \eta$ that 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 that adjusted their price j periods ago.

The coefficient A_{t+j} in (2) is a productivity shifter that 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 while matching the empirical identification scheme.[16] 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 alternative policy rules.

3.3 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:[17]

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

   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.

[16] We examined cases in which the technology shock was stationary yet persistent. We found no qualitative differences in the theoretical impulse responses. We concluded that cross-sectional differences in this speed of adjustment were not responsible for the qualitative differences in response to technology shocks (although a more quantitative examination might consider this as a free parameter). Thus, we forgo discussion of these alternative processes here.

[17] Here, we deviate from King and Wolman (1996). In their model, they do not explicitly model a Taylor-type rule of this form.

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 setup of the model, the following first-order conditions obtain:

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

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

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

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

and

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

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.

4. 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. In table 3, we offer four model parameterizations that characterize a variety of alternative responses to a positive technology shock.[18] The differences in the price responses underlie variations in the employment response to technological innovations.

[18]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

Our goal is to generate theoretical impulse responses. To this end, we linearize the model around its steady-state growth path (King and Watson 1998). Figure 5 plots the theoretical impulse responses of selected variables to a 1 percent positive shock to technology under the Taylor rule for the first parameterization, which we henceforth term a *creative* technology shock. 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 technology 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, Galí, and Gertler 2000), responds by raising both the nominal and real interest rates to counteract rising prices.

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. One major difference between these two specifications is how the decline in employment is generated. When the policymaker employs a Taylor rule in this parameterization, 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.

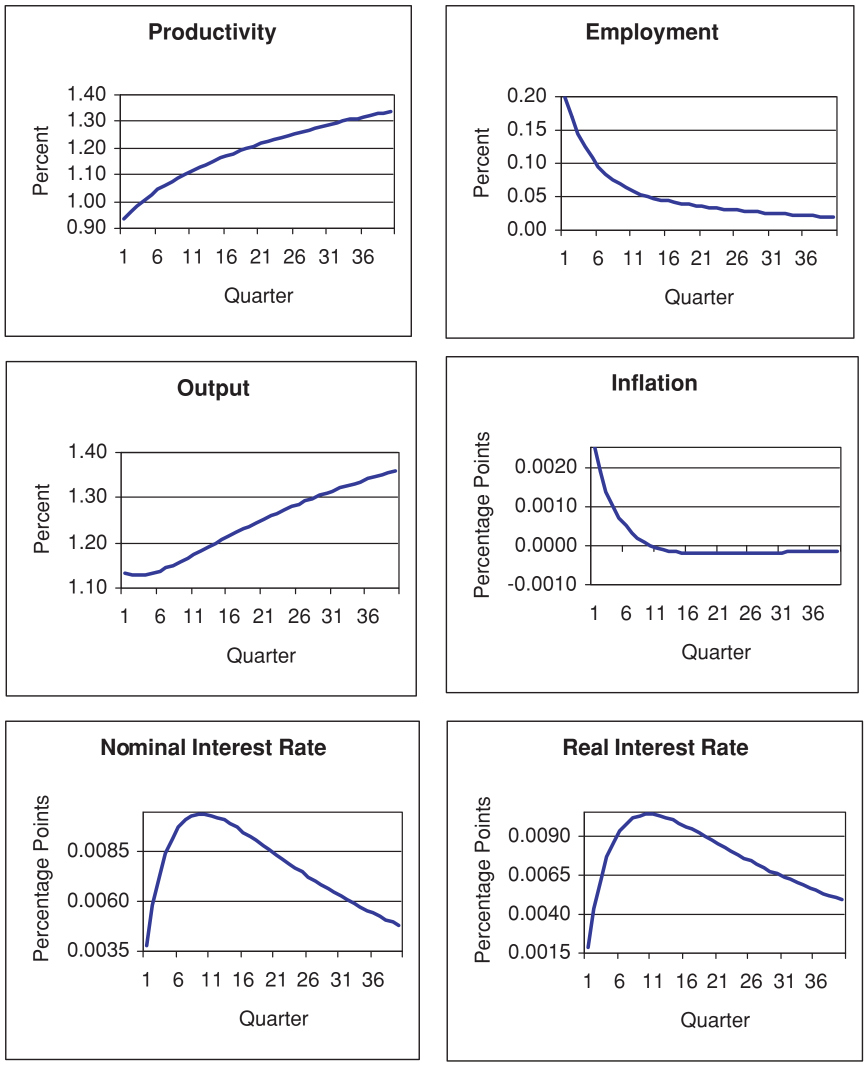
In the case of money-growth targeting, the level shift in output forces the consumer to spend more time shopping. In the previous parameterization, the central bank injects liquidity by dropping the interest rate, thereby decreasing the shopping time cost. Here, the

