Essays on Monetary Economics and Applied Econometrics

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To my father, who fostered a curious child.
To my mother and sister, who told me to work less.
To Peggy, my best reason to do as they said.
And to the Almighty, who gave me them all.

Contents

Acknowledgments

When I came to Stockholm in 1998 (after a Msc in Barcelona) I did not have much first-hand information on the PhD. The faculty list and the course offer in monetary economics and in econometrics (my main interests) looked promising though, and the financial conditions favorable. I never regretted that decision, not even during the grey winter months (that is to say, between October and May). In fact what I found exceeded my expectations: high ratio of professors to students, informal environment, accessible professors, superb hardware and software facilities, low teaching load, efficient and helpful secretaries.

Still, having for several years cultivated the dream of studying in a university overseas, I kept nurturing that dream for some time after my arrival. I finally stayed on this side of the Atlantic, and I have not regretted that choice either. The ones close to me were glad, and I with them. But I also believe that my studies did not suffer: I have attended courses (only to mention the field of monetary economics) with Jordi Gali, Fabio Canova, Lars Svensson and Paul Söderlind, and mini-courses with Thomas Sargent, Glenn Rudebusch, Ellen McGrattan and Larry Christiano. Beat that!

The series of courses and mini-courses organized at HHS is really impressive and spanning several fields. For what concerns macro, I wish to thank Lars Ljungqvist and the macro group for their effort. These courses are a very efficient way of being exposed to frontier research on many diverse topics and I have taken avid advantage of this opportunity. I have also appreciated the variety of scientific positions of both local and invited researchers.

If the overall environment for research in Stockholm has impressed me as very favorable, I have been even luckier in the choice of advisors. Paul Söderlind has been a constant reference since my first year at HHS. We discussed my ideas at their very birth, when they were vague and at the stage of mere conjectures. Once these ideas had taken written form, his comments were detailed, informative and fast to arrive, as fast as "Paolo, I don't have time today, but you'll have my comments by Wednesday". The first paper I wrote (the fourth in this monograph) is joint work with him. I learnt a lot from that experience, and writing on my own became much easier afterwards. We are currently working at another joint program, and I hope that with this thesis I will not loose the privilege of Paul's comments. I was immediately struck by an aspect of Paul's attitude: it seemed, from my first year, that he expected me to complete my dissertation with the same celerity as he was producing his comments. This kept some pressure on me, counter-balanced by his encouraging attitude. Paul: I hope it will not come as a disappointment that I have taken no less than 37 months to reach this point!

It has also been a privilege to receive comments and advice from Lars Svensson. Having accepted a position at Princeton, he will be greatly missed in Stockholm. We'll look forward to having him back during the summer months (nice timing of your commitments, Lars!).

The research department at the Swedish Central Bank hosted me during the summer of 1999. Talking daily to experienced researchers at such an early stage of my studies increased my excitement for the subject, and I hold a good memory of that period.

I also want to thank my fellow students, and in particular my office pals, Nina and Erik. The climate in the office may not have always been one of strenuous concentration, but it felt like a good place to be.

My original plan for the cover of this monograph was to include a picture of Karl Popper. On second thought I realized it was not appropriate. I would encourage any young researcher to read his "*Secrets of scientific success*". One such "secret" has been

particularly helpful to me, and I would be flattered if the reader could find its mark in this work. It reads: "*Every time that a theory appears to you as the only possible one, consider this as a sign that you have not understood the theory nor the problem that it was intended to solve*".

Stockholm, September 2001.

Introduction and summary

This dissertation collects five independent essays. I felt that there was a natural progression in the first three, which appear in the same order as they were written. Together they represent the result of my research on the empirical properties of the New-Keynesian framework for monetary policy analysis. This framework, which has come to dominate the discussion of monetary policy, is identified by a core structure consisting of three equations: an IS relation, a Phillips curve and a monetary policy rule. Variations on the theme abound, with important differences between models. Nonetheless, the label "New-Keynesian" is quite informative, since there are several qualitative predictions shared by all models to which the label is commonly attached. I will mention three, which are–in the same order–the focus of the first three essays: i) a contractionary monetary policy shock decreases output and prices ii) the drop in output is temporary (a form of long-run money neutrality) iii) for a given interest rate, the quantity of money is irrelevant to determine the path of output and prices.

Each essay deals with an alleged failure of the basic model on the above-mentioned predictions. The first two are found in previous literature. I argue that they are due to misspecification at the stage of building the econometric model corresponding to the theoretical model, and that the correctly specified model confirms the first two predictions. The third is an original contribution of this monograph, and my hope is that someone will take the challenge and either prove our methodology wrong or amend the model to take account of our results.

An Alternative Explanation of the Price Puzzle– the first essay—is maybe the major defense of the New-Keynesian framework offered in this monograph. Previous literature on VAR analysis of monetary policy has often found that a contractionary monetary policy shock drives prices upward for several quarters (the price puzzle). The most widely accepted explanation of the puzzle, due to Chris Sims, conjectured that the it was caused by the model's inadequate forecasting of inflation, and that variables useful in forecasting inflation other than those specified in New-Keynesian models should be brought into the VAR. The position of my article, instead, is that the finding of a price puzzle is due to a seemingly innocent misspecification in taking the theoretical model to the data: a measure of output gap is not included in the VAR (output alone being used instead), while this variable is a crucial element in every equation of the theoretical models. When the VAR is correctly specified, the price puzzle disappears.

Building on results contained in the first paper, the second–*Stronger Evidence of Long-Run Neutrality: A comment on Bernanke and Mihov*—improves the empirical performance of the model on the second prediction, namely that a monetary policy shock should have temporary effects on output. It turns out that the same misspecification causing the price puzzle is also responsible for overestimation of the time needed for the effects on output of a monetary policy shock to die out. The point can be proven in a theoretical economy, and is confirmed on US data.

Monetary Policy Without Monetary Aggregates: Some (Surprising) Evidence (joint with Giovanni Favara) is the third essay. It points to what seems to be a falsified prediction of models in the New-Keynesian framework. In this framework monetary aggregates are reserved a pretty boring role, so boring that they can be safely excluded from the final lay out of the model. Such a loss of splendor stems from the microfoundations of these models, where individuals and firms operate in an environment free of financial frictions. With money appearing in neither the IS nor in the Phillips equation, the models predict that a money demand shock, if identified by conditioning on contemporaneous values of all other variables, should have no effect on output, inflation and interest rate. If this prediction were supported by the data, I would not have a third article. However, the prediction seems to be quite wrong. The essay doesn't go much further, but Giovanni and I are hoping to reach (in future research) a better understanding of the mechanisms that could be at the root of this finding.

The last two articles deal with problems quite unrelated to one another and to those mentioned so far.

Inflation Forecast Targeting (joint with advisor Paul Söderlind), takes a step (a stroll?) outside the representative-agent framework. In RE models, all agents typically have the same information set, and therefore make the same predictions. However, in the real world variety is the salt of life, and even professional forecasters show substantial disagreement. This disagreement can have an impact on asset prices and transaction volumes, among other things. Within certain theoretical contexts, it can also affect investment and growth, particularly to the extent that it is associated with uncertainty. However, there is no unique way of aggregating forecasts (or forecast probability density functions) from individual agents into a measure of disagreement. The paper deals with this problem, using data from the Survey of Professional Forecasters, and surveying some proposed methods. The most appropriate measure of disagreement turns out to depend on the intended use, that is, on the model. Moreover, forecasters underestimate uncertainty or, which is the same, are over-confident in their forecasts (their error bands are too small). This finding is well established in experimental economics and behavioral finance, and it is interesting that we reach similar conclusions using different methodology and data.

Constitutions and Central-Bank Independence: An Objection to McCallum's Second Fallacy (joint with Giancarlo Spagnolo) is an excursion into the field of Political Economy, of which I had almost no knowledge; I was therefore often blindly holding Giancarlo's arm. There are, however, solid connections to monetary policy. First and foremost, the topic: delegation of monetary policy to a central banker, and design of the optimal delegation contract.

Most of the literature on monetary policy delegation assumes that the government can credibly commit to the delegation contract or that renegotiation involves a cost. However, the nature of these costs is not clear. The essay provides some foundations for the assumption that renegotiating a delegation contract can be costly by illustrating how political institutions can generate inertia in re-contracting, reduce the gains from it or prevent it altogether. Once the nature of renegotiation costs has been clarified, it is easier to see why certain institutions can mitigate or solve dynamic inconsistencies better than others.

Chapter 1

An Alternative Explanation of the Price Puzzle

Abstract:

This paper proposes a simple explanation for the frequent appearance of a price puzzle in VARs designed for monetary policy analysis. It suggests that the best method of solving the puzzle implies a close connection between theory and empirics rather than the introduction of a commodity price. It proves that the omission of a measure of output gap (or potential output) spuriously produces a price puzzle in a wide class of commonly used models. This can happen even if the model admits a triangular identification and if the forecasts produced by the misspecified VAR are optimal. In the framework of a model due to Svensson, the omission of a measure of output gap is shown to generate several other incorrect conclusions. When the model is tested on US data, all predictions are supported.

[0]I would like to thank David Domeij, Martin Eichenbaum, Lars Ljungqvist, and Anders Vredin for comments, and Charles Evans for providing data. A special thank to Paul Söderlind and Lars Svensson for comments and discussions. Financial help from the Wallanders Foundation is gratefully acknowledged.

1.1 Introduction

A vast literature has produced a reference framework for VAR analysis of monetary policy.[1] This reference VAR includes a commodity price index. The first VAR studies showed that omitting a commodity price and taking a short interest rate as the policy instrument produced a response of the price level to contractionary monetary policy shocks which was positive for many quarters, a finding that took the name of price puzzle. Sims (1992) proposed a rationale for the puzzle, and a way to fix it. His conjecture was that the information set available to policy makers may include variables useful in forecasting future inflation that the econometrician has not considered. If the VAR forecast of inflation is in fact a poor one, the VAR will mistakenly identify as shocks movements in the instrument of policy which are in fact endogenous responses to signals of future inflation, hence the finding that prices increase after a contractionary monetary policy shock.[2] Sims himself (1992) and later studies building on this suggestion have found that the puzzle disappears in the US, at least to a large extent, when the VAR is extended to include a commodity price index, a variable useful in forecasting inflation.

Besides solving the price puzzle, the inclusion of a commodity price changes the overall picture of monetary policy, in that the response of output to a MP shock is smaller and MP shocks are less important in the variance decomposition of output and of the federal funds rate (the policy instrument). Based on these results, Leeper, Sims and Zha (1996) warn that the exclusion of a commodity price can result in serious misspecification.

But while no one wants a price puzzle in their VAR, eliminating it sometimes comes at a cost since the models monetary economists work with do not include a commodity

[1] For a summary of this literature see Christiano, Eichenbaum and Evans (1998) or Leeper, Sims and Zha (1996). For a thorough presentation of the framework VAR for monetary policy analysis, see Favero (2000).

[2] Henceforth MP shock.

price. Of course the models are not meant to be complete representations of reality, and if monetary authorities do react to information not incorporated in the models, so much worse for the models. Nevertheless, having to include a commodity price in the VAR can be disturbing if a researcher is trying to bring a model to the data and she is interested in identifying all shocks, or anyway more than just MP shocks. For example, how are we to interpret the structural shocks if the VAR has two price levels, say CPI and commodity prices, but the theoretical model only has one? Adding variables to the VAR to solve the price puzzle makes interpretation and identification of shocks other than the MP shock more problematic and less model-driven. This paper argues that this situation may be avoidable.

The paper explores the possibility that the price puzzle may be due to something other than the omission of a variable useful in forecasting inflation (such as a commodity price). It shows that a wide class of models produces a price puzzle when subjected to a seemingly innocent misspecification common in applied research: output is used in applications while theory speaks of the output gap. The key requirements needed to produce a puzzle is that the monetary authority has the output gap in its policy function and that there are lags in the transmission of monetary policy, so that monetary policy affects output first and then inflation. The intuition is that since the output gap is omitted from the inflation equation, the interest rate spuriously appears in the equation with a positive coefficient, because the interest rate reacts positively to output gap increases.

The rest of the paper proceeds as follows. Section 2 presents a model for monetary policy analysis (Svensson, 1997), which incorporates in a simple form some key features of more complex models and admits a triangular identification scheme in the order: potential output (or output gap), output, inflation and interest rate (the model also admits a three variable representation including output gap and omitting output). Taking the Svensson model as the data generating process (DGP), this section explores analytically the consequences of estimating a three variable VAR that includes output but not the output gap. Among other things, a price puzzle emerges and the variance of the MP shocks is overestimated. The impact of a MP shock on output is also overestimated. The consequences of the misspecification are also shown through impulse responses, giving more color to the analytical results. These results extend to a rich class of models (Section 2.3). Section 3 takes the theory to the data, using as output gap a measure of capacity utilization produced by the Federal Reserve Board. A three variable VAR in the order: output gap, inflation and federal funds rate, is compared to a VAR including output rather than the output gap. The second VAR produces a large price puzzle, the first none. In the first VAR monetary policy is more endogenous and accounts for much less of the forecast error variance of output. Overall, the results produced by the first VAR are closer to those implied by theory and by larger VARs that include a commodity price. Section 3.1 estimates a four variable VAR (derived from the model) in the order: potential output, output, inflation, federal funds rate, allowing technology shocks to enter the picture. Technology shocks identified with short run restrictions taken from the model yield predictions consistent with the model and with the assumption (not imposed) that only technology shocks affect output in the long run. Section 4 argues that the commodity price index does not solve the price puzzle because it is useful in forecasting inflation, but rather because it is correlated with the output gap. Section 5 concludes.

1.2 A simple model for monetary policy analysis: Svensson (1997)

Svensson (1997) presents a model designed to capture some key features of the transmission mechanism of monetary policy. In fact, it is more generally a model of business cycle fluctuactions. The same model is used in Rudebusch and Svensson (1999), in Judd and Rudebusch (1998) and, extended to a small open economy, in Ball (1999). A forward looking version appears in Clarida, Gali and Gertler (1999) and in Svensson

(2000a and 2000b). Romer (2000) presents the same model as an improvement over the traditional *IS-LM*. The model consists of an *IS* equation, a Phillips curve and a Taylor rule obtained from the monetary authority's optimization problem. This core three-equation structure is shared by many recent New-Keynesian models for monetary policy analysis. A distinctive feature of the model is that it incorporates delays in the transmission of monetary policy. Monetary policy can affect output only with a lag. Output, in turn, affects inflation with a lag. Since the transmission from policy action to prices goes through output variations, monetary policy affects prices with two lags. The *IS* and Phillips relations are backward-looking, but section 2.3 shows that the main results hold in a very general framework, which includes forward looking and (totally or partially) microfounded models, the key requirement being that they display delays in the transmission of monetary policy. The *IS* relation is given by

$$y_{t+1}^{g} = \beta_y y_t^g - \beta_r (i_t - \pi_t) + \epsilon_{t+1}^{AD}, \tag{1.1}$$

where i_t is a short term interest rate set by the monetary authority, y^g is the output gap, defined as $y_t^g = Y_t - Y_t^N$, where Y_t is the log of output and Y_t^N the log of natural (or "potential") output. Natural output is assumed to follow an exogenous AR(1) process[3]

$$Y_{t+1}^N = \rho Y_t^N + \epsilon_{t+1}^N. \tag{1.2}$$

The Phillips curve is modelled as

$$\pi_{t+1} = \pi_t + \alpha_y y_t^g + \epsilon_{t+1}^{CP}. \tag{1.3}$$

All shocks are *iid*.[4] They are labelled: aggregate demand shock, technology shock and cost-push shock. Denote their standard deviations by σ_{AD}, σ_N, σ_{CP}. The model is

[3]Svensson (1997) makes no assumption about potential ouput. I follow Svensson (2000a and 2000b) in assuming an AR(1) process.

[4]The assumption of *iid* shocks is not particularly restrictive, as more lags can be added to equations (1) to (3) without any difficulty.

supplemented by a loss function for the monetary authority of the standard type

$$L_t = E_t \sum_{i=0}^{\infty} \beta^i [\lambda (y^g_{t+i})^2 + (\pi_{t+i} - \pi^*)^2]. \tag{1.4}$$

The solution takes the form of a Taylor rule (See Svensson (1997) for the closed-form solution. Since the model is backward-looking the discretionary solution and the commitment solution are the same):

$$i_t = \gamma_\pi \pi_t + \gamma_y y^g_t. \tag{1.5}$$

A monetary policy shock can be added by assuming that the Taylor rule is not followed deterministically. In that case, the shock ϵ^{MP} with std σ_{MP} is added to the Taylor rule.

1.2.1 The correct identification

AD shocks affect output but not inflation contemporaneously while *MP* shocks affect neither output nor inflation contemporaneously. Technology shocks increase output contemporaneously, leaving output gap, inflation and interest rate unchanged (the extension of Section 2.3 can accomodate technology shocks that affect all variables). The model delivers a three variable VAR with triangular identification in the order: output gap, inflation, interest rate (output gap and inflation can be reversed). Four variable formulations are also admissible, with any two of output, output gap, natural output, appropriately ordered. However, the model does not justify a three variable VAR including output, inflation and interest rate, which is the core of VARs that researchers have estimated in practice.[5]

[5] Two exceptions are Leichter and Walsh (1999) and Rudebusch and Svensson (1999).

1.2.2 From the VAR implied by theory to the empirical VAR, taking a false step

Let the *DGP* be given by equations (1.1) – (1.5). The Taylor rule is assumed deterministic for simplicity (all results generalize to the case $\sigma_{MP} > 0$: the Appendix shows the form taken by the system if $\sigma_{MP} > 0$, and a simulation for this case appears later in this section). Suppose that a researcher estimates a VAR including: output, inflation and interest rate (identified in the same order) but not the output gap.[6] What are the effects of this common and seemingly innocent change?