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.

Table 3. Model Parameterizations

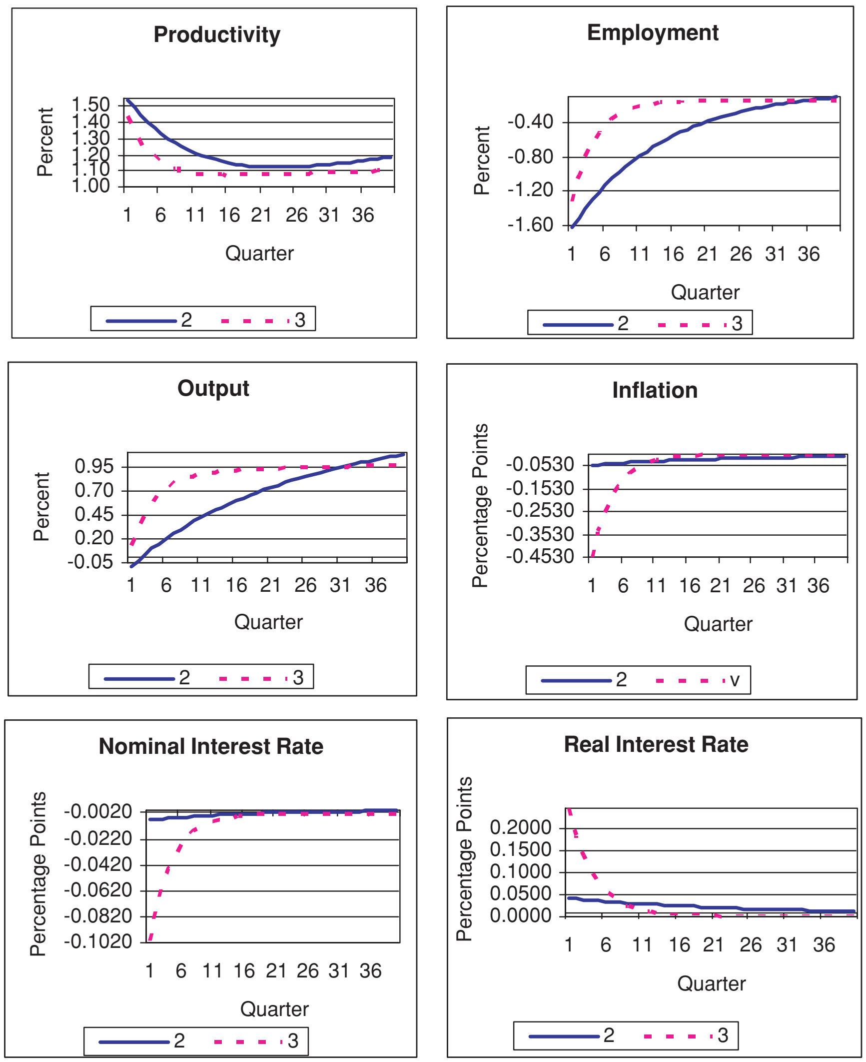
	Group 1	Group 2		Group 3
	Taylor Rule	**Money Target**	**Taylor Rule**	**Taylor Rule**
Parameter/Model #	**1**	**2**	**3**	**4**
Own price elasticity (ε)	4.33	4.33	4.33	4.33
Prob. firm does not adjust price (η)	0.90	0.75	0.75	0.75
Coefficient on $h(\cdot)$ (ς)	0.0116	0.0116	0.0116	0.0116
Curvature of $h(\cdot)$ (u)	0.8004	0.8004	0.8004	0.8004
Intercept of $h(\cdot)$ (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 (π)	0.0122	0.0122	0.0122	0.0122
Investment adjustment cost (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

Figure 5. Theoretical Responses Parameterization 1



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

Figure 6. Theoretical Responses Parameterizations 2 and 3



bank's policy rule.[19] The relative tightness in money also produces the decline in prices.

[19] 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

Finally, we present a fourth parameterization in figure 7 that reflects a policymaker employing a Taylor rule with a low weight on inflation but an even lower weight on output. 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.

We summarize the individual effects of the varied parameters as follows: higher capital adjustment costs cause employment to fall since investment is slow to adjust and consumption demand is curbed with sticky prices, which forces households toward more leisure. Price and interest rate responses depend jointly on the degree of price stickiness and the nature of the monetary policymaker's rule. Since prices are sticky, a relatively higher coefficient on inflation in the Taylor rule lowers the magnitude of the price response. However, the instability of the Taylor rule under parameterization 4 causes the responses of interest rate and inflation to be longer lived even though they are smaller in magnitude.

5. 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 that the empirical impulse responses from section 2 differ across countries. Here, we consider whether variations in the parameters that spur differences in the theoretical model can be possible explanations for these empirical cross-country differences.[20]

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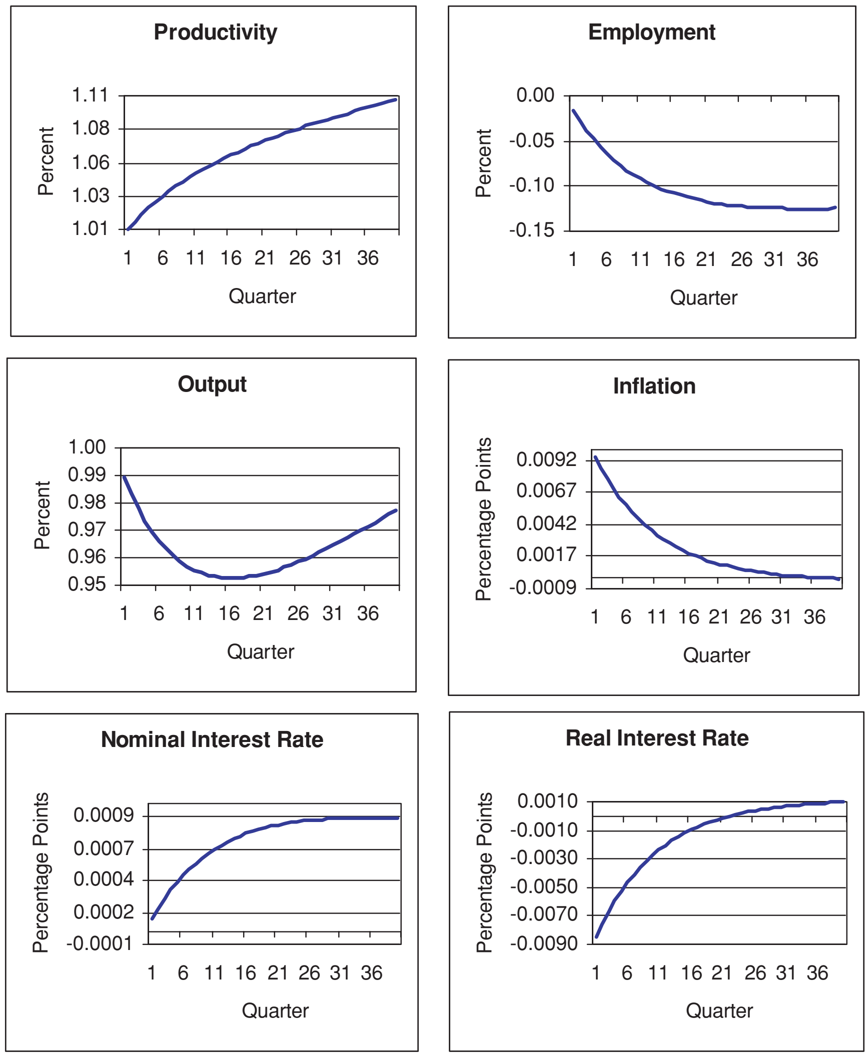
this wedge is expected to diminish over time, expected real wages rise and agents reduce their short-run labor supplied due to the intertemporal substitution effect. See figure 6 in King and Wolman (1996).