I start investigating the consequences of this misspecification by relating the true structural moving average representation to the one recovered by the misspecified VAR. To avoid mixing problems of misspecification and of parameter uncertainty due to small sample size, assume that the sample is large. The *DGP* has a VAR(1) representation

$$A_0 X_t = A_1 X_{t-1} + \epsilon_t,$$

which can be inverted to obtain the moving average representation of the *DGP*

$$X_t = \sum_{i=0}^{\infty} D_i \epsilon_{t-i},$$

where

$$X_t' = \{Y_t^N, Y_t, \pi_t, i_t\} \qquad \epsilon_t' = \{\frac{\epsilon_t^N}{\sigma_N}, \frac{\epsilon_t^{AD}}{\sigma_{AD}}, \frac{\epsilon_t^{CP}}{\sigma_{CP}}\} \qquad VCV(\epsilon_t) = I$$

$$D_0 = \begin{bmatrix} \sigma_N & 0 & 0 \\ \sigma_N & \sigma_{AD} & 0 \\ 0 & 0 & \sigma_{CP} \\ 0 & \gamma_y \sigma_{AD} & \gamma_\pi \sigma_{CP} \end{bmatrix} \tag{1.6}$$

The researcher is estimating a VAR in Y, π, i[7], working under the (erroneous) assumption that the moving average representation for the structural residuals is given by

[6] This group of three variables, with this same ordering, plus a commodity price index ordered after prices, is the core of the framework VAR model for monetary policy analysis (see, for example, Bagliano and Favero (1998) and Favero (2000)).

[7] Throughout the paper I refer to the VAR in output, inflation and interest rate as "misspecified VAR".

(asterisks denote the misspecified system)

$$Z_t = \sum_{i=0}^{\infty} D_i^* \epsilon_{t-i}^*,$$

where $Z_t' = \{Y_t,\ \pi_t,\ i_t\}$. The researcher identifies the system by assuming that D_0^* has a lower triangular structure (the system of equations is assumed recursive). Since $D_0^* D_0^{*\prime} = \sum$, where $\sum$ is the variance-covariance matrix of the reduced form residuals, the recursive assumption implies that $D_0^* = Cholesky(\sum)$. The researcher will then interpret D_0^* as

$$D_0^* = \begin{bmatrix} \sigma_{AD}^* & 0 & 0 \\ b_{21} & \sigma_{CP}^* & 0 \\ \gamma_y^* \sigma_{AD}^* & \gamma_\pi^* \sigma_{CP}^* & \sigma_{MP}^* \end{bmatrix}$$

If $\sigma_{MP} = 0$, the exclusion of Y^N produces no loss of fit in any equation, a result driven by the deterministic form of the Taylor rule that allows to retrieve Y^N (and thus y^g) with no error as a linear combination of the three variables of the system. Therefore the misspecified VAR produces optimal forecasts of inflation at all time horizons, excluding the possibility that the standard explanation for the price puzzle may be relevant in this setting. Consequently

$$\sum = D_0^* D_0^{*\prime} = [D_0 D_0']_2^4,$$

where $[D_0 D_0']_2^4$ is the 3×3 matrix obtained deleting the first row and the first column of $D_0 D_0'$.

$$\begin{aligned}
[D_0 D_0']_2^4 &= \begin{bmatrix} \sigma_N^2 + \sigma_{AD}^2 & 0 & \gamma_y \sigma_{AD}^2 \\ & \sigma_{CP}^2 & \gamma_\pi \sigma_{CP}^2 \\ & & \gamma_y^2 \sigma_{AD}^2 + \gamma_\pi^2 \sigma_{CP}^2 \end{bmatrix} = D_0^* D_0^{*\prime} = \qquad (1.7) \\
&= \begin{bmatrix} \sigma_{AD}^{*2} & \sigma_{AD}^* b_{21} & \gamma_y^* \sigma_{AD}^{*2} \\ & \sigma_{CP}^{*2} + b_{21}^2 & b_{21} \gamma_y^* \sigma_{AD}^* + \gamma_\pi^* \sigma_{CP}^{*2} \\ & & \gamma_y^{*2} \sigma_{AD}^{*2} + \gamma_\pi^{*2} \sigma_{CP}^{*2} + \sigma_{MP}^{*2} \end{bmatrix}
\end{aligned}$$

The relations between the actual and estimated shocks are straightforwardly obtained from the equalities in (1.7). b_{21} is correctly set to zero, since $\sigma^*_{AD}b_{21} = 0$. It follows that:

1. $\sigma^{*2}_{AD} = \sigma^2_N + \sigma^2_{AD}$. The variance of the labelled AD shock is the sum of the variances of the AD shock and of the technology shock The importance of AD shocks in the variance decomposition of output is overestimated.

2. $\sigma^{*2}_{AD} = \sigma^2_{AD} + \sigma^2_N$ and $\gamma_y \sigma^2_{AD} = \gamma^*_y \sigma^{*2}_{AD}$ imply $\frac{\gamma_y}{\gamma^*_y} = \frac{\sigma^2_{AD}+\sigma^2_N}{\sigma^2_{AD}} > 1$, that is the output gap coefficient in the Taylor rule is underestimated. Some simple algebra gives $\gamma_y \sigma_{AD} - \gamma^*_y \sigma^*_{AD} = \gamma_y \sigma_{AD}(1 - \frac{\sigma_{AD}}{\sqrt{\sigma^2_{AD}+\sigma^2_N}}) > 0$. This means that **the intensity of the response of the monetary authority to a one std AD shock is underestimated** even though the std of AD shocks is overestimated. The intuition is that some unforecasted movements in output are due to technology shocks, to which monetary policy does not respond. Since the misspecified VAR registers a small average reaction of the interest rate to unforecasted output movements, the coefficient γ_y in the Taylor rule is underestimated. The underestimation grows with σ_N.

3. $\sigma^2_{CP} = \sigma^{*2}_{CP}$, following from the fact that $b_{21} = 0$.

4. Finally, **the variance of MP shocks is overestimated**. To derive the result, start from (1.7), which sets $\gamma^2_y \sigma^2_{AD} + \gamma^2_\pi \sigma^2_{CP} = \gamma^{*2}_y \sigma^{*2}_{AD} + \gamma^{*2}_\pi \sigma^{*2}_{CP} + \sigma^{*2}_{MP}$. Use the results obtained so far, namely

(a) $\gamma^2_\pi \sigma^2_{CP} = \gamma^{*2}_\pi \sigma^{*2}_{CP}$

(b) $\sigma^{*2}_{AD} = \sigma^2_N + \sigma^2_{AD}$

(c) $\frac{\gamma_y}{\gamma^*_y} = \frac{\sigma^2_{AD}+\sigma^2_N}{\sigma^2_{AD}}$

to obtain

$$\sigma^{*2}_{MP} = \gamma^2_y \frac{\sigma^2_{AD}\sigma^2_N}{\sigma^2_{AD} + \sigma^2_N} > 0. \tag{1.8}$$

Even though the Taylor rule is deterministic, the VAR finds that the variance of the labelled MP shock is strictly positive. The intuition is that since the interest rate does not react in the same way to technology and AD shocks, when a movement in output (of a given amount) is observed the VAR will sometimes register a certain change in the interest rate (when the movement is caused by an AD shock) and sometimes a different change (when caused by a technology shock) and will be tricked into interpreting this as random behavior of the monetary authority.[8] If $\sigma_{MP} > 0$, the right-end-side of equation (1.8) gives a lower bound for $\sigma^{*2}_{MP} - \sigma^2_{MP}$. Notice that if $\sigma_N = 0$, all misspecifications disappear, as they should since in that case $y^g_t = Y_t$.

I now use the result that $\sigma^*_{MP} > 0$ to prove that the misspecified system will display a price puzzle. The strategy is to derive the coefficients of the inflation equation in the misspecified VAR.

Use the Taylor rule in (1.5) to obtain an expression for the output gap

$$y^g_t = \frac{1}{\gamma_y}(i_t - \gamma_\pi \pi_t), \tag{1.9}$$

and substitute it into the Phillips relation. This yields

$$\pi_{t+1} = [1 - \alpha_y \frac{\gamma_\pi}{\gamma_y}]\pi_t + \frac{\alpha_y}{\gamma_y} i_t + \epsilon^{CP}_{t+1}. \tag{1.10}$$

Equation (1.10) is both the inflation equation in the VAR and the structural equation of the recursive system, since $b_{21} = 0$ (see (1.7)) implies that Y_{t+1} has a zero coefficient. If $\sigma_N = 0$, it follows that $y^g_t = Y_t$, so there is no misspecification and (1.10) is equivalent to

$$\pi_{t+1} = \pi_t + \alpha_y Y_t + \epsilon^{CP}_{t+1}. \tag{1.11}$$

Y_t, π_t, and i_t are perfectly collinear and choosing between (1.10) and (1.11) is a matter of taste. On the other hand, if $\sigma_N > 0$, no other autoregressive representation fits as

[8] In this model the interest rate does not react at all to technology shocks, but the intuition applies more generally, as long as the monetary authority reacts differently to technology and AD shocks.

well as (1.10). Therefore OLS will retrieve (1.10). The reason why i_t appears with a positive coefficient in (1.10) is that movements in the interest rate help retrieve movements in the output gap, which is omitted. Since $\alpha_y/\gamma_y > 0$ and output does not appear in the equation, the impact of a MP shock (which causes i_t to be higher than forecasted) on inflation is estimated to be zero contemporaneously and positive at one lag. In other words, a positive response of inflation to a contractionary MP shock (a price puzzle) at lag one is guaranteed as long as the variance of the retrieved MP shocks is estimated to be strictly positive, which will be the case if $\sigma_N > 0$ (see equation (1.8)). The magnitude of the puzzle at lag one is given by $\frac{\alpha_y}{\gamma_y}\sigma^*_{MP}$, so it grows with the variance of technology shocks (see equation (1.8)). If the econometrician is not ordering the interest rate last she will obtain an even larger price puzzle, since (1.10) does not change and σ^*_{MP} is obviously larger.[9]

To gain further understanding of the puzzle, it is useful to show that the misspecified MP^* shocks are positively correlated with the true AD shocks and negatively correlated with the true technology shocks.

In the DGP, the one-step-ahead forecast error is given by

$$i_{t+1} - E_t i_{t+1} = \gamma_y \epsilon^{AD}_{t+1} + \gamma_\pi \epsilon^{CP}_{t+1}, \tag{1.12}$$

while the one-step-ahead forecast error in the misspecified model is given by

$$i_{t+1} - E^*_t i_{t+1} = \gamma^*_y \epsilon^{*AD}_{t+1} + \gamma^*_\pi \epsilon^{*CP}_{t+1} + \epsilon^{*MP}_{t+1}. \tag{1.13}$$

Asterisks denote the shocks obtained from the misspecified VAR. Since the assumption that $\sigma_{MP} = 0$ implies $E_t i_{t+1} = E^*_t i_{t+1}$, we can equate the right-hand-sides and use the results just obtained, namely $\gamma_\pi \epsilon^{CP}_{t+1} = \gamma^*_\pi \epsilon^{*CP}_{t+1}$, $\epsilon^{*AD}_{t+1} = \epsilon^{AD}_{t+1} + \epsilon^{N}_{t+1}$ to obtain as expression for ϵ^{*MP},

$$\epsilon^{*MP}_{t+1} = (\gamma_y - \gamma^*_y)\epsilon^{AD}_{t+1} - \gamma^*_y \epsilon^{N}_{t+1}. \tag{1.14}$$

[9]The existence of a price puzzle does not depend crucially on the fact that the central banker can observe inflation and output gap contemporaneously (see Section 2.3).

Since $cov(\epsilon_{t+1}^{AD}, \epsilon_{t+1}^{N}) = 0$ by assumption, using $\frac{\gamma_y}{\gamma_y^*} = \frac{\sigma_{AD}^2 + \sigma_N^2}{\sigma_{AD}^2} > 0$ gives

$$cov(\epsilon_{t+1}^{*MP}, \epsilon_{t+1}^{AD}) = (\gamma_y - \gamma_y^*)\sigma_{AD}^2 > 0, \tag{1.15}$$

$$cov(\epsilon_{t+1}^{*MP}, \epsilon_{t+1}^{N}) = -\gamma_y^* \sigma_N^2 < 0. \tag{1.16}$$

These results provide further intuition for the origin of the price puzzle: the misspecified monetary policy shocks are positively correlated with the true aggregate demand shock, which in turn raise inflation with a lag. Since at lag one the true monetary policy shocks cannot affect inflation, only the spurious part is active at lag one, so we are certain to find a price puzzle. Moreover, monetary policy shocks are spuriously correlated with technology shocks. This means that the misspecified impulse response of output to a contractionary monetary policy shock is contaminated by the response of output to a negative technology shock. If potential output is more persistent than the output gap, the response of output to a monetary policy shock will be longer lived than the true one.

There are more potentially erroneous conclusions that can be derived from the misspecified system. To illustrate them, I obtain the reduced form equation for output in the misspecified system. Start with the IS equation (1.1) and eliminate y_{t+1}^g, y_t^g using the definition, $y_t^g = Y_t - Y_t^N$. Move Y_{t+1}^N to the right-hand-side and substitute it using (1.2). This leaves ϵ_{t+1}^N and Y_t^N on the right-hand-side. Finally, eliminate Y_t^N from the right-hand-side by rearranging (1.9) as

$$Y_t^N = Y_t - \frac{1}{\gamma_y}(i_t + \gamma_\pi \pi_t), \tag{1.17}$$

which gives the equation for output in the misspecified model

$$Y_{t+1} = \rho Y_t + [(\rho - \beta_y)\frac{\gamma_\pi}{\gamma_y} + \beta_r]\pi_t - [(\rho - \beta_y)\frac{1}{\gamma_y} + \beta_r]i_t + \epsilon_{t+1}^{AD} + \epsilon_{t+1}^{N}. \tag{1.18}$$

Some implications of equation (1.18) are worth noticing.

- If $\rho > \beta_y$, for example when the output gap is stationary while technology has a unit root, AD shocks will appear to have a more persistent effect on output than they actually do.

- If $\rho > \beta_y$, the effect of a given interest rate shock on output one step ahead is overestimated, since the coefficient attached to i_t is larger than β_r. The same is true of CP shocks.

The derivation of (1.10) and (1.18) assumed that the Taylor rule is deterministic. The Appendix shows the form taken by the system if $\sigma_{MP} > 0$, and a simulation for this case appears later in this section. If $\sigma_{MP} > 0$, the misspecified system (Y, π, i) is no longer VAR(1), but VARMA(2,1). This implies that the econometrician who is selecting lag length for a VAR is likely to choose a VAR with more than one lag, and will produce sub-optimal fit and forecasts even is she estimates a VARMA(2,1).

A more complete picture of the consequences of the misspecification can be gained from looking at impulse responses. The experiment is as follows. Each graph plots the response of output or inflation or interest rate to a shock in the theoretical economy together with the response to the same shock in the misspecified three variable VAR (output, inflation, interest rate).

The model parameters are set as in Ball (1999): $\alpha_y = 0.4$, $\beta_y = 0.8$, $\beta_r = 1$. Reflecting the idea that potential output is a highly persistent process, I set $\rho = 0.98$. The standard deviations are $\sigma_{AD} = \sigma_{CP} = \sigma_N = 1$. For ease of comparison, the parameters in the Taylor function are not set to the optimal value in each case, but are kept constant at $\gamma_y = 0.5$, $\gamma_\pi = 1.5$.[10] These parameters are kept fixed. The only difference between Figure 1.1 and Figure 1.2 is the standard deviation of the true monetary policy shock. In Figure 1.1 $\sigma_{MP} = 0$, so all results are analytical. Recall that the differences between theoretical and misspecified responses cannot be accounted for

[10]The optimal value of the parameters of the Taylor function has a closed form solution given in Svensson (1997).

by parameter uncertainty. The response of output to a labelled AD shock is higher than the true one upon impact and more persistent thereafter, while the response of the interest rate to an AD shock is underestimated. In the low-right corner, notice that the estimated std of a MP shock, which is zero in the DGP, is a substantial 0.35. Therefore in the variance decomposition of all variables the role of MP shocks, which is truly zero, is estimated to be positive. The price puzzle has warning proportions. The response of output to a misspecified MP shock is highly persistent, reflecting the fact that the misspecified MP shocks are negatively correlated with the true technology shocks.

In the second experiment a stochastic element is added to the behavior of the monetary authorities by setting $\sigma_{MP} = 1$. The results are displayed in Figure 1.2. As previously argued, the misspecified system is no longer VAR(1) when $\sigma_{MP} > 0$, and impulse responses for the misspecified VAR have to be obtained numerically if we are to give the misspecified model its best chance.[11] Portmanteau test of residual correlation is first passed at four lags, so a VAR(4) is fit to the misspecified system. If less than four lags are chosen, the misspecifications maintain the same qualitative pattern but become larger. The response of the interest rate to an AD shock is underestimated, again as expected. Responses to MP shocks are once again those that display the most obvious misspecification. On the low-right corner, the std of the MP shock is overestimated. The price puzzle is substantial and can now be confronted with the true behavior of inflation in response to a MP shock. As for the response of output to a MP, not only is the size of the response overestimated, but the response is much longer lived than the true one (the reason being that the retrieved MP shocks are negatively correlated with the true technology shocks). These results extend without surprises to different combinations of ρ, σ_N, σ_{MP}.

In fact, the main results are valid if potential output is a non-constant deterministic

[11]The missspecified impulse responses are obtained by fitting a VAR on data generated by the DGP. The first 500 observations are not used in estimation. The VAR is estimated on 10000 observation to eliminate parameter uncertainty.

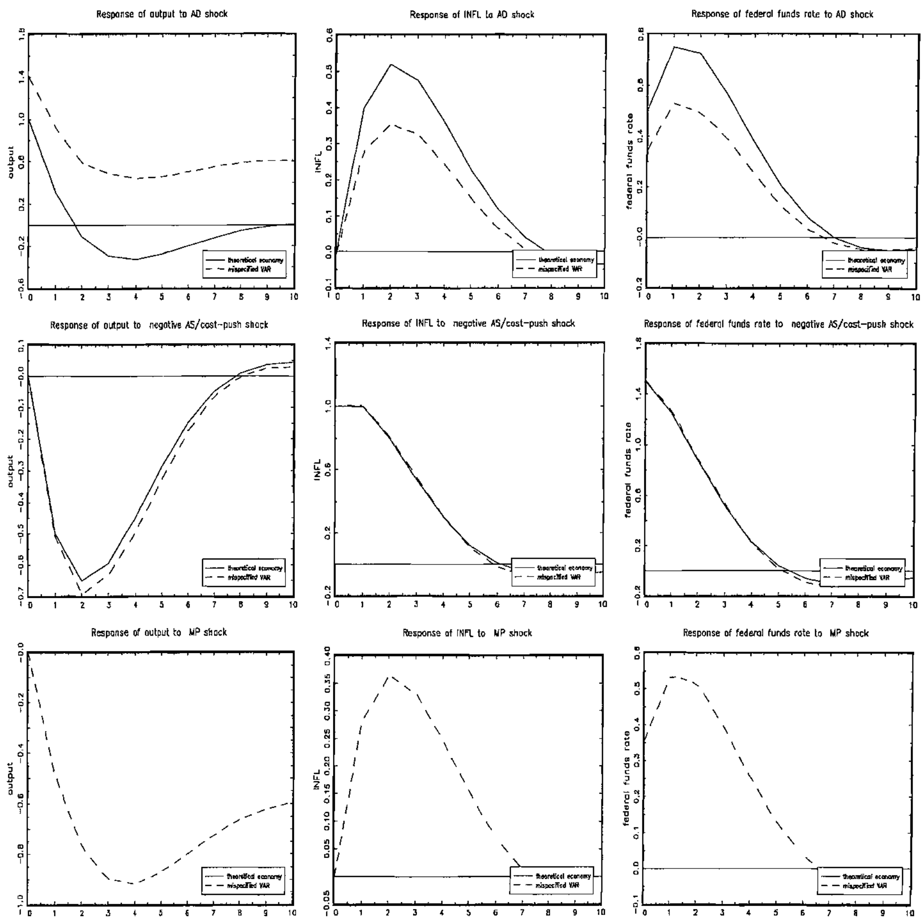

Figure 1.1: True impulse responses (thick line) and impulse responses from misspecified VAR (dashed line). $\sigma_{MP} = 0$.

function of time while the only exogenous variable in the misspecified VAR is a constant. In that case equation (1.10) does not change, while $\sigma^*_{MP} > 0$, since no combination of the included variables is perfectly correlated with the output gap: therefore there will be a price puzzle. Simulations using deterministic trends have shown that the effects of MP shocks in this case look much like in Figure 2.

1.2.3 Robustness of the main results to modifications in the model

The adoption of a completely specified model has allowed us to quantify the misspecifications. However, the result of a spurious appearance of a price puzzle holds in a wide class of models. The models in this class have a reduced form solution characterized by[12] *i*) inflation responds with a lag and positively to the output gap *ii*) the monetary policy authority can affect inflation with no less than two lags *iii*) the output gap appears with a positive coefficient in the monetary policy function and y^g_t cannot be reduced to a linear combination of: a constant, Y_t, π_t, and varibles dated $t-1$ or earlier.

Overestimation of MP shocks follow from the fact that the output gap appears in the true policy function

$$i_{t+1} = \gamma_y y^g_{t+1} + ... \tag{1.19}$$

Since the output gap is omitted in the misspecified model, assumption *iii*) implies that the fit of the equation must deteriorate (notice that i and y^g are both dated $t+1$, so the forecasting power need not deteriorate). Therefore $\sigma^*_{MP} > 0$.

The price puzzle generates from the fact that the policy instrument appears in the misspecified inflation equation to pick up the role of the omitted output gap. If the reduced VAR form (only variable dated t or earlier in the right-hand-side) of the true

[12] The conditions are sufficient, not necessary.

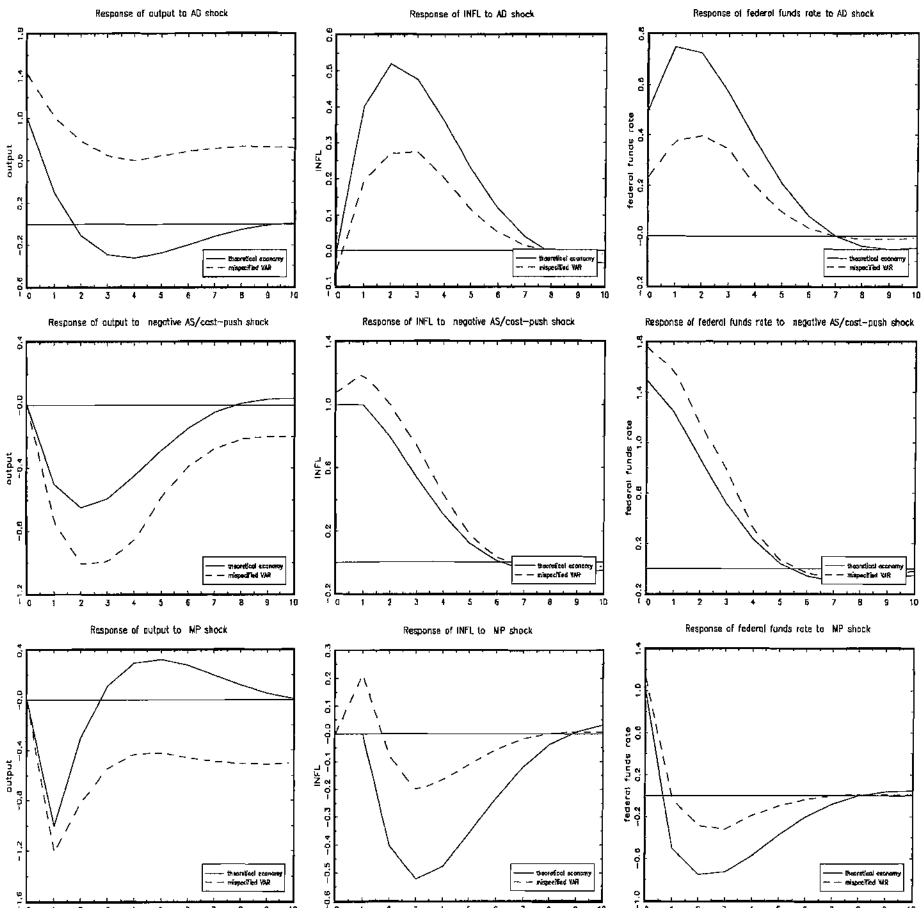

Figure 1.2: True impulse responses (solid line) and impulse responses from misspecified VAR(4) (dashed line). $\sigma_{MP} = 1$.

inflation equation is

$$\pi_{t+1} = \alpha_y y_t^g + ..., \tag{1.20}$$

and monetary policy cannot affect inflation contemporaneously or at one lag, then, rearranging (1.19) and plugging it in (1.20), we'll find a price puzzle feature in the misspecified inflation equation, since $\frac{\partial \pi_{t+1}}{\partial i_t} = \frac{\alpha_y}{\gamma_y} > 0$ and $\sigma^*_{MP} > 0$.

Notice that these assumptions can be satisfied by models that

- Include microfounded and/or and forward looking relationship, as, for example, in Svensson (2000a and 2000b) and Clarida, Gali and Gertler (1999).

- Have a fair amount of contemporaneous reactions. For example, technology shocks are allowed to affect all variables and potential output need not be exogenous. The only contemporaneous responses ruled out by assumptions are: inflation to AD shocks and all variables (except the interest rate) to MP shocks. In fact, the assumptions only guarantee that MP shocks can be identified using short-run restrictions, while all other shocks may not be.[13]

- Do not allow the central bank to observe prices and output gap contemporaneously. This may require some slightly stronger assumptions on the transmission lags. Suppose, for example, that the reaction function is (notice the timing)

$$i_{t+1} = \gamma_\pi \pi_t + \gamma_y y_t^g, \tag{1.21}$$

and change the timing in the Phillips curve to

$$\pi_{t+2} = \pi_{t+1} + \alpha_y y_t^g + \epsilon_{t+2}^{CP}. \tag{1.22}$$

[13] Canova and Pina (1999) have an example of misspecification arising when the econometrician imposes short-run restrictions while the DGP does not have enough restrictions on contemporaneous responses to identify any shock.

Then the misspecified inflation equation becomes

$$\pi_{t+2} = \pi_{t+1} - \frac{\alpha_y}{\gamma_y}\pi_t + \frac{\alpha_y}{\gamma_y}i_{t+1} + \epsilon_{t+2}^{CP}, \tag{1.23}$$

which delivers a price puzzle for the same reason that (5.5) does.

- Include a more complex loss function for the monetary authority, interest rate smoothing being a particularly interesting example.

The key assumption that MP shocks affect output with a lag and inflation with a longer lag is strongly supported in empirical work, including VAR studies, and is commonly incorporated in macro models for monetary policy analysis (for example the MPS macro model for the US).[14]

1.3 Solving the puzzle on US data

The strategy to test the hypothesis presented so far is straightforward:

1. Estimate a three variable VAR (the misspecified VAR) including: output (log of real GDP), CPI inflation, federal funds rate (same identification ordering).

2. Estimate the same VAR but with a measure of output gap rather than output. (I call this VARgap).

3. Compare the impulse responses of the two VARs and check whether they behave as predicted by the analysis of the Svensson model.

In relation of the second point, a VAR including: a measure of output gap, inflation and federal funds rate is estimated in Rudebusch and Svensson (1999) and it does not produce a significant price puzzle. One of the contributions of this paper is to rationalize their finding.

[14]See, for example, Christiano, Eichembaum and Evans (1998) and Clarida, Gali and Gertler (1999).

As a measure of the output gap I use the series of capacity utilization built by the Federal Reserve Board.[15] Since capacity utilization is expressed as a percentage of full capacity for the manufacturing sector, a scale adjustment was used to account for the fact that industrial production (manufacturing) is more volatile than GDP. Therefore the series used in estimation is capacity$\times 0.5$.[16] The response of a variables to a given shock in the two VARs are plotted on the same graph. A VAR(3) was estimated in all cases.[17] I checked the robustness of the results to different lag length structure (range 1-8) and starting sample dates (1960-1980). Switching capacity and inflation in the identification ordering also has no effect on either impulse responses or variance decompositions, as predicted by the Svensson model. Using the log of prices instead of inflation does not change any result in this and later sections. Figure 1.3 plots impulse responses for the two VARs estimated on the sample 1970:1 2000:2 (unless otherwise stated all figures are produced with a VAR(3) on the sample 1970:1 2000:2).

Variance decomposition for VARgap and for the misspecified VAR are presented in Figure 1.4 and Figure 1.5 respectively.

The reader is invited to compare Figures 1.3 and 3.2: in all nine cases the theoretical model correctly predicts whether the impulse response of VARgap lies above or below the impulse response of the misspecified VAR. I wish to underline the following results:

1. There is no price puzzle in VARgap, while there is a huge price puzzle in the

[15] Data description:
Capacity utilization is seasonally adjusted. It is available at FRED data base, http://www.stls.frb.org/fred/data/business/cumfg
The federal funds rate series is also taken from FRED, aggregated from monthly (averages), available at http://www.stls.frb.org/fred/data/business.
All other series are from the IMF database: GDP at constant prices (base year 1995), sa, CPI (all items), sa, were logged before estimation. All series used in this paper are available in an E-views workfile (please request them at nepgi@hhs.se).

[16] The number 0.5 is the result of the following computations. I assume that the output gap for GDP (in logs) is a multiple of the output gap in manufacturing. That is
$y_t^g = \alpha y_t^{g,manufacturing}$, implying that $\alpha = std(y_t^g)/std(y_t^{g,manufacturing})$. Using data on sa industrial production and taking std of deviations from linear trends, I estimate $\alpha = 0.5$.

[17] The Schwarz and HQ criteria both select two lags for VARgap and, respectively, two and four lags for the misspecified VAR.

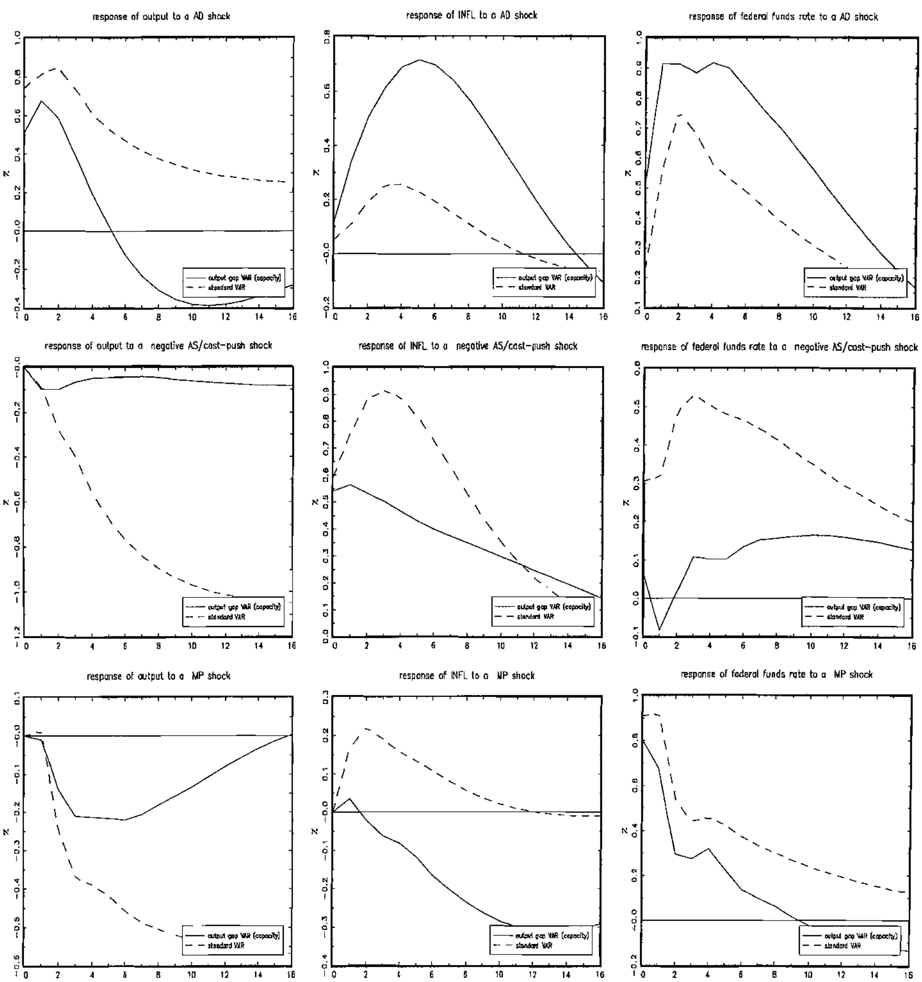

Figure 1.3: Impulse responses for misspecified VAR (real GDP, inflation and federal funds rate. Dashed line) compared with those from VARgap (output gap rather than output. Solid line). US data, quarterly, sample 1970:1 2000:2

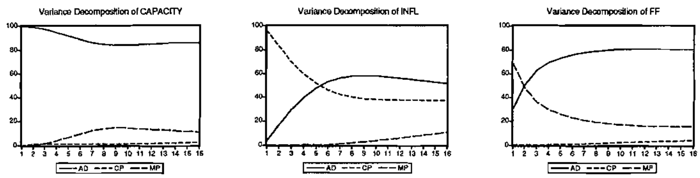

Figure 1.4: Variance decomposition for VARgap.

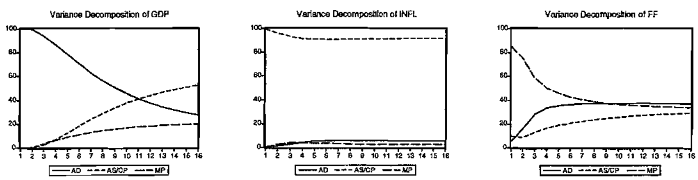

Figure 1.5: Variance decomposition for the misspecified VAR.

misspecified VAR.

2. The response of the federal funds rate to an AD shock is higher in VARgap, even though the AD shock has a lower standard deviation.

3. The responses of output gap to all shocks are shorter-lived.

4. The std of MP shocks is 12% lower in VARgap, and standard deviations of the inflation equation and of the federal funds rate equation (in reduced form) are 7% and 11% lower. Therefore VARgap is expected to produce superior forecasts.

5. Monetary policy looks much more endogenous as the percentage of the federal fund rate forecast error variance due to MP shocks is substantially reduced in VARgap.

6. The share of MP shocks in the variance decomposition of output gap in VAR-gap is less (one half at the 16th lag) then in the decomposition of output in

misspecified VAR.

7. The share of MP shocks in the variance decomposition of output in the misspecified VAR grows with the forecast horizon, as predicted (the reason being that the labelled MP shocks are correlated with technology shocks). In contrast, MP shocks in VARgap display no such behavior (the result doesn't change at forecast horizons longer than four years).