[20]We acknowledge that examination of the responses to other types of shocks (e.g., monetary policy shocks, capital tax shocks) might prove fruitful

Figure 7. Theoretical Responses Parameterization 4



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

in identifying cross-country differences. However, this is not our focus and we leave this to future research.

central bank, the parameters of the policy rule, and capital market rigidities. 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. However, before we conclude that these differences in the impulse responses can truly be attributed to these country characteristics, we explore further evidence. We conduct these tests in this section.

5.1 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 money growth. We accomplish this by evaluating the statistical significance of the money-growth impulse responses (see GLV figure 8 and their analysis).

During the sample periods, the responses of the money-growth rate in Germany is statistically negligible, which suggests that the Bundesbank seems to behave as though it targets money growth. 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 statistically significant on impact and not suggestive of the Federal Reserve targeting money growth. Additionally, for Canada and the prebreak United Kingdom, the money-growth-rate responses are also negative on impact, providing some evidence against money targeting by the Bank of Canada and the Bank of England. While the point estimates for the responses for these countries are negative, they are not significant at the 5 percent level. There remains some possibility that Canada and the prebreak United Kingdom are targeting money. Fortunately, our theoretical model allows us to make a further test of money targeting by considering the rigidity of capital markets.

5.2 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 adjustment cost is unavailable, we

Table 4. Cross-Country Differences

	Detrended Investment Volatility*	Taylor Rule Coeff.	
		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-targeting rule.
****Since Germany was estimated with a linearly detrended labor coefficient, its output coefficient is not directly comparable to that of the other countries.
Note: Taylor rule coefficients extracted from:
[a]Clarida, Galí, and Gertler (2000).
[b]Clarida, Galí, and Gertler (1998).
[c]Nelson and Nikolov (2004).
[d]Fougere (2001).

consider a crude proxy of the capital market rigidity in the volatility of quarterly investment. We posit that a higher capital adjustment cost implies a greater rigidity in the capital market and, thus, lower investment volatility. The first column of table 4 shows the detrended investment volatility for each country.[21]

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

The theoretical model predicts that all the countries in group 1 (France, Japan, and the postbreak United Kingdom) and the potential money-growth-targeting country in group 2, Germany, should have low capital adjustment costs and, thus, more-volatile investment. On the other hand, Canada, the prebreak United Kingdom, the United States (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. Germany, however, has investment volatility inconsistent with the theoretical prediction. Germany's volatility is relatively too low as a money-growth-targeting country.[22] Canada's volatility is relatively higher than expected if it has truly adopted a Taylor rule, but is consistent with the hypothesis of money targeting.[23]

5.3 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 responses for Italy, the Taylor rule implied by the empirical model must be unresponsive 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 4.[24] Since these studies explicitly set out to model and estimate monetary policy reaction functions, in this regard, they

[22]We point out here that these results are merely suggestive. Rigidities in capital investment can enter through channels other than capital adjustment costs.

[23]Canada changed from money targeting to inflation targeting mid-sample (Bernanke et al. 1999). While we found no evidence of a break in the model, it remains plausible that the change occurred too late to significantly alter Canada's classification as a money-targeting country.