I have considered alternative measures of output gap, namely log deviations from a linear and from a quadratic trend and, for the fun of it, the cycle component of HP filtered log output.[18] All the main results are robust to the choice of the output gap proxy. However, using capacity utilization (and HP filter), nearly identical results are obtained for every reasonable choice of lags (range 1-8), while deviations from linear and quadratic trends (which remain highly persistent) produce a price puzzle for some choices of lags (four or higher). Capacity utilization produces the best fit in all equations.

1.3.1 Extending the VAR to include output: Technology shocks

The Svensson model admits both a three variable representation and four variable representations (see Section 2.1). So far three variable VARs have been estimated. Of course there is no reason why output should be excluded from the VAR as long as a measure of output gap is included. In this case technology shocks become part of the picture. The Svensson model then predicts that all responses to shocks other than technology shocks should be the same as in the three variable VARgap. Two orderings suggested by the model are: output gap, output, inflation, federal funds rate, and potential output, output, inflation, federal funds rate. I choose the second because it has the advantage of being correct even if technology shocks do affect the output gap

[18]The HP filter is two-sided, therefore the filtered data should not be used in regression analysis, since they will lead to inconsistent estimates.

(conditional, of course, on a good measure of potential output). It turns out that all results are robust to the choice of using output gap instead of potential output.[19] I construct potential output (logged) from real GDP and the measure of capacity used in the previous section.[20]

The impulse responses and variance decompositions are shown in Figure 1.6 and Figure 1.7. The following results stand out:

1. The inclusion of output does not produce any change worth noticing on any of the responses (the comparison is with the three variable VARgap). This is encouraging evidence that the shocks in VARgap had been identified correctly.

2. Impulse responses and variance decomposition indicate that natural output is an exogenous unit root process (AR modelling suggests that a random walk with drift is a good description).

3. The response of output to a technology shock is very similar to the response of natural output, while inflation and the federal funds rate have small and insignificant responses to technology shocks. That is, technology shocks do not affect the output gap, supporting the identification: output gap, output, inflation, federal funds rate. In fact, results from the two alternative identifications are fully compatible.

4. Variance decompositions also confirm the results obtained for the three variable VARgap. The share of technology shocks in the decomposition of inflation and federal funds rate is negligible, as predicted by the model. The share of technology shocks in the variance decomposition of output is substantial at all horizons (almost always above 50%).

[19] The first ordering retrieves the shocks in the order: *AD*, technology, *CP*, *MP*. The second in the order: technology, *AD*, *CP*, *MP*.

[20] Log of natural output is defined as $y^n = y - (capacity/100)$, where capacity is obtained by multiplying the original series by 0.5, as motivated in Section 3.

5. Section two showed that, in the theoretical framework, the MP^* shocks retrieved from the misspecified VAR are positively correlated with the true AD shocks and negatively correlated with the true technology shocks. Using technology shocks and AD shocks taken from the four variable VAR and MP^* shocks from the misspecified VAR, this prediction can be tested and is in fact correct: $corr(\epsilon_{AD}, \epsilon^*_{MP}) = 0.35$, $corr(\epsilon_N, \epsilon^*_{MP}) = -0.32$.

6. The impulse responses at long lags (five years or longer, not shown) show that the long run effect of technology shocks on output is one to one, while all other shocks have a zero long run effect. Thus, although the identification is based on short-run restrictions, the results are fully consistent with the hypothesis that only technology shocks have a long-run impact on output.

1.4 Why does a commodity price index solve the price puzzle? Discriminating between two alternative explanations

This section argues that the commodity price index solves the price puzzle mainly because it contains useful information about the output gap, not because it is useful in forecasting inflation. PcomCEE[21] and capacity utilization do tend to move together (correlation 0.58 on the sample 1970:1-1998:4).[22]

The standard explanation implies that the price puzzle should disappear when a good leading indicator of inflation is included in the VAR. Since commodity prices have added value in predicting inflation, commodity prices should solve the price puzzle. The

[21] I call PcomCEE the index used by Christiano, Eichenbaum and Evans (1998).

[22] The publication of the commodity price index used in Christiano, Eichenbaum and Evans (1998) has been discontinued around 1996. The series was used by the Department of Commerce as a leading indicator. Data up to 1998Q4 have been kindly provided by Charles Evans, who constructed the last few data points following the procedure used by the DOC.

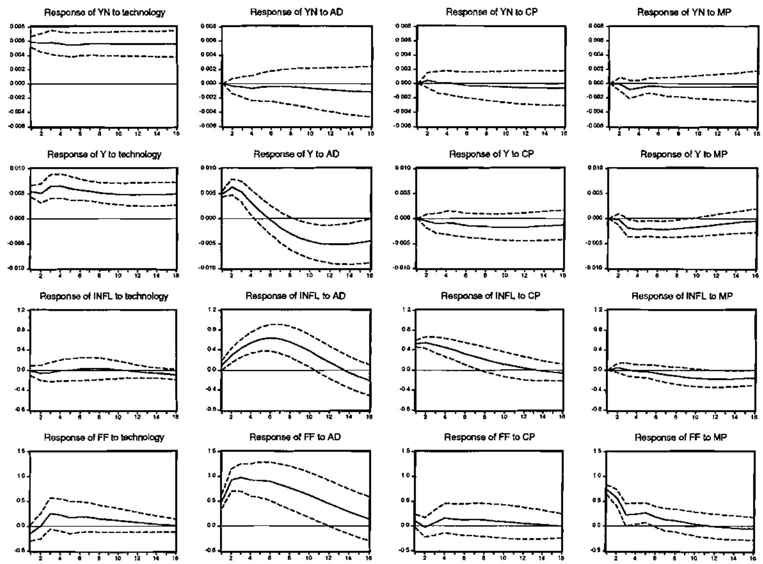

Figure 1.6: Impulse responses for the VAR: natural output, output, inflation, federal funds rate. Error bands include four standard deviations.

puzzle does almost completely disappear in a four variable VAR with the standard ordering: output, inflation, PcomCEE, federal funds rate.

But other powerful leading indicators of inflation should also go at least some way in solving the puzzle, if this theory is correct. For example, a long interest rate should react quickly to news of future inflation. This suggested using the yield on ten year government bonds instead of commodity prices. The results are surprising: the price puzzle is very large, as large as if this variable is omitted.

Next I estimate a four variable VAR including (in this order): output, inflation, inflation forecast, federal funds rate. Inflation forecast is the forecast of average inflation during the next four quarters, a reasonable time horizon for policy makers. The fore-

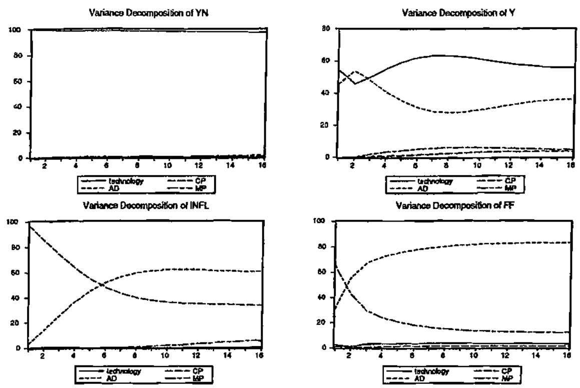

Figure 1.7: Variance decomposition for VAR4 (natural output, output, inflation, federal funds rate).

casts are produced with a VAR estimated recursively.[23] The resulting forecast series is then included in the four variable VAR in place of commodity price. The forecast do have some value, since in response to a forecast shock inflation grows monotonously. The response is significant at the 5% level for several quarters. Based on the standard explanation of the puzzle, the inclusion of the inflation forecasts in the VAR should eliminate or at least mitigate the puzzle. In fact it doesn't help a bit. The response of prices to a *MP* shock (not reported) is unaffected. The same exercise is repeated with a forecast from a different source, the ASA/NBER Survey.[24] I take the mean across forecasters of the forecast of average inflation during the next four quarters (the same variable as before). The response of inflation to an expectation shock is highly

[23]The variables are: inflation, log of real output, commodity price index, federal funds rate and the three year yield on government bills. The VAR is first estimated on the sample 1960:1 to 1970:1 and the forecast is produced for average inflation during the periods 1970:2 to 1971:1. The VAR is then re-estimated adding one observation, another forecast is produced and so on.

[24]Also known as the Survey of Professional Forecasters. Joutz and Stekler (2000) find that "The FED forecasts (*of GNP and GNP deflator*) were not significantly different from the predictions of ASA/NBER surveys". Since forecasts of CPI inflation are only available from 1981, I take the forecasts of GNP deflator inflation. Data and details are available at http://frb.libertynet.org/files/spf

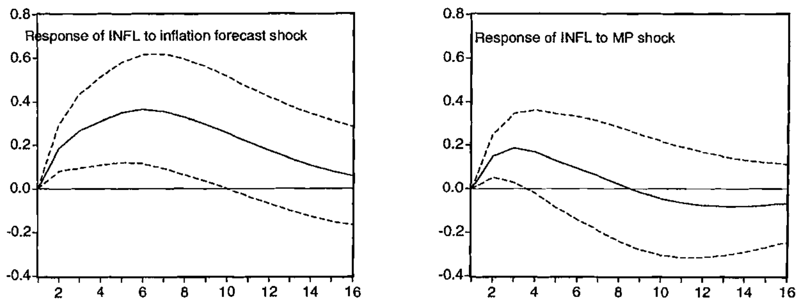

Figure 1.8: Response of inflation to news of future inflation and to a MP shock in a VAR including the forecast of future inflation from the ASA/NBER survey.

significant (the error bands in Figure 1.8 are for ± 2 *std*), but the price puzzle remains substantial in both size and time extension.

These figures do not change if the forecast of future inflation is substituted with future inflation itself (one or two quarters ahead), with a little white noise error added to avoid having a singular variance-covariance matrix. Also, they do not change much using a standard "price of commodity" (as opposed to the leading indicator used by Christiano, Eichembaum and Evans (1998)), or the price of intermediate goods or industrial prices.

In order to further test the claim, I test the following two hypothesis (the statements are for the null):

1. Once capacity is included in the Fed reaction function, PcomCEE is redundant.

2. Once PcomCEE in included in the Fed reaction function, capacity is redundant.

The testing procedures start with a model that nests both: federal funds rate regressed on a constant, three lags of itself, contemporaneous and lagged (three lags) values of inflation, output, PcomCEE, capacity (sample 1970:1 1998:4). The p-value for the F-statistic that commodity prices are redundant is 0.18. On the other hand, the hypothesis that capacity is redundant is clearly rejected (p-value 0.0003). In fact a better fit is obtained in the equation above excluding both output and PcomCEE than excluding capacity only.

Some researchers have found that the price puzzle almost completely disappears in some larger VARs that do not include a commodity price. I conjecture that this is due to some linear combination of the regressors being highly correlated with measures of output gap. For example, capital formation (logged and linearly detrended) has a correlation of 0.79 with linearly detrended log output (1970-2000). The correlation of unemployment rate [25] and capacity utilization is 0.74. In fact, the unemployment rate used instead of capacity (ordered in any position, except the last) does a rather good job at solving the price puzzle, with inflation negative after four lags. Profits and all other strongly cyclical variables are likely candidates.

1.5 Conclusions

This paper argues that the finding of a positive response of inflation to a contractionary MP shock (price puzzle) in VARs designed for monetary policy analysis may not be due to monetary authorities having better forecasts than those produced by the VAR. Rather, it may be due to the omission of a measure of output gap in the VAR. This omission is shown to produce a price puzzle in a wide class of models that would display no such effect if correctly estimated and identified. The key requirement is that monetary policy affects output with a lag and inflation with a longer lag, a hypothesis strongly supported by empirical evidence. Using a model due to Svensson, it is shown that the omission of output gap also leads to overestimation of the variance of monetary policy shocks and to incorrect identification of the response of monetary policy to all the shocks in the economy. Moreover, the importance of monetary policy shocks in the

[25] Standardized unemployment rate, sa, OECD data base.

variance decomposition of output is overestimated, and their effects are estimated to be longer than they actually are. The spurious appearance of a price puzzle is shown to be guaranteed in a wide class of models.

When the implications of the theoretical analysis are tested on US data all the main predictions are confirmed: the comparison of two three-variable VARs, one of which includes output rather than the output gap, gives the predicted results in terms of impulse responses and variance decompositions. In particular, MP shocks do not cause a price puzzle, have shorter-lived effects on output and less relevance in the variance decomposition of all variables. Thus very small VARs (three of four variables) can reproduce the results of much larger systems concerning the effects of MP shocks, while permitting identification of all shocks in the economy.

Finally, it is argued that the effectiveness of a commodity price index in solving the puzzle does not depend on its usefulness in predicting inflation. Rather, it is probably due to its fairly high correlation with the most popular measures of output gap. Using a measure of output gap (or potential output) is not only theoretically more appealing, but also leads to a better fit of the reaction function.

1.6 Appendix: the correct and misspecified representation if the DGP has monetary policy shocks

The correct VAR.

$$\begin{bmatrix} y^g_{t+1} \\ \pi_{t+1} \\ i_{t+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \gamma_y & \gamma_\pi & 1 \end{bmatrix} \begin{bmatrix} \beta_y & \beta_r & -\beta_r \\ \alpha_y & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} y^g_t \\ \pi_t \\ i_t \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \gamma_y & \gamma_\pi & 1 \end{bmatrix} \begin{bmatrix} \epsilon^{AD}_{t+1} \\ \epsilon^{CP}_{t+1} \\ \epsilon^{MP}_{t+1} \end{bmatrix}$$

The misspecified VAR(1)

Use $y^g_t = Y_t - Y^N_t$ in the previous VAR, expand out the Y^N_{t+1} and Y^N_t terms and use $Y^N_{t+1} = \rho Y^N_t + \epsilon^N_{t+1}$.

$$\begin{bmatrix} Y_{t+1} \\ \pi_{t+1} \\ i_{t+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \gamma_y & \gamma_\pi & 1 \end{bmatrix} \begin{bmatrix} \beta_y & \beta_r & -\beta_r \\ \alpha_y & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Y_t \\ \pi_t \\ i_t \end{bmatrix} + \begin{bmatrix} -\beta_y + \rho \\ -\alpha_y \\ -\gamma_y \rho \end{bmatrix} Y^N_t + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \gamma_y & \gamma_\pi & 1 \end{bmatrix} \begin{bmatrix} \epsilon^{AD}_{t+1} + \epsilon^N_{t+1} \\ \epsilon^{CP}_{t+1} \\ \epsilon^{MP}_{t+1} - \gamma_y \epsilon^N_{t+1} \end{bmatrix}$$

Eliminate Y^N_t rearranging the Taylor rule

$$Y^N_{t+1} = Y_t - \frac{1}{\gamma_y} i_t. + \frac{\gamma_\pi}{\gamma_y}\pi_t + \frac{1}{\gamma_y}\epsilon^{MP}_t,$$

to obtain the final representation

$$\begin{bmatrix} Y_{t+1} \\ \pi_{t+1} \\ i_{t+1} \end{bmatrix} = \begin{bmatrix} \rho & (\rho - \beta_y)\frac{\gamma_\pi}{\gamma_y} + \beta_r & -[(\rho - \beta_y)\frac{1}{\gamma_y} + \beta_r] \\ 0 & 1 - \alpha_y \frac{\gamma_\pi}{\gamma_y} & \frac{\alpha_y}{\gamma_y} \\ 0 & \beta_r \gamma_y - \beta_y \gamma_\pi + \gamma_\pi - \frac{\alpha_y}{\gamma_y}\gamma^2_\pi & -\beta_r \gamma_y + \beta_y - \frac{\alpha_y}{\gamma_y}\gamma_\pi \end{bmatrix} \begin{bmatrix} Y_t \\ \pi_t \\ i_t \end{bmatrix} + \begin{bmatrix} \epsilon^{AD}_{t+1} + \epsilon^N_{t+1} \\ \epsilon^{CP}_{t+1} \\ \gamma_y \epsilon^{AD}_{t+1} + \gamma_\pi \epsilon^{CP}_{t+1} + \epsilon^{MP}_{t+1} \end{bmatrix} + \begin{bmatrix} \rho - \beta_y \\ -\alpha_y \\ -\gamma_y \beta_y - \gamma_\pi \alpha_y \end{bmatrix} \epsilon^{MP}_t.$$

If $\sigma_{MP} > 0$, a VAR(1) will have autocorrelated errors. Therefore the econometrician is likely to select a longer lag lenght. It will soon be proved that the myspecified system has a VARMA(2,1) representation. Therefore the misspecified system will have inferior fit and forecasting efficiency than the correctly specified one, even if a VARMA(2,1) is estimated.[26]

Proposition 1 *The misspeficied system Y, π, i has a VARMA(2,1) representation.*

Proof. *Write the DGP as*

$$\begin{aligned} \begin{bmatrix} 1-\rho L & 0 \\ A_0 - A_1 L & B_0 - B_1 L \end{bmatrix} \begin{bmatrix} Y_t^N \\ Z_t \end{bmatrix} &= \begin{bmatrix} \epsilon_t^N \\ \epsilon_t^Z \end{bmatrix}, \text{ or, in compact notation,} \\ F(L)X_t &= \epsilon_t, \text{ where } Z_t' = \{Y_t \ , \pi_t, \ i_t\}, \ \epsilon^Z = \{\epsilon_t^{AD}, \ \epsilon_t^{CP}, \ \epsilon_t^{MP}\}'. \end{aligned} \tag{1.24}$$

Where L denotes the lag operator and

$$A_0 = \begin{bmatrix} -1 \\ 0 \\ \gamma_y \end{bmatrix}, \ A_1 = \begin{bmatrix} \beta_y \\ \alpha_y \\ 0 \end{bmatrix}, \ B_0 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\gamma_y & -\gamma_\pi & 1 \end{bmatrix}, \ B_1 = \begin{bmatrix} \beta_y & \beta_r & -\beta_r \\ \alpha_y & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}.$$

Premultiply both sides of (1.24) *by* $F(L)^{-1}$. *The resulting system for* Z_t *is*

$$Z_t = (B_0 - B_1 L)^{-1}(A_0 - A_1 L)(1-\rho L)^{-1}\epsilon_t^N + (B_0 - B_1 L)^{-1}\epsilon_t^Z.$$

Premultiply both sides by $(B_0 - B_1 L)(1-\rho L)$ *and rearrange*

$$Z_t = (B_0^{-1}B_1 + \rho I)Z_{t-1} - \rho B_0^{-1}B_1 Z_{t-2} - (A_0 - A_1 L)\epsilon_t^N + (1-\rho L)B_0^{-1}\epsilon_t^Z,$$

where $-(A_0 - A_1 L)\epsilon_t^N + (1-\rho L)B_0^{-1}\epsilon_t^Z$ *has a multivariate* $MA(1)$ *represenation of the form* $-(A_0 - A_1 L)\epsilon_t^N + (1-\rho L)B_0^{-1}\epsilon_t^Z = (I + ML)u_t$, *$u$ multivariate (three dimensional) white noise (Lutkepohl (1993), pag. 231).* ■

[26] See Lutkepohl (1993), pag. 234.

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Chapter 2

Stonger Evidence of Long-Run Neutrality: A Comment on Bernanke and Mihov

Abstract:

Few propositions in macroeconomics are less controversial than long-run money neutrality, yet clear and robust empirical support has not been found in time series studies. Bernanke and Mihov (1998) are comparatively successful in this hunt, but their output response to monetary policy shocks remains stubbornly persistent. This paper argues that the omission of a measure of output gap from the VAR estimated by Bernanke and Mihov lies at the heart of this "excessive" persistence. In the theoretical framework of a New Keynesian model similar to that of Svensson (1997) and Clarida, Gali and Gertler (1999), I prove that this omission induces persistence overestimation under relatively mild assumptions. The inclusion of a proxy for the output gap in the VAR is then shown to drastically increase the evidence for long-run money neutrality on US data, as predicted by the theoretical analysis.

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2.1 Introduction

Few propositions in macroeconomics are less controversial than long-run money neutrality (henceforth LRN), the assertion that a monetary contraction (expansion) has no effect on employment and real output in the long run. Yet, clear and robust empirical evidence in favor of LRN seems hard to gather in time series studies. Bernanke and Mihov (1998b) address this problem and go a long way in clarifying the errors that had caused previous empirical research to reject LRN. Bernanke and Mihov (henceforth BM) start with a strong prior in favor of LRN: they are out to find support for it. But although their work is more successful than previous research in this hunt, their success lies in not providing a clear rejection of LRN rather than in providing strong evidence in its favor: a null hypothesis of large long-run effects would not be rejected either. Their strategy consists in isolating a monetary policy shock (henceforth MP shock) by way of a structural VAR, and in computing the response of output to that shock. LRN implies that the response should converge to zero as the time horizon grows. There is a number of interesting methodological advances in BM; among these, they convincingly argue that choosing a broad monetary aggregate (monetary base or broader) as the instrument of monetary policy is a poor choice which leads to huge mistakes on the issue of LRN. But in spite of these improvements, the response of output is not back at zero after ten years. In their own words:

> "We find that the liquidity effect and LRN propositions are not inconsistent with our approach to identifying monetary policy, although the point estimates for the output response imply what might be viewed as an "excessive" degree of persistence from the perspective of the LRN hypothesis".[1]
>
> "At four years the output response is no longer statistically different from zero. It is a bit troubling however, that the point estimates of the output

[1] Pg. 154.

response remain above zero even at the ten-year horizon".[2]

If LRN is so hard to nail down, should we take a pause and doubt it? After all, "hysteresis" is a word which many economists are not ashamed of using in other contexts. Mankiw (2000) does raise the question and does use the word in a section titled "Hysteresis?". In fact, Mankiw reads BM's results as a ringing bell in favor of a more agnostic position on LRN, rather than as evidence for it. In his words:

> "One question about which I remain agnostic is whether the natural rate hypothesis is true or whether some form of hysteresis causes monetary shocks to have long-lasting effects on unemployment. [...] Bernanke and Mihov estimate a structural vector autoregression and present the impulse response functions for real GDP in response to a monetary policy shock. (See their Figure III) Their estimated impulse response function does not die out toward zero, as is required by long-run neutrality. Instead, the point estimates imply a large impact of monetary policy on GDP even after ten years. Bernanke and Mihov don't emphasize this fact because the standard errors rise with the time horizon. Thus, if we look out far enough, the estimated impact becomes statistically insignificant. But if one does not approach the data with a prior view favoring long-run neutrality, one would not leave the data with that posterior. The data's best guess is that monetary shocks leave permanent scars on the economy".

In what follows I propose an explanation for the persistent effect of MP shocks which assumes LRN. The question I ask is: if LRN holds, why does BM's VAR produce such a persistent response of output to MP shocks? My answer is fully based on economic theory, indeed in a model that incorporates LRN and a short interest rate as the main operating tool of modern central banking. The model, which is borrowed from

[2] Pg. 171.

Svensson (1997) with minor additions, is designed to capture the essential features of the monetary transmission mechanisms, as outlined in Svensson (1997 and 2000a) and in Clarida, Gali and Gertler (1999). In the model the output gap plays an important role: it affects inflation and it belongs to the reduced form reaction function of the monetary authority (which turns out to be a simple Taylor rule). This paper shows that, under reasonable parameter values, the omission of a measure of output gap from the model results in overestimating the persistence of the output response to monetary policy shocks. Since BM do not include a measure of output gap in their VAR, this analysis is potentially a valid explanation for their results. My next step is then to move to the data, to check whether adding a measure of output gap to the VAR does produce stronger evidence in favor of LRN. The result I propose is that the evidence in favor of LRN becomes much stronger once a measure of output gap is added to the VAR, just as predicted by the model. I am eager to stress at this early point that this large improvement (from the prospect of BM) relies entirely on the introduction of one additional variable (a measure of the output gap), as suggested by theory: everything else, including identification, is the same for both specifications.

The intuition for why the omission of an output gap measure results in an overly persistent response of output to MP shocks is as follows. The output gap belongs to the reduced form monetary policy rule, in such a way that, for a given unexpected increase in output, the monetary authority raises the interest rate by more if the increase is due to an aggregate demand shock than if it is due to a technology shock, defined as a shock that changes potential output (this result is rather standard in the literature); since the output gap is omitted, when output increases, the VAR sometimes observes a large increase in the interest rate (AD shock) and sometimes a smaller one (technology shock), and therefore estimates that the interest rate response to an unforecasted output increase is somewhere in between. It follows that when a positive technology shock increases output, the VAR expects the interest rate to raise by more than it actually does, and interprets the difference as an expansionary MP shock. Therefore the MP shocks estimated by the econometrician are contaminated by technology shocks. If technology shocks have a longer lasting effect on output than MP shocks, as commonly believed, the response of output to a MP shock in the misspecified system looks more persistent than it actually is. The rest of the paper proceeds as follows. Section 2 develops this intuition formally, by presenting the model and showing the consequences of omitting a measure of output gap in the VAR, both analytically and through simulations. Section 3 tests the implications of the analysis carried out in Section 2. The VAR used by BM is compared with one that, ceteris paribus, adds a measure of output gap to the non-policy variables, finding that the evidence in favor of LRN is drammatically increased, as predicted. Section 4 concludes.

2.2 Model and consequences of VAR misspecification

In order to understand the consequences of omitting a measure of output gap from the VAR, I refer to a simple model which replicates, with some additions, the one in Svensson (1997). Reference to this model will allow for a clear and rigorous exposition. However, the main result I am after (overestimated degree of persistence) is grounded on an intuition which holds for a more general class of models.

Svensson (1997) presents a model designed to capture some key features of the transmission mechanism of monetary policy. In fact, it is more generally a model of business cycle fluctuactions. The same model is used in Rudebusch and Svensson (1999), in Judd and Rudebusch (1998) and, extended to a small open economy, in Ball (1999). A forward-looking version appears in Clarida, Gali and Gertler (1999) and in Svensson (2000a and 2000b). Romer (2000) presents the same model as an improvement over the traditional IS-LM. The model consists of an IS equation, a Phillips curve and a Taylor rule obtained from the monetary authority's optimization problem. This core three-equation structure is shared by many recent New-Keynesians models for monetary policy analysis. The model assumes that the monetary authority uses a short interest rate as its main operating target.

The IS relation is given by

$$y^g_{t+1} = \beta_y y^g_t - \beta_r(i_t - \pi_t) + \epsilon^{AD}_{t+1}, \tag{2.1}$$

where i_t is a short-term interest rate set by the monetary authority, π is inflation and y^g is the output gap, defined as $y^g_t = Y_t - Y^N_t$, where Y_t is the log of output and Y^N_t the log of potential (or "natural") output. Potential output is assumed to follow an exogenous AR(1) process[3]

$$Y^N_{t+1} = \rho Y^N_t + \epsilon^N_{t+1}. \tag{2.2}$$

The Phillips curve is modelled as

$$\pi_{t+1} = \pi_t + \alpha_y y^g_t + \epsilon^{CP}_{t+1}. \tag{2.3}$$

All shocks are *iid.*[4] They are labelled: aggregate demand shock, technology shock and cost-push shock. Denote their standard deviations by σ_{AD}, σ_N, σ_{CP}. The model is supplemented by a loss function for the monetary authority of the standard type

$$L_t = E_t \sum_{i=0}^{\infty} \beta^i [\lambda (y^g_{t+i})^2 + (\pi_{t+i} - \pi^*)^2]. \tag{2.4}$$

The solution takes the form of a Taylor rule (See Svensson (1997) for the closed-form solution). Since the model is backward-looking the discretionary solution and the commitment solution are the same:

$$i_t = \gamma_\pi \pi_t + \gamma_y y^g_t. \tag{2.5}$$

[3] Svensson (1997) makes no assumption about potential ouput. I follow Svensson (2000a and 2000b) in assuming an AR(1) process.

[4] The assumption of *iid* shocks is not particularly restrictive, as more lags can be added to equations (2.1) to (2.3) without any difficulty.

A monetary policy shock can be added by supposing that the Taylor rule is not followed deterministically. In that case, the shock ϵ^{MP} with std σ_{MP} is added to the Taylor rule. MP shocks affect neither output nor inflation within the period.

Money does not have an interesting role to play in this model: it does not appear in the IS and Phillips equations, and i being the policy instrument, money supply is perfectly elastic. Therefore, for a given money demand equation, the quantity of money can be determined residually, after solving the rest of the model, and the omission of money does not result in any misspecification.[5]

In this model, MP shocks can be identified by the assumption that they do not affect output, potential output and inflation within the period. Thus MP shocks can be recovered with a triangular identification, where all variables except money are ordered before the interest rate (within these limits, the ordering of the other variables is irrelevant for the identification of MP shocks). The identifying assumption that MP shocks do not affect output and inflation within the period is a rather uncontroversial one, and is used extensively in the literature (see, e.g., Christiano et al., 1998, and Rudebusch and Svensson, 1998). Therefore, in this respect, BM's assumptions are fully in line with the model. On the other hand, the model does not justify the omission of the output gap (or potential output) from the VAR, as in BM and in much of the literature.

2.2.1 Omitting a variable from the VAR and finding excessive persistence

Let the DGP be given by equations (2.1) – (2.3) and (2.5). Suppose that we estimate a VAR including: output, inflation, interest rate and money, with MP shocks identified as interest rate shocks, and interest rate ordered second to last (money last). The identification would be in accordance with the model if output gap or potential output were

[5]Given these premises, it is not surprising that the literature adopting models of this type does not specify a money demand equation. However, Leeper (2000) expresses some doubts on the appropriateness of omitting money from the analysis.

added to the VAR, ordered before the interest rate. The message of this paper is that omitting a measure of output gap from the VAR results in excessive (overestimated) persistence.

A perspective on excessive persistence can be gained by inspecting the retrieved MP shocks. In fact, though the Taylor rule is assumed deterministic, the econometrician will retrieve a positive std of the structural MP shocks. This point is proved formally in Giordani (2001).[6] However, the reason for the overestimation of the variance of MP shocks is intuitively clear: since the output gap is omitted from the estimated Taylor rule, the fit deteriorates (since the output gap is not perfectly collinear with inflation, output and lags of all variables). The intuition is that since the interest rate does not react in the same way to technology and AD shocks, when a movement in output (of a given amount) is observed, the misspecified VAR sometimes registers a large change in the interest rate (when the movement is caused by an AD shock) and sometimes a smaller (possibly null) change (when caused by a technology shock) and is tricked into interpreting this as random behavior of the monetary authority. It also estimates that the interest rate response to an unforecasted output increase is somewhere in between.[7] It follows that when a positive technology shock pushes output up, the VAR expects the interest rate to raise by more than it actually does, and interprets the difference as an expansionary MP shock. Therefore the MP shocks estimated by the econometrician are contaminated by technology shocks; more precisely, they are negatively correlated with technology shocks. If technology shocks have a longer-lasting effect on output than MP shocks, as commonly believed, the response of output to a MP shock in the misspecified system will be more persistent than in reality. Giordani (2001) shows that the covariance is given by

$$cov(\epsilon_{t+1}^{*MP}, \epsilon_{t+1}^{N}) = -\gamma_y \frac{\sigma_{AD}^2 \sigma_N^2}{\sigma_{AD}^2 + \sigma_N^2} < 0. \tag{2.6}$$

[6]The std of the retrieved MP shocks is $\sigma_{MP}^{*2} = \gamma_y^2 \frac{\sigma_{AD}^2 \sigma_N^2}{\sigma_{AD}^2 + \sigma_N^2} > 0$.

[7]In this model the interest rate does not react at all to technology shocks, but the intuition holds as long as the output gap belongs in the reduced form policy function.

2.2.2 Simulation

So far I have presented analytical arguments predicting that the omission of a measure of output gap will lead to excessive persistence of the output response to the estimated MP shocks. To develop a quantitative measure of the importance of this effect, I present a simulation. The model parameters are set as in Ball (1999): $\alpha_y = 0.4$, $\beta_y = 0.8$, $\beta_r = 1$. The standard deviations are $\sigma_{AD} = \sigma_{CP} = \sigma_N = \sigma_{MP} = 1$. Results generalize without surprises to different parameters. The parameters in the Taylor function are set to $\gamma_y = 0.5$, $\gamma_\pi = 1.5$.[8] When $\sigma_{MP} > 0$, the misspecified model is more easily estimated numerically and allowing for several lags (here 4), for reasons explained in Giordani (2001). I abstract from parameter uncertainty by setting the number of observations to 50000. Figure 2.1 shows the true impulse response of output to a MP shock together with the impulse responses retrieved by the misspecified VAR, for increasing values of the autoregressive parameter ρ. As implied by the theoretical analysis, the degree of excessive persistence increases with ρ. Most researchers' prior is that ρ is either one or close to one, which in this model could explain why the response is so slow in returning to zero.[9]

2.3 Moderate persistence in US data

The natural next step is to verify the accuracy of these predictions on US data. To iterate, the prediction is that the support for LRN will be stronger if a measure of output gap is included in the VAR, among those that BM call "non-policy variables". Notice that the model presented above supports the identification assumption, adopted by BM, that monetary policy does not affect non-policy variables within the period, with one exception and one clarification. The exception is that the broad monetary

[8]These parameters are commonly adopted. However, the optimal values of the parameters of the Taylor function has a closed form solution given in Svensson (1997).

[9]A Monte Carlo exercise supports Gali (1998)'s argument that, with a small sample (200 observations in the experiment) and in the presence of (close to) unit root output, estimating the VAR in levels will lead to underestimating the persistence of the response. However, this effect is small.

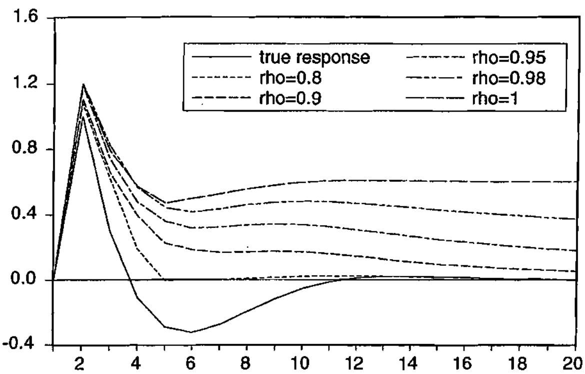

Figure 2.1: Impulse response of output to an expansionary MP shock in the correctly specified model and in the misspecified model for various degree of persistence of potential output.

aggregat –M2–should be ordered after the policy variables, not before. The clarification is on the role of the commodity price index, which does not appear in the model. Giordani (2001) argues that the commodity price index[10] is useful in solving the price puzzle because it is correlated with popular measures of the output gap (in the period considered by BM (1966-1996), the correlation is 0.43 with capacity utilization[11] and -0.23 with unemployment), and that it is no longer essential if a better proxy of the output gap is included in the VAR. The results that follow support this claim: while BM's results (in terms of persistence of the output response) worsen considerably if commodity price (henceforth Pcom) is omitted, this omission has no consequences if the output gap is included.

[10]The commodity price index I choose is the series used in Christiano et al. (1998), which is a leading indicator published by the Department of Commerce, arguably the most useful in correcting the price puzzle. This series does not have an upward trend, as the word "price" may suggest and as other similarly denominated series do (such as the international commodity price index used by Favero, 2000).

[11]Capacity utilization for the industrial sector is published by the Federal Reserve Board, also available at FRED (www.stls.frb.org/fred/data/business/comfg).