[24]Note that there are features of the theoretical model, such as capital adjustment cost and shopping time, that may not be captured in these empirical estimates, which may negate any direct comparison of the two. However, we proceed with the comparison under the assumption that either (i) these factors affect (contemporaneous) output and employment found in the Taylor rule or (ii) their influence is not sufficient to render the comparison useless.

provide more accurate coefficients than those from our interest-rate equations.

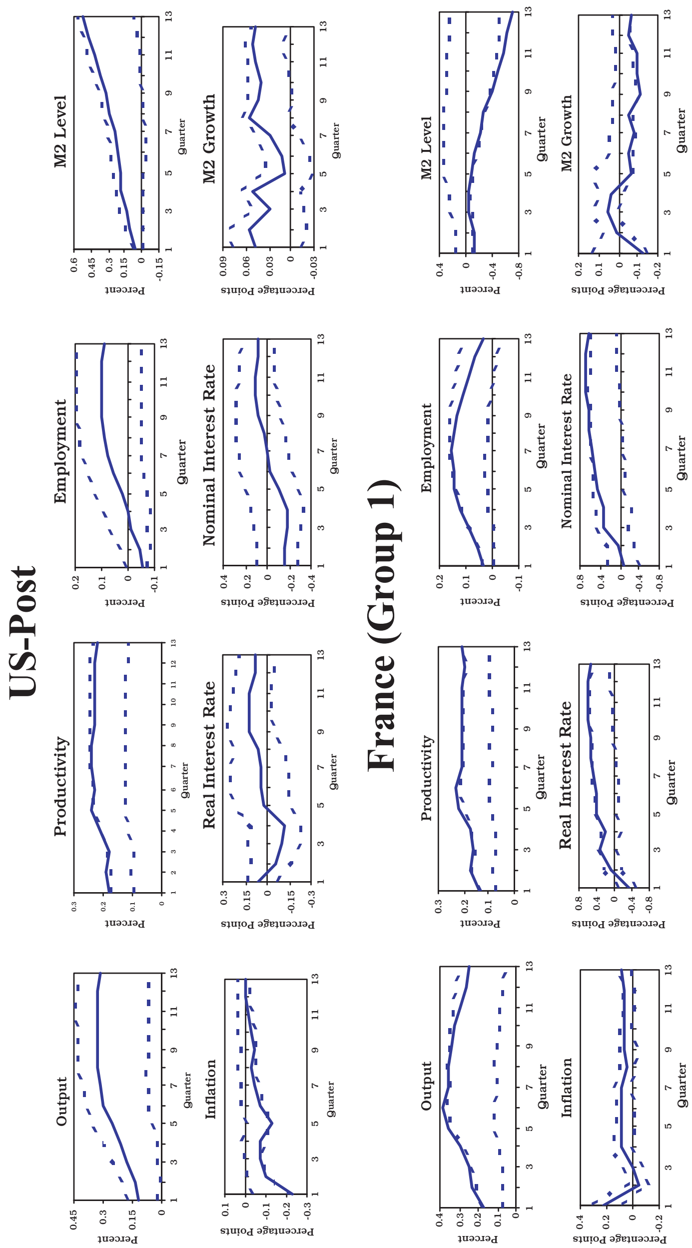
Three key results are suggested from the Taylor-rule equations obtained from the literature. First, the Taylor rule for each of the group 1 countries has an inflation coefficient statistically equal to or greater than 1 and an output coefficient less than 0.5. This is consistent with the parameterization from our theoretical model and the relatively high investment volatility discussed in the previous section. Second, the prebreak Bank of England appears relatively too responsive to fluctuations in output versus inflation. This, coupled with the United Kingdom's relatively low investment volatility, supports the hypothesis that the prebreak United Kingdom 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 result consistent with previous literature (Bernanke et al. 1999). Third, the Bank of Italy appears relatively unresponsive (compared with 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.