I will simplify exposition by reducing the policy variables to one only: the federal funds rate. Bernanke and Mihov (1998a and 1998b), who also consider total reserves and nonborrowed reserves, in fact conclude that this is a good approximation for most of the post-1965 period.

I will reproduce the first two graphs of Figure III in BM (1998b), namely the response of real GDP to a MP shock and the p-value for the null that the response is zero after a given number of periods; but I will do this comparing the results of two VARs:

1. A VAR identical (in variables and identification) to the one used by BM (except for the simplification of the policy block to the federal funds rate): real GDP, inflation, Pcom, M2, federal funds rate.[12]

2. The VAR suggested by the model, which is the same as above (same identification ordering) but adding capacity utilization (among the non-policy variables) and without M2 and Pcom. The results obtained by this second VAR are very similar to one in which M2 and Pcom are included. I present the smaller VAR because of Ockham's razor principle (here: if a small model performs as well as a large one, use the small) and to avoid Sims' objection to ordering Pcom before the policy instrument.

Data are quarterly, sample 1966Q1-1998Q4.[13]. The VARs have three lags.[14] Figure 2.2 graphs the impulse response of GDP to an expansionary MP shock in the two models (for 40 quarters, as in BM), together with 68% error bands (approximately two standard deviations) for the second model.[15]. Figure 2.3 plots the p-values for the

[12]M2, in BM (1998b) and here, is deflated by the DGP deflator and logged (the same is true of GDP). I use inflation, rather than prices, to improve efficiency in estimation.

[13]BM use monthly data (1966-1996), for which capacity utilization is not available.

[14]The HQ criterion suggests two lags for the first VAR and three for the second. BM (1998b) use seven lags on monthly data.

[15]Error bands and p-values are obtained by Monte Carlo numerical integration (10000 draws) with the Bayesian procedure outlined in Doan (1992). Error bands are obtained leaving out the lowest and highest 16% at each step.

two hypothesis that the response is zero after a given number of periods in the first VAR (first hypothesis) and in the second VAR. The results from the first VAR are

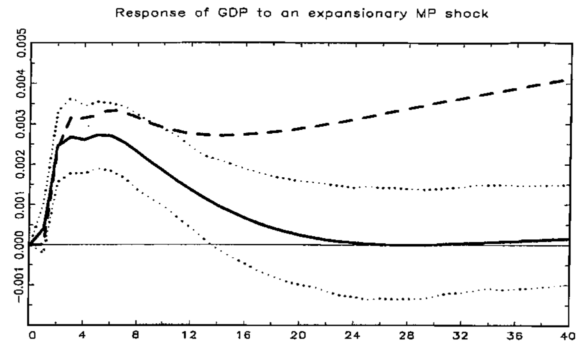

Figure 2.2: Impulse response of GDP to an expansionary MP shock in the second VAR (capacity, GDP, inflation, federal funds rate)–continuous line, error bands in dotted lines–and in the first VAR (GDP, inflation, Pcom, M2, federal funds rate)–dashed line.

slightly different from those obtained by BM (see their Figure III): the p-value raises above 0.1 sooner, but at longer horizons provide less support for LRN. On the other hand, the second VAR drastically increases the support for LRN, while preserving very significant short-run effects. Notice the similarities between Figure 2.1 and Figure 2.2: in the VAR that includes capacity utilization, the response is smaller, but peaks at approximately the same time, and is shorter-lived. This baseline result, namely that simply including a measure of output gap in the VAR drastically reduces the persistence of the output response, is robust to a wide range of modifications including: changing lag length, adding Pcom and M2 to the second VAR, differencing GDP in estimation (as suggested by Gali, 1998), using CPI rather than GDP deflator, shortening the sample, using unemployment instead of capacity utilization as a measure of output gap. The exclusion of Pcom, irrelevant if capacity is included, leads to much weaker

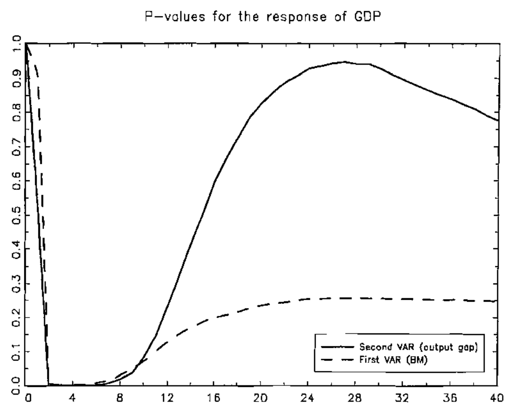

Figure 2.3: P-values for the null that the response of output at a given horizon is zero for the first VAR (BM) and the second VAR (capacity, output, inflation, ff).

evidence in support of LRN in the first VAR (the p-value at lag 40 is 0.07).

The one presented here is not the first VAR that does not display "excessive" persistence. The impulse response in, for example, Rotemberg and Woodford (1998)–who detrend output–and Rudebush and Svensson (1999)–who include the CBO measure of output gap–also do not. The contribution of this paper is to rationalize their findings, explaining what drives the differences in results across apparently similar VARs.

2.4 Conclusions

Few propositions in macroeconomics are less controversial than long-run money neutrality, yet clear and robust empirical support has not been found in time series studies. Have economists been too stubborn in interpreting evidence against LRN as a failure of the empirical methodology rather than as evidence against the hypothesis? This paper suggests that they have not. Commenting on work by Bernanke and Mihov (1998b), and sharing their main assumptions on monetary policy identification, the paper argues that the omission of a measure of output gap (or potential output) from the VAR estimated by Bernanke and Mihov lies at the heart of the "excessive" persistence of the output response to MP shocks. In a theoretical framework, this omission is proven to induce persistence overestimation under relatively mild assumptions. The inclusion of a proxy for the output gap in the VAR is then shown to drastically increase the evidence for long-run neutrality on US data, as predicted by the theoretical analysis.

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Chapter 3

Monetary Policy Without Monetary Aggregates: Some (Surprising) Evidence

with Giovanni Favara

Abstract:

Recent monetary business cycle models with sticky prices assign no role to monetary aggregates, in the sense that the level of output, price and interest rate can be determined without knowledge of the quantity of money. This paper evaluates the empirical validity of this position by studying the effects of money demand shocks for these variables. We use an identified VAR analysis, isolating money-demand shocks by means of identifying restrictions supported by all models in this class. Contrary to the prediction of the theory, real money balances have substantial predictive power for future movements in inflation and output.

[0]We thank Lars Svensson, Paul Söderlind and participants at a IIES seminar in Stockholm for comments, and (Giordani) the Wallanders foundation for funding.

3.1 Introduction

In recent years it has become standard practice to discuss monetary policy without any reference to monetary aggregates. Most central banks have de-emphasized the role of money for gauging economic and financial conditions and some recent empirical evidence has documented the weakness of the relationship connecting money to income and prices (see for example Friedman and Kuttner (1992, 1996) and Estrella and Mishkin, 1997).

Current models of monetary policy with sticky prices also assign minimal role to monetary aggregates. This feature is shared by both backward-looking and micro-founded forward-looking monetary policy frameworks[1] . Within those models, money is irrelevant: (a) in the transmission of monetary policy; (b) in setting monetary policy; and (c) for the private sector to form expectations about policy.

Woodford, for instance, has argued on several occasions that it is theoretical coherent to study monetary policy without reference to money. In much of his work (see Woodford, 1996, 1998) there is no reference whatsoever to any monetary aggregate, and in a recent paper he writes " ... the equilibrium evolution of inflation and output can be understood without reference to the implied path of the money supply or the determinants of money demand" (Woodford, 2000).

McCallum (2001) shows that money is not redundant in the standard framework unless consumer utility is separable in money. However, under reasonable parameter values his calibration exercise suggests that there is nothing fundamentally misguided in excluding monetary aggregates, as the approximation error is extremely small.

Though the results seem clear from a theoretical point of view, there are few attempts to measure the empirical relevance of money within this class of models. Ireland

[1]For the first group of model, see among others Svensson (1997), Ball (1999), Taylor (1999), Rudebusch and Svensson (2001). For forward looking models see, King and Watson (1996), Ireland (1997), Woodford and Rotemberg (1997,1999), McCallum and Nelson (1999), Clarida, Gali and Gertler (1999).

(2001) has proposed a maximum likelihood estimation of a microfounded forward-looking model of monetary policy. Using U.S. data for the period 80-98, he concludes that real balances are statistically insignificant and enter with the wrong sign for both output and inflation determination. Conversely, Nelson (2000) estimates a backward looking aggregate demand curve and, using a measure of real base money for both U.S. and U.K., finds that real money growth affects aggregate output sizably, positively and significantly.

In this paper we provide further empirical counterpart to this analysis. By means of an identified vector autoregression (VAR), we examine the role played by money demand shocks in shaping the dynamic behavior of output, inflation and interest rates. A distinctive feature of our VAR analysis is that both the variables included in the system and the identifying restrictions used to isolate money-demand shocks are suggested by a broad class of models recently used to study monetary policy. All of them share the implication that money demand shocks have no effect on any macro-economic variable other than money itself. This feature is worth noticing as different researchers have reached contrasting results depending on the specific empirical strategy implemented and/or structural model adopted. Our results, using USA data for the period, 1966-2001, suggest that shocks to money demand significantly affect the dynamic behavior of output gap and inflation and can explain a sizable fraction of inflation's variability.

The rest of the paper proceeds as follows. Section 2 defines the class of models that supports our VAR identification scheme, briefly lays out one model in this class, which is then used for the ex-position, and highlights the lack of importance of monetary aggregates within that framework. Section 3 discusses the empirical strategy adopted to identify money demand shocks, reports the results and conducts a number of robustness checks. In Section 4 the dynamic properties of the model of Section 2 are analyzed, once a direct role of money in output and inflation determination is allowed for. The final section offers concluding remarks.

3.2 The theoretical model

Our discussion is conducted in the context of a standard class of monetary business cycle model with sticky prices widely used for monetary policy analysis. The essence of these models rest in three core equations: an aggregate supply (the Phillips curve), an aggregate demand (the IS curve) and a policy rule which instructs the monetary authority to set the interest rate (typically) as function of inflation and output gap (i.e. a Taylor rule).[2] Private sector's expectations are treated as (partially) adaptive or fully rational, depending on the specification.

To simplify the discussion, we will adopt a specific model in this class, previously used in Svensson (1997), Ball (1999) and Rudebusch and Svensson (2001). A stripped down version of the model can be summarized as follows:

$$\pi_{t+1} = \pi_t + \alpha_x x_t + \epsilon_{t+1}^{CP} \tag{3.1}$$

$$x_{t+1} = \beta_x x_t - \beta_r (i_t - E_t \pi_{t+1}) + \epsilon_{t+1}^{AD} \tag{3.2}$$

$$i_t = f + f_\pi (\pi_t - \pi^*) + f_x x_t + \epsilon_t^{MP}, \tag{3.3}$$

where π is (the rate of) inflation, π^* a given inflation target, $E_t \pi_{t+1}$ denotes the conditional expectation for inflation in period $t+1$ based on information at time t, x is the output gap, i is the policy instrument—a short interest rate– and f is a constant. The coefficients are positive and the disturbances are iid with zero mean and constant variances σ_{CP}^2, σ_{AD}^2, σ_{MP}^2.

The first equation is the aggregate supply equation (a Phillips curve in its accelerationist form) where current inflation depends on past change in price level and on

[2]Lagged values of the interest rate itself, of inflation and of output can also be part of the policy rule. See Walsh (1998) and Clarida, Gali and Gertler (1999) for a comprehensive discussion of this class of models.

past realization of output gap. Equation (3.2) is the aggregate demand equation (a traditional Keynesian IS curve). It relates the output gap to its past realization and to the current ex-ante real interest rate. Finally, equation (3) describes the Taylor rule – derived in Svensson's model as the solution of the monetary authority's optimization problem, defined in terms of a quadratic loss function for inflation and output gap.

The short-term interest rate is assumed to be the main operational instrument for the Central Bank.

We use this model because it displays two desirable features. First, it is similar in spirit to many recent forward-looking models of monetary policy for (a) it embeds the same monetary transmission mechanism (operating through the interest rate channel) and (b) does not consider any role for monetary aggregates.[3] Second, the model is a useful benchmark for empirical analysis as it is simple and has enough dynamics to be confronted with the data.

The model implies the following view of the transmission mechanism. There is a sluggish private sector in the economy that determines the level of output gap and inflation; the monetary authority observes prices and output before setting the policy instrument; interest rate changes affect the out-put gap after one period and inflation after two.

A noteworthy feature of equations (3.1)-(3.3) is the lack of reference to any monetary aggregates. The reason is straightforward. Under the assumption that the monetary authority sets the interest rate, the inclusion of an interest-rate-elastic money demand equation would be superfluous since the first three equations are sufficient to determine time paths for output gap, inflation and interest rate. The money demand equation's only function is to determine the amount of money needed to implement the Taylor

[3]The model can be reformulated to include forward-looking variables as in King and Wolman (1996), Woodford (1996, 1998) or Clarida, Gali and Gertler (1999). This modification would certainly add new channels to the monetary trans-mission mechanism, without, however, affecting the fundamental structure of the model. Throughout this paper we will not be concerned whether the backward-looking behaviour of the Svensson's model can be rationalized in a fully opti-mising framework; we will only be interested in extracting the model's dynamics for empirical analysis.

rule. To see this point more clearly, we can append to the model a demand for real money balances $m_t - p_t$,

$$m_t - p_t = ky_t - \eta i_t + \epsilon_t^{MD}, \tag{3.4}$$

where p is the price level, y the level of output[4] and ϵ_t^{MD} a random disturbance. Then, the logic of the model's transmission mechanism implies that the interest rate affects inflation through the output gap, (via the IS and Phillips curve) while the quantity of money is determined residually. Money supply is perfectly elastic and shocks to money demand are completely accommodated and neutralized through passive expansion of money supply without altering the equilibrium values of output, inflation, and interest rate.

In the remaining part of this paper we assess the empirical validity of this prediction.

3.3 The empirical model

We use an identified VAR analysis to test the implication that money demand shocks should have no effect on any variable other than money. While the model outlined above makes it possible to identify all shocks, we will be concerned with two: monetary policy shocks and money demand shocks.

Our recursive VAR consists of a first block of predetermined variable including output, output gap and inflation, and a second block of monetary variables including the interest rate and real money balance. Monetary policy shocks are identified by ordering the interest rate in the second-to-last position of a Cholesky ordering. Money-demand shocks are retrieved by placing real money last. This ordering reflects the assumption that the monetary authority responds contemporaneously only to output

[4] Since money demand depends on output rather than on the output gap, a process for potential output should also be added to the system to determine m. In line with the literature, we assume that potential output follows an exogenous autoregressive process.

gap and inflation (and possibly output), which it cannot affect within the period.[5] Money demand instead is allowed to respond contemporaneously to all variables but to affect none within the period. [6]

This last assumption is supported by all models in the class considered above. In fact, the proposed ordering is equivalent[7] to regressing real money on contemporaneous values of all the other variables and on lags of all variables; the other variables may instead depend on money only through its lagged values. The theoretical assumption that money-demand shocks have no effect on any variable other than money implies, a fortiori, that they have no contemporaneous effects. Therefore, the money demand equation can be estimated consistently and money demand shocks should produce no effects on output, inflation and interest rates.[8]

3.3.1 The effects of money demand shocks: evidence from impulse response functions

In line with the analysis outlined above, our VAR includes five variables: output, output gap, inflation, interest rate and real money balances.[9] Data are for the US, quarterly, seasonally adjusted, 1966.1-2000:2. Output is real GDP. The output gap is proxied with a measure of capacity utilization produced by the Federal Reserve Board.

[5] On periods of a quarter or less the evidence gathered by the empirical literature in favour of this assumption is strong.

[6] Our money demand specification is deliberately simple. Clearly, the federal fund rate - the instrument of the monetary authority - cannot be considered a precise measure for the opportunity cost of holding money. However, as discussed in Leeper, Sims and Zha (1996) and Gordon and Leeper (1994), modelling the details for the right opportunity cost does not substantially alter the analysis. Moreover, typical models of money with more accurate institutional details, calculate the opportunity cost as the spread between short and long-term interest rate. We allow for such specification in Section 3.3.

[7] The two approaches may nonetheless give slightly different estimates in small samples.

[8] Our identification assumption is no longer valid if the central bank is allowed to change the interest rate within the period in response to money demand shocks. However, in the models we consider such behaviour would be sub-optimal, since money does not belong to either the IS or the Phillips equation.

[9] Output is needed to correctly estimate the money demand function. All the results enphasised in this paper are unaffected if output is not included.

The inflation rate is computed by the log change in the CPI level; the interest rate is the federal fund rate, and real money balances are measured by the logged ratio of M2 over CPI.[10] The number of lags is set to two as favored by the Hannan-Quinn criterion.[11] All equations pass Andrews' test of parameter stability (Andrews, 1993) at 10%, except the interest rate equation, which passes the test at 5%.

Figure 1 plots the estimated impulse response functions (solid lines) and confidence bands including four standard deviations (dashed lines); responses of all variables are plotted for a contractionary monetary policy shock (first row) and a money demand shock (second row).

The responses to a monetary policy shocks are standard and consistent with the qualitative effects of a monetary policy shock offered in the literature (see among others Christiano, Eichenbaum and Evans (1999) or Leeper, Sims and Zha, 1996). Following a contractionary monetary policy shock (a rise in the federal funds rate) output gap falls, inflation responds very slowly and real money balances decline. The output gap has a hump shaped response function with bottom at 6 quarters. The response of inflation is almost flat for 4 quarters and persistently declining afterwards. There is also a sizable liquidity effect as real money balances decrease upon impact, and this effect is persistent.

The second row of Figure 1 reports the effects of a money demand shock. Contrary to the prediction of the theory (flat responses), the responses of all variables are significantly different from zero for several quarters. Output and the output gap display an

[10] Real GDP and CPI are taken from the IMF database. M2 is taken from the FRED database, aggregate from s.a. monthly data. Capacity utilization for the manufacturing sector is published by the Federal Reserve Board, also available at FRED (www.stls.frb.org/fred/data/business/comfg). All series used in this paper are available in an E-Views work-file and can be requested to any of the authors.

[11] Similar VARs (but excluding output and money) have been estimated by Rotemberg and Woodford (1999) for the USA and by Gerlach and Smets (1998) for the G7 countries. The standard VAR used in the empirical literature of monetary policy prefers, instead of using a measure of output gap, to include a commodity price to avoid the "price puzzle" i.e. a monetary contraction failing to produce any decline in prices. However, as explained in Giordani (2000), this is not necessary if the VAR includes a measure of output gap as explicitly suggested by standard models of monetary policy.

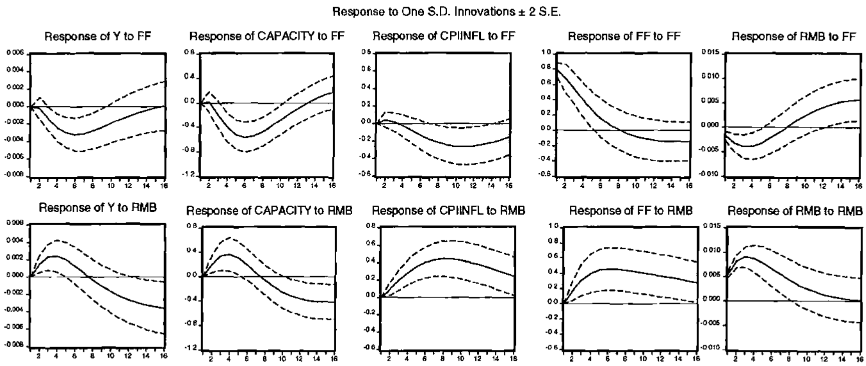

Figure 3.1: Response of all variables in the VAR to a monetary policy shock (FF, first row) and to a money demand shock (RMB, second row). Sample 1966-2000.

hump-shaped response: they increase on impact, reach a peak at almost 4 quarters and return to their original level over the course of about 2 years. Inflation also responds strongly and persistently: it rises by a statistically significant amount for 8 quarters and then slowly returns to its original level.

A third notable feature of Figure 1 is that the federal fund rate's response is positive, significant and prolonged. Interpreting this last result is not straightforward. Does it only reflect the endogenous response of policy –via the feedback rule– to the increases in inflation and output that follow a money demand shock, or does it also include the direct response of interest rate to unexpected money demand innovations? In this second instance, money (at some lag) would belong to the policy function, as it should if policy has to be optimal and money demand shocks have an impact on output and inflation. Simulations carried out in Section 4 suggest that, while we cannot exclude the second option, working with the first is sufficient to reproduce the response functions we just presented.

We conclude this subsection by examining how sensitive our results are to the

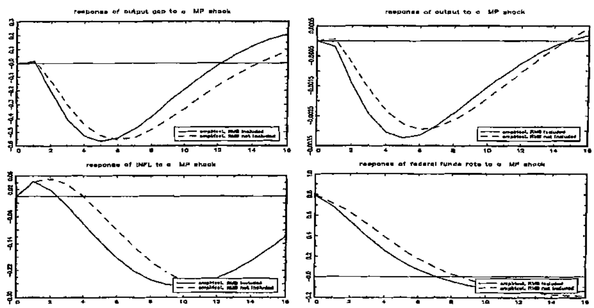

Figure 3.2: Impulse response functions to a monetary policy shock in a VAR with money (continuous line) and without money (dashed line). Sample 1966-2000.

exclusion of real money balances from the VAR. As displayed in Figure 2, excluding money from the VAR does not change at all the picture of the effects of monetary policy shocks: the impulse response of all variables are almost identical.

3.3.2 The effects of money demand shocks: evidence from forecast error variance decomposition

We now examine the relative contributions of money demand shocks to the variance of the k-step-ahead forecast errors in inflation, output, output gap and federal funds rate. The results are reported in Figure 3. Surprisingly, money demand shocks are a large source of disturbance for inflation, accounting for up to 40 % of its variance after 10 quarters. The contribution of money demand shocks to the variance decomposition of output gap is smaller, but comparable to that of monetary policy shocks.

Again, we have examined how the results are affected by estimating a four variable VAR without money. For this purpose we have identified all shocks using the restrictions implied by the model, and discussed at lenght in Giordani (2001). It turns out that money demand shocks are confused with aggregate demand shocks, in the sense

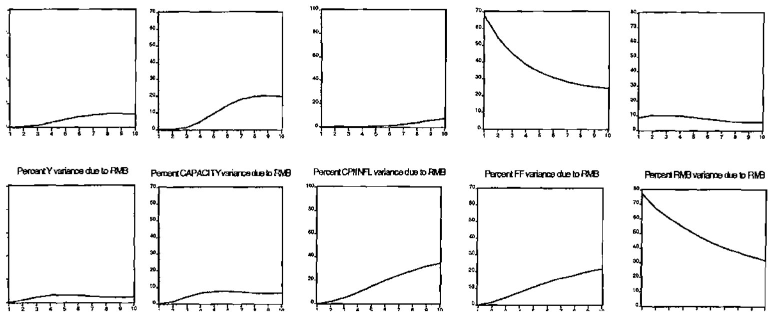

Figure 3.3: Variance due to monetary policy shocks (ff) and to money demand shocks (rmb). Sample 1966-2000

that omitting a measure of real money balances results in an overestimation of the contribution of aggregate demand shock to the variability of all variables.

To summarize, contrary to theoretical predictions, money demand innovations play a non-negligible role in explaining the variability of other variables in the model's economy, particularly of inflation.

3.3.3 Robustness of the results

We have conducted several experiments to check the robustness of our results. Our sample period includes two oil shocks and a change in the Federal Reserve operating procedures in 1979. It might be the case that estimating the VAR for the full sample period can affect the validity of our results. We have thus decided to exclude the pre-1979 years of the sample and re-estimate the 5-variable VAR over the period 1980:1-2001:2 as, for example, in Rotemberg and Woodford (1999). Figure 4, displays the results. The last column is of central interest. The shorter sample does not imply a change in the shape of any of the responses plotted in Figure 1. The point estimates are

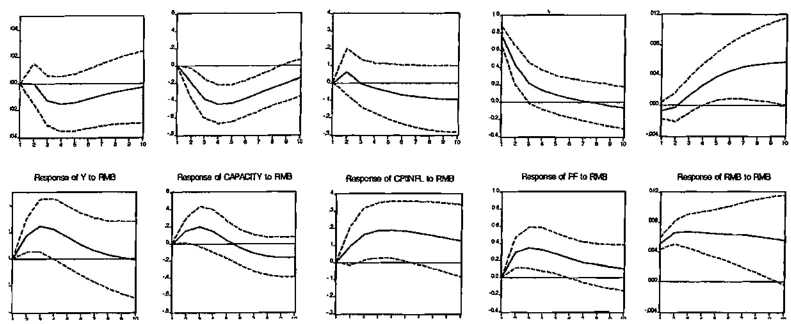

Figure 3.4: Response of all variables in the VAR to a monetary policy shock (FF, first row) and to a money demand shock (RMB, second row). Sample 1980-2000.

similar, although less precisely estimated due to the reduced number of observations available.

We have also used a VAR specification including the log-level of M2 (instead of real money balances) and the log-level of CPI (instead of inflation). The responses of all variables to a money demand shock are essentially unaltered. Moreover, no effects worth of notice were obtained by replacing M3 with M2 as proxy for real money balances.

As further robustness check, we have added a long-term interest rate (the yield on 10 year bonds) to the VAR. We have ordered the long-term interest rate after the policy instrument but before real money balances (measured by M2). The argument for this restriction is based on the inherent difficulty in allowing a response by monetary authority to market interest rates: if market rates depend on policy, a CB reacting to market rates can create indeterminacy. The new ordering allows for a money demand equation that includes a contemporaneous long interest rate term. Nelson (2000), has recently suggested that the direct effect of real money on aggregate demand may be, in fact, a proxy for an effect operating via a long interest rate. Our orthogonalization allows us to check this prediction: once we control for a long-term interest rate, shocks to money demand should have no longer effects on output or inflation. The impulse responses do not support this prediction; our benchmark results are virtually unaffected by this addition.

The standard model assumes that investments are a constant fraction of output. To check whether this simplification could be responsible for our results, we have added investments to the VAR (ordered before money), which did not result in any change worth reporting. The response of investments to money-demand shocks is almost identical in shape (but somewhat larger) to that of output.

Some researchers have argued that the money demand equation shows a break in the early 90s. For M2 and M3 this break is less clear than for M0 and M1: Andrews's test is easily passed, while a (less powerful) CUSUM test is failed. All tests are easily passed if a dummy for the 90s is included in the equation. Adding this variable to the VAR produces only minor changes.

Finally, we have changed the lag order of the VAR (two and four lags), and switched the order of interest rate and real money balances – although this is not predicted by the theory. Once again, the qualitative features of the results do not change. Overall our conclusion is that unpredictable shifts of money demand have significant and fairly robust effects for the dynamics of output, inflation, and interest rate. In the case of inflation, the effect is also sizable.

3.4 Further empirical evidence from an unrestricted reduced-form VAR

In the previous section we discussed the empirical relationships between money and output and money and prices by means of impulse response functions and variance decompositions. A more traditional approach is based on reduced-form F-tests. In line with this approach, we next examine how fluctuations of money contribute to predicting part of the subsequent fluctuations of output and prices not already predictable from past values of output, prices and interest rates. For this purpose we use a standard reduced form VAR including output gap, inflation, interest rate and real (M2) money balances. We report the statistics related to the coefficients of lags of real money balances, including F-tests of the null that those coefficient are all zero. Results for the entire sample are appear in Table 1.

Table 1: Sample 1966-2000

indip. var. capacity	coefficient	t-statistic	prob
rmb(-1)	39.06093	3.226369	0.0016
rmb(-2)	-38.53288	-3.260103	0.0014
		F-test:	p-value=0.007665

indip. var. inflation	coefficient	t-statistic	prob
rmb(-1)	18.28702	2.848781	0.0051
rmb(-2)	-17.40038	-2.776536	0.0063
		F-test:	p-value=0.006757

For both output gap and inflation, lagged values of real money balances enter positively and significantly. The lower part of the table presents F statistics for test of the null that 2 lags of real money are zero. It is essentially a Granger-causality statistics testing whether lagged values of real money balance help to predict inflation and output gap. The F-test strongly rejects the null for both equations.

For purposes of comparison, Table 2 and Table 3 also presents statistics for analogous regressions over two sub-samples: 1966:1-1979:4 and 1980:1-1999:4.

Table 2: sample 1966-1979.

indip. var. capacity	coefficient	t-statistic	prob
rmb(-1)	23.29724	0.750260	0.4570
rmb(-2)	-17.36029	-0.548762	0.5859
		F-test:	p-value=0.041519

indip. var. inflation	coefficient	t-statistic	prob
rmb(-1)	30.39007	3.534549	0.0010
rmb(-2)	-28.23104	-3.222914	0.0024
		F-test:	p-value=0.000027

Table 3: sample 1980-2000.

indip. var. capacity	coefficient	t-statistic	prob
rmb(-1)	30.83923	2.23502	0.0285
rmb(-2)	-30.96672	-2.215054	0.0299
		F-test:	p-value=0.089286

indip. var. inflation	coefficient	t-statistic	prob
rmb(-1)	15.43360	1.446232	0.1524
rmb(-2)	-14.70439	-1.359966	0.1780
		F-test:	p-value=0.307931

The evidence of this section combined with the estimated impulse response of the previous section, point towards the strong contribution of money to subsequent movement in the output gap and inflation.

3.4.1 Comparison with related literature

Recent work on the effects of money on output and inflation can be organized in two categories. The first examines the role of money within simple backward looking frameworks (similar in spirit to the one presented in Section or with F-tests (such as Granger Causality) in VAR reduced-form equations. The second category uses microfounded forward-looking models of monetary policy.

Within the first category, Rudebusch and Svensson (2001) use U.S. data for the sample 1961:1-1996:4 to conclude that lags of money (in levels or growth rate) were insignificant in their AD-AS structural model. Similar arguments are proposed by Gerlach and Smets (1996) who study the monetary transmission mechanism in the G7 countries using a VAR with output, inflation and interest rate, but without incorporating monetary aggregates in the analysis. Different conclusions are instead drawn by Meltzer (1999) and Nelson (2000) using base money. While Meltzer examines the effects of real money changes for the U.S. aggregate consumption, Nelson use the Rudebusch and Svensson's specification and concludes that the contribution of real money growth is a significant determinant for aggregate demand both in USA and UK, even after conditioning on the short-term real interest rate.

F-tests in multivariate regressions using U.S. data have also given mixed results. Sims (1980) found that including a short term interest rate in a VAR with output, inflation and money makes marginal the predictive content of money for output. Stock and Watson (1989) concluded that money helps in predicting future industrial production even after controlling for inflation and interest rates. Fried-man and Kuttner (1992, 1996) and Estrella and Mishkin (1997) have presented evidence that the predictive content of money for inflation and output has diminished since the 80's, due to the erratic behavior of M2 velocity. Correcting the tests used by Friedman and Kuttner for heteroskedasticity, Cheung and Fujii (2001) find that the effect of money on output is significant, though not sizeable.

The main contribution within the second category of work is given by Ireland (2001). He proposes a small structural model of monetary business cycles with forward looking IS and Phillips equations. Cross equations restrictions of his model imply that real money balances have a direct impact on the dynamics of output if and only if they also have a direct impact on the dynamics of inflation. A maximum likelihood estimation of the model, using quarterly U.S. data for the period 1980:1-1999:4, gives the puzzling result that changes in real balances fail to enter the IS and Phillips curves, but are the main variable in the central bank reaction function. Similar conclusions are obtained by Fuhrer (1994), though he works with the forward-looking model without microfoundations, developed in Fuhrer and Moore (1994). More recently, contrasting results are reported by Leeper and Zha (2000). They use a theoretical framework analogous to Ireland's model and conclude that the exclusion of money from this class of models is not empirically innocuous as the interpenetrations of historical policy behavior can change dramatically once money is reintroduced into the analysis.

It is clear that the literature has obtained mixed and often contrasting results, depending on the structural model and the empirical strategy used in each instance. How can we relate our results with those reported in the literature? It is well know that F-tests in multivariate models are subject to several pitfalls. Sims, Stock and Watson (1986) have for example shown that when the variables are highly persistent, and even if they don't have a unit root, conventional inference breaks down as F-statistics take non-standard distributions. In light of this, we consider our evidence based on impulse response function to be more informative and robust than F-tests. Moreover, although instability of the money-income and money-price relationships is a major concern of most of the work considered, formal test for stability is rarely performed. The Andrews' stability test reported above gives more strength to the robustness of our results, despite the conventional belief that the role of money for predicting output and inflation has evaporated after the 80's.

Given this uncertain state of things, our strategy has been to write an unconstrained VAR that nests the reduced forms of a well-specified class of models. The identifying restrictions we use are also supported by each model in the same class. We are aware of no study examining these empirical relationships in a similar fashion.

3.5 Model's simulations

On the basis of the results presented above, we have made an attempt at modifying the traditional model of the transmission mechanism and explore the consequences of including a direct role for money in the aggregate supply and aggregate demand equations. Specifically, we have changed the model of Section 2 by: (a) inserting a money term into the pair IS-AS equation, (b) adding a money demand equation and (c) specifying a process for potential output. Formally the augmented model has the following structure:

$$\pi_{t+1} = \pi_t + \alpha_x x_t + \alpha_m x_t + \epsilon_{t+1}^{CP} \tag{3.5}$$

$$x_{t+1} = \beta_x x_t - \beta_r (i_t - E_t \pi_{t+1}) + \beta_m m_t + \epsilon_{t+1}^{AD} \tag{3.6}$$

$$i_t = f + f_\pi (\pi_t - \pi^*) + f_x x_t + \epsilon_{t+1}^{MP} \tag{3.7}$$

$$m_t = \gamma m_{t-1} + k y_t - \eta i_t + \epsilon_{t+1}^{MD} \tag{3.8}$$

$$y_{t+1}^N = \rho y_t^N + \epsilon_{t+1}^N \tag{3.9}$$

$$y_t = x_t + y_t^N, \tag{3.10}$$

where y^N is potential output, modelled as an exogenous AR(1) process, and m is (log) real money balance.

The rational for the above specification is simple. We are interested in evaluating the dynamics of the Svensson's model, once money is allowed to play a direct role in output and inflation determination, separate from interest rates. We are aware of the lack of theoretical foundations for favouring this specification. Nevertheless, we want to assess to what extend such modified model may reproduced some of the estimated impulse responses functions reported in Section 3.1. [12]

[12] Indeed, there are at least two ways in which the above specification can be rationalized. Bernanke and Blinder (1988) propose, for example, a modified IS equation that incorporate a money term within an enlarged IS-LM model including a role for the banking sector into the economy. Svensson (2001) includes, instead, an exogenous stochastic extra term into the IS and Phillips curve and interpret it as additional determinant of future inflation and the output gap or as the deviation of the true model of inflation and output-gap determination from a simpler model with the deviation equal to zero.