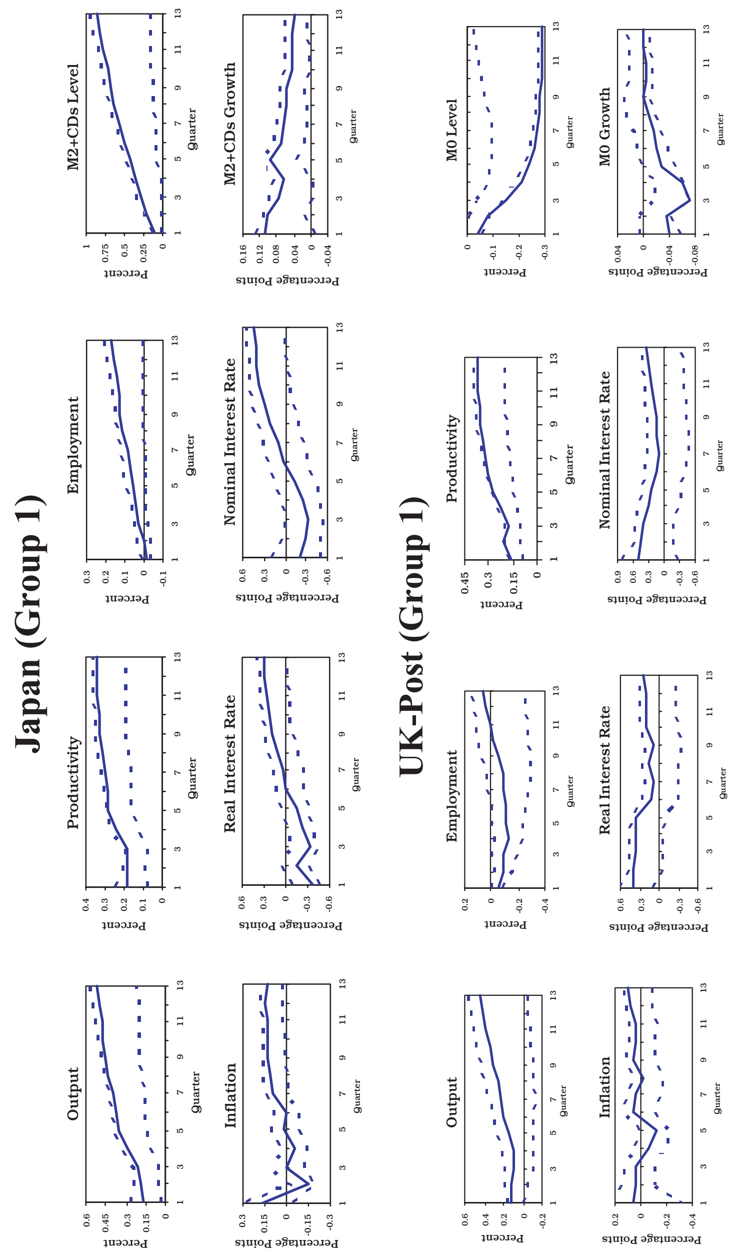
6. Conclusion

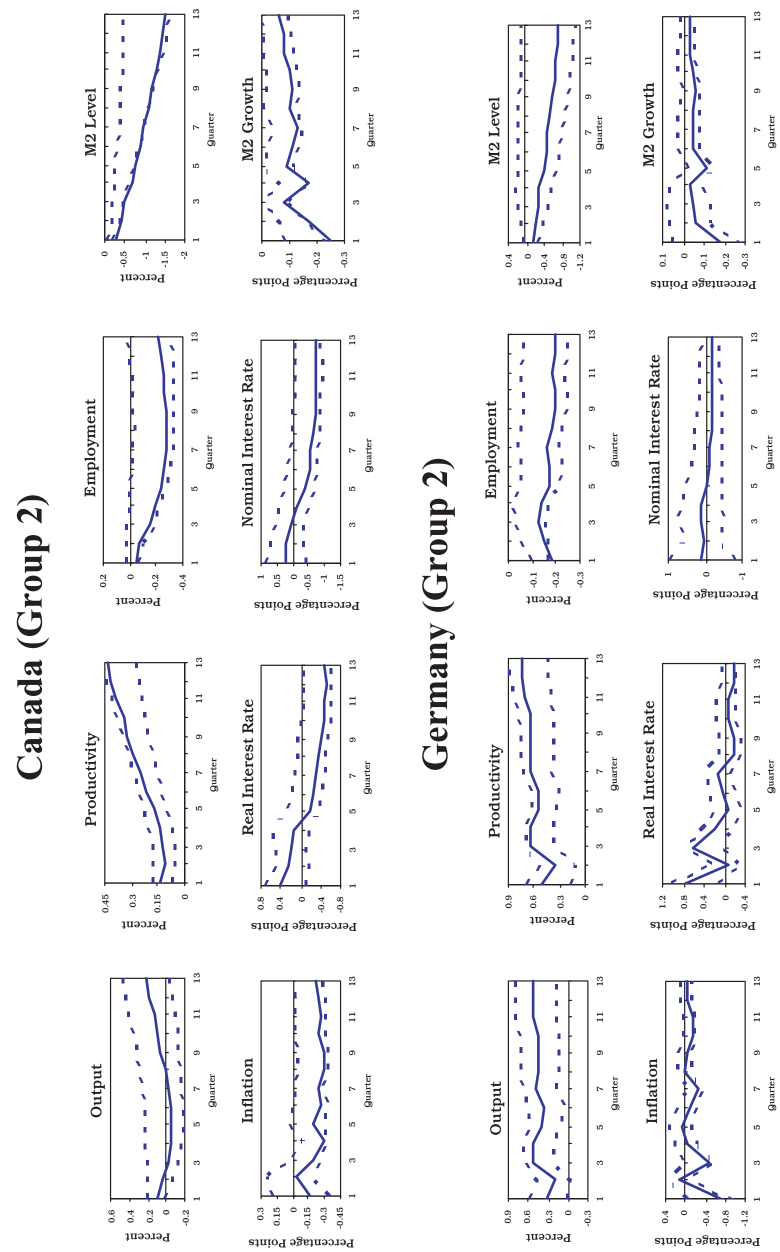
In this paper, we extend the empirical analysis of Galí (1999) and Galí, López-Salido, and Vallés (2003) to an international context. We find considerable cross-country variation in the response to the identified technology shock. In particular, we identify three subgroups consisting of countries whose 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.