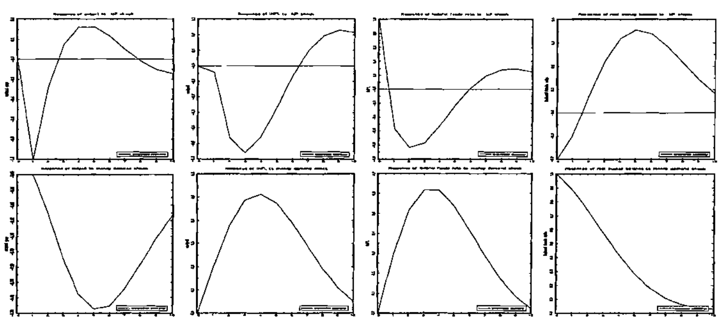

Figure 3.5: Impulse response functions to monetary policy shocks and to money demand shocks in the theoretical economy.

We choose the following parametrization. As in Ball (1999) we set $\alpha_y = 0.4$, $\beta_y = 0.8$, $\beta_r = 1$. The values assigned to the money parameters in the IS and Phillips equation are obtained by running least square regression with biannual data from 1996:1 through 1999:4:, $\alpha_m = 0.1$, $\beta_m = 0.2$. The money demand function is estimated similarly. The standard deviations are $\sigma_{CP}^2 = \sigma_{AD}^2 = \sigma_{MP}^2 = \sigma_{MD}^2 = 1$. The parameters in the Taylor rule are set to $f_y = 0.5$, $f_\pi = 1.5$. $\rho = 0.98$.

The simulated impulse responses of the model are reported in Figure 5.

The similarity of the simulated dynamics of the model with the empirical impulse response functions of the identified VAR of Section 3 is striking. The second column reports the effect of a money demand shock. Both the sign and the shape of the impulse responses are in line with those presented above: output, inflation and interest rate rise.

Thus, while the model parametrization is far from being uncontroversial, we can reproduce most of the findings reported in the previous section if and only if we allow for a direct real money effect for inflation and output gap. Moreover, the model is consistent with our empirical results in another aspect. If we fit the five variable VAR

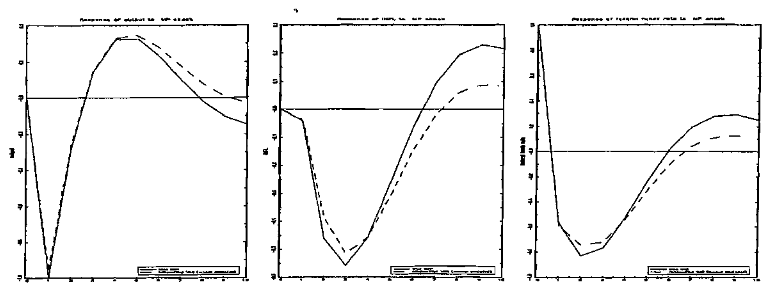

Figure 3.6: Response to a monetary policy shock in the VAR including money (continuous line) and excluding money (dashed line). Data are generated by the theoretical model.

of Section 3 to this model, we obtain the impulse response functions depicted in Figure 5 (abstracting from parameter uncertainty due to a small sample). Only if we calibrate the money's coefficient to zero in equations (3.5) and (3.6) will we recover flat responses.

However, if we generate data from the model and then estimate the four variable VAR of Section 3, which excludes money, we obtain a nearly identical picture of the effects of a monetary policy shock, as shown in Figure 6 (compare with Figure 2).[13]

Finally, variance decomposition exercises (not reported) indicate that when money is excluded, it is mainly the role of aggregate demand shocks to be overestimated, just as found on US data in Section 3.2.

3.6 Conclusions

This paper has examined the role played by money demand shocks in shaping the dynamics of output, inflation and interest rates, using an identified VAR. The identifying restrictions of our exercise were suggested by a class of models for monetary policy

[13]In producing the responses for the misspecified system we abstract from parameter uncertainty by setting the sample size to 10000.

analysis that assign a residual role to money.

Surprisingly, our results indicate that money demand shocks might be important determinants of output and inflation. We have argued that the results are robust to different measures of real money balances and to changes in VAR specification. Finally, we have observed that if a standard backward-looking model of monetary policy is modified to include a direct role of money for inflation and aggregate output, the implied dynamics of the model mimic quite well the estimated impulse responses functions.

However, a caveat is in order. What our exercise seems to imply is that there is a flaw in the standard framework, not that we have found an independent role for money demand shocks in the transmission mechanism. In fact, we have not offered a model-driven explanation, or even a reasonable story, to clarify what may lie behind the label "money demand shocks". For presentation purposes, a label was needed, but it should not be taken too seriously at this point. It could well be the case that money is acting as a proxy for some other omitted variable or that it appears because of some other misspecification. This said, the results presented seem robust enough to suggest that current models of monetary policy may neglect an important determinant of output and inflation dynamics by assuming away any reference to monetary aggregates. Within this class of models, our results present a challenge for researchers interested in finding rigorous explanations for why monetary aggregates should pick up a role in output and inflation determination, separate from interest rates.

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Chapter 4

Inflation Forecast Uncertainty

with Paul Söderlind

Abstract:

We study the inflation uncertainty reported by individual forecasters in the Survey of Professional Forecasters 1969-1999. Three popular methods of estimating uncertainty from survey data are analyzed in the context of models for forecasting and asset pricing. We find that disagreement can be a good proxy for uncertainty in some cases, but not in others. Uncertainty is highly correlated with the level of inflation, in particular with recent positive inflation surprises, but it contains more information than what is implied by popular time series models. Finally, forecasters underestimate uncertainty.

[0]We thank Thom Stark for help with the data; and Kajal Lahiri and Lars Erik Öller for comments.

4.1 Introduction

Modern economic theory predicts that agents' behavior depends on their assessment of the probabilistic distribution of the variables that they need to forecast. It is only under very restrictive assumptions that the point forecast is sufficient to characterize their choices. In general, higher moments also matter. This paper focuses on inflation uncertainty, but several issues raised and all techniques employed can be applied to other macroeconomic variables. A large number of studies have investigated the forecasting properties (unbiasedness, efficiency) of point forecasts from surveys.[1] Our paper has little to say about that. Instead, we focus on uncertainty, which we take to be captured by the standard deviation (we will consider different distributions and related standard deviations).

Since Friedman's conjecture that higher inflation uncertainty has a negative effect on the efficiency of the economic system, the empirical literature have used proxies for inflation uncertainty in investigating its relationship with a variety of macro variables, including real and nominal interest rates, unemployment, fiscal deficit, wages, industrial production and output.[2]

This paper start from the premise that agents' expectations revealed in surveys can sometimes be preferable to measures obtained by time series models. Some circumstances where this argument can apply more forcefully include:

- A series that has recently undergone a structural change such that the new data generating process has uncertain parameters (take, for example, the adoption of an inflation target).

[1]See, for instance, Thomas (1999) for a recent study of several surveys and Davies and Lahiri (1999) for a recent study of the Survey of Professional Forecasters.

[2]Studies that have used measures of uncertainty extracted from survey data or from time series methods to analyze the effects of inflation uncertainty on macroeconomic variables include Barnea et al. (1979), Lahiri et al. (1988), Levi and Makin (1980), Mullineaux (1980), Bomberger and Frazer (1981), Melvin (1982), Makin (1982, 1983), Ratti (1985), Holland (1986, 1993), Evans and Wachtel (1993), and Grier and Perry (2000).

- Forward looking behavior, so that agents' foresee a regime change before this shows up in the data (such changes can be difficult to model).

- Different time series methods disagree largely on the conditional variance and it is difficult to point to a superior one.

- Whenever an empirical rather than a normative measure of uncertainty is requested, so that the interest focuses on actual agents' expectations.

As an example of this last point, consider Sargent's (1993) claim that a policy of reduction of the inflation rate need not cause any loss of output if the change in regime is credible. To be made operational, the claim needs a measure of credibility. One way to assess credibility is then to consider the mean and width of agents' forecast error bands. As another example, forecast error bands makes it possible to evaluate the credibility of inflation targets, including the tolerance intervals, used by many central banks. In such circumstances a survey measure of uncertainty has clear advantages over an econometric one. If a change in regime is suspected, these advantages are magnified. A main concern of the paper is to compare survey and time series measures of inflation uncertainty and to assess whether the two can coherently be modelled in the same way.

But if having a measure of uncertainty from survey data is often desirable, there is no clear, uncontroversial, way of extracting such a measure. In this paper we present alternative methods of extracting a measure of uncertainty from survey data, with an application to the inflation forecasts from the Survey of Professional Forecasters. We discuss advantages and drawbacks of the different methods and argue through some examples that the relevant measure of uncertainty depends on its intended use. We can also give new insights on whether disagreement on the point forecast, a readily available but (at present) theoretically unfounded measure of uncertainty, is a good proxy for more theoretically appealing measures.

The rest of the paper proceeds as follows. Section 2 presents the data (mainly the Survey of Professional Forecasters). Section 3 discusses alternative measures of uncertainty from the survey data in the context of a forecasting model and also in a model of asset pricing. Section 4 discusses the estimation of uncertainty. Section 5 presents the empirical results, and Section 6 concludes.

4.2 The Survey of Professional Forecasters

The data used in this paper are from the Survey of Professional Forecasters (SPF), which is a quarterly survey of forecasters' views on key economic variables. The respondents, who supply anonymous answers, are professional forecasters from the business and financial community. The survey was started in 1968 by Victor Zarnowitz and others of the American Statistical Association and National Bureau of Economic Research. The number of forecasters was then around 60, but decreased in two major steps in the mid 1970s and mid 1980s to as low as 14 forecasters in 1990. The survey was then taken over by the Federal Reserve Bank of Philadelphia and the number of forecasters stabilized around 30. See Croushore (1993) for details.

There is no guarantee that respondents in a survey give their best (in statistical sense) forecasts. They may simply give nonsense answers, or biased answers due to, for example, strategic considerations. For instance, Laster et al. (1999) argue that forecasters may have an incentive to publish forecasts that stand out. However, their argument relies on the answers being public, and the answers to the SPF survey are anonymous. As for the risk of nonsense answers, we believe that the appointment procedure of the respondents, which includes a screening of the candidates, goes far in ensuring that most of the answers, most of the time, accurately represents the respondents' beliefs. There may still be odd or erroneous (sloppy handwriting...) answers in the SPF data base. This is one of the reasons why we use robust estimation methods which mitigate the problems with outliers. We believe that it is a strength of the SPF that the forecasters are close to important economic decision makers, since this makes it more likely that the survey reflects beliefs that affect the most important pricing and investment decisions.

A unique feature of the SPF is that it asks for probabilities (on top of the usual point forecasts) for a few variables. In particular, it asks for probabilities of different intervals of (annual average) GDP deflator inflation, that is, the GDP deflator for year t divided by the GDP deflator for year $t-1$, minus one.[3] CPI inflation would perhaps have been more interesting, but probabilities are not available for it. Besides, GDP deflator inflation and CPI inflation are typically very similar (the correlation is 0.95 for the sample 1955Q1-2000Q2).[4]

The SPF is a quarterly survey, but we have chosen to use the first quarters only. The reason is that there are indications that the survey in the other quarters are not comparable across years (at least not before 1981Q3) since the forecasting horizon shifted in a non-systematic way. We therefore choose to focus on the first-quarter surveys: they refer to the growth rate of the deflator from the previous to the current year (annual-average). From 1981Q4 the survey includes also probabilities for GDP deflator inflation between the current and the next year. We will take a look at these numbers as well.

The inflation intervals for which survey respondents are asked to give probabilities have changed over time. There is an open lower interval, a series of interior intervals of equal width, and an open upper interval. The width of the intervals has changed over time (1% before 1981Q3 and after 1991Q4, 2% in the intermediate period) which may influence estimates of variance. We will take this into account. See Appendix A for more details.

The results from this survey are typically reported in three ways: the median point

[3]Before 1981Q3, the questions were about GNP and the GNP deflator instead. The two deflators are virtually the same during this sample.

[4]The major difference between the GDP deflator inflation and CPI inflation is that the latter is more volatile. In particular, it seems to temporarily react more to oil price shocks.

forecast, the dispersion of the individual point forecasts, and the aggregate (or mean) histograms which are constructed by averaging the probabilities from the individual forecasters' histograms.

As a preview of the data, *Figure 1* shows the aggregate histogram for all first quarters 1969-2000. The means of these "distributions" (vertical lines) follow the well-known story about US inflation.

For most years, the histograms are reasonably symmetric with most of the probability mass in interior intervals, so the SPF data seems useful for eliciting measures of uncertainty. However, 1985 is a striking exception with 60% of the mass in the open lower interval of inflation lower than 4%: it is clear that the placement of the survey intervals did not keep track with the lower inflation after the "Volcker deflation." The intervals were adjusted only in 1985Q2. It is very difficult to say anything about the moments of the distribution with so little information as in 1985Q1. Moreover, the Federal Reserve Bank of Philadelphia (2000) suspects that the surveys in both 1985Q1 and 1986Q1 may have asked for the wrong forecasting horizon. We will therefore disregard these two observations in the rest of the analysis (including them does not affect our main findings).

4.3 Which measure of uncertainty?

In this section we discuss what we should take as the relevant measure of inflation uncertainty. Not surprisingly, the answer depends on why we want a measure of uncertainty. There are three main candidates: disagreement among forecasters, average individual forecast error variance (or standard deviation), or the variance of SPF's aggregate histogram. They have all been used in previous research and macroeconomic analysis.[5]

[5] Studies that have used measures of uncertainty extracted from survey data to analyze the effects of inflation uncertainty on macroeconomic variables include Barnea et al. (1979), Lahiri et al. (1988), Levi and Makin (1980), Mullineax (1980), Bomberger and Frazer (1981), Melvin (1982), Makin (1982,

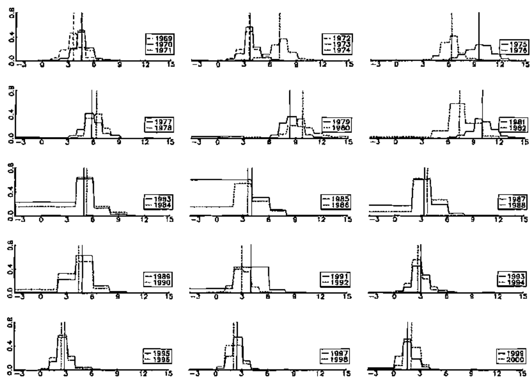

Figure 4.1: **Aggregate proabilities for SPF 1966-2000.** This figure shows the aggregate probabilities (vertical axis) for different inflation rates (horizontal axis). Estimated means are indicated with lines. Each subfigure shows the probabilities for two (or three years).

Disagreement on the most likely outcome has the advantages of being readily available and easy to compute. The disadvantages are also clear. This measure becomes meaningless as the number of agents goes to one or when agents have the same information and agree on the model to use in forecasting. In this case, the measure of uncertainty is zero as if the economy was deterministic. One of the questions tackled in this paper is if disagreement mirrors other measures of uncertainty that are theoretically more appealing, but less easily available.

The average standard deviation of individual histograms does not have the drawbacks of the first measure. It is attractive because it is easy to associate with the uncertainty of a representative agent. On the other hand, it sweeps disagreement under the rug, and disagreement must reflect some type of uncertainty.

The third measure of aggregate uncertainty is computed as the variance in the

1983), Ratii (1985), and Holland (1986, 1993).

aggregate histogram. In this case aggregate uncertainty is higher than the average variance of the individual distributions, which is to say that individual forecasters underestimate uncertainty. This last result does cause some perplexity. However, the possibility cannot be excluded a priori: if someone consults two doctors, obtaining different diagnoses, she will be uncertain to some degree, no matter how certain the doctors are.

4.3.1 A Simple model of forecasting

This section sets up a small model of many forecasters in order to discuss the relation between individual uncertainty, disagreement, uncertainty of a combined forecast and SPF's aggregate uncertainty. Note that the distributions and moments discussed here refer to a particular period. To economize on notation we suppress time subscripts, with the hope that the context makes it clear that we are discussing separate distributions for each period.

In this model, *individual forecasters* face different, but correlated, information sets which they use in an optimal way to make the best possible inflation forecast. By "best" we mean the conditional mean, which minimizes the expected squared forecasting error. For notational convenience, the information set and forecasting model of forecaster i is summarized by a scalar "signal" z_i, which is useful for forecasting only if it is correlated with actual inflation, π. Let $\mathrm{pdf}(\pi|i)$ be the probability density function of inflation conditional on receiving the signal of forecaster i; this corresponds to the histograms reported by forecaster i in a given quarter. The mean and variance of this distribution are μ_i and σ_i^2, which can be different for different forecasters. One natural measure of inflation uncertainty is the average (across forecasters) individual uncertainty, which we denote by $\mathrm{E}\,\sigma_i^2$.

Example 2 *As an example, suppose π and z_i have a multivariate normal distribution with zero means (to simplify the algebra), variances $s_{\pi\pi}$ and s_{ii}, and covariance $s_{\pi i}$.*

In this case, $\mathrm{pdf}(\pi|i)$ *is a normal distribution with mean* $\mu_i = (s_{\pi i}/s_{ii})\, z_i$ *and variance* $\sigma_i^2 = s_{\pi\pi} - s_{\pi i}^2/s_{ii}$*, which is the standard least squares result.*

It is well established, both in theory and practice, that an unweighted combination of several different methods/forecasters typically reduces the forecast uncertainty (see, for instance, Granger and Ramanathan (1984) for a general discussion of optimal combinations; Zarnowitz (1967) and Figlewski (1983) for applications to inflation data).

Anyone who has access to the survey data can use the cross sectional average of the individual forecasts, $\mathrm{E}\,\mu_i$, as a *combined forecast.* If the number of forecasters go to infinity, then all individual movements in the forecast errors are averaged out, and only the common movements remain. It is straightforward to show (see reference above) that the (expected