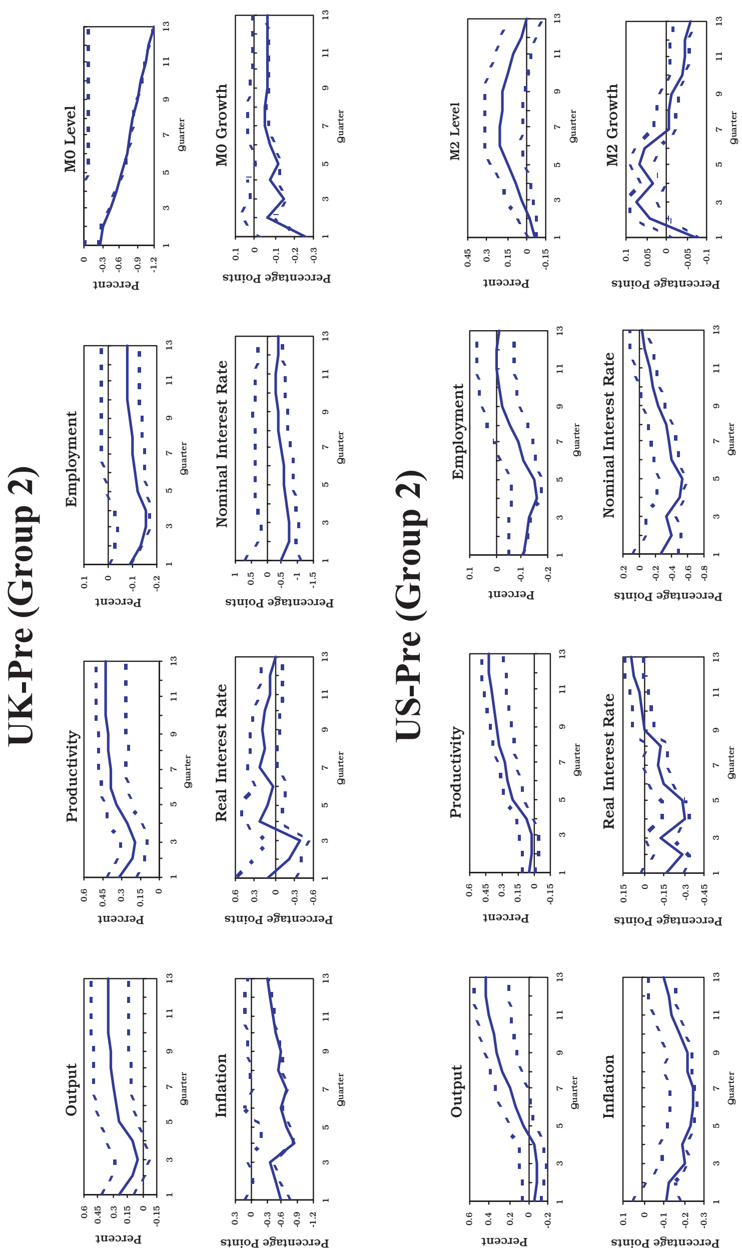
Using a theoretical model adapted from King and Wolman (1996), we find that the empirical responses can be matched with theoretical responses. Differences in these theoretical responses can be attributed to alternative policy rules and changes in the cost of capital adjustment. Further tests verify that 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.

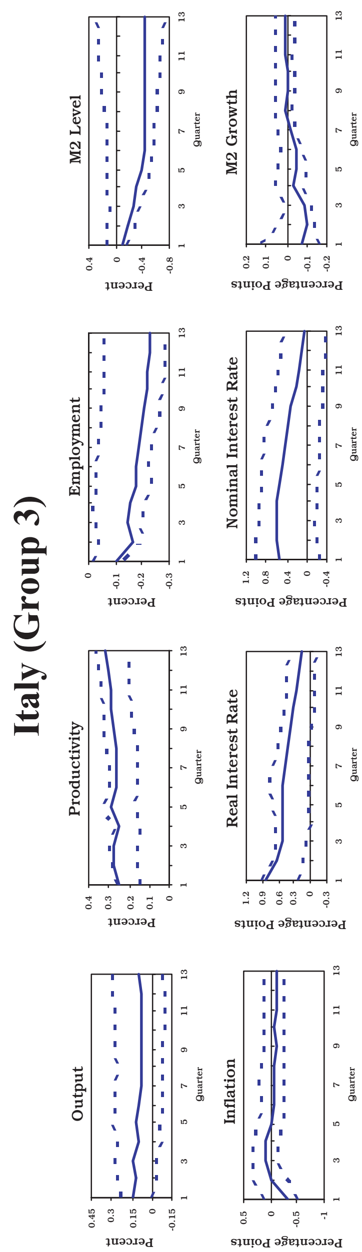
Appendix. Empirical Responses for all Variables by Group and Country (With 68% Bootstrapped Error Bands)




Japan (Group 1)
Output
Productivity
Employment
M2+CDs Level
Inflation
Real Interest Rate
Nominal Interest Rate
M2+CDs Growth
UK-Post (Group 1)
Output
Employment
Productivity
M0 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M0 Growth
Percent
Percentage Points
Quarter


Canada (Group 2)
Output
Productivity
Employment
M2 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M2 Growth
Germany (Group 2)
Output
Productivity
Employment
M2 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M2 Growth
Percent
Percentage Points
quarter


UK-Pre (Group 2)
Output
Productivity
Employment
M0 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M0 Growth
US-Pre (Group 2)
Output
Productivity
Employment
M2 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M2 Growth
Percent
Percentage Points
quarter


Italy (Group 3)
Output
Productivity
Employment
M2 Level
Inflation
Real Interest Rate
Nominal Interest Rate
M2 Growth
Percent
Percentage Points
quarter

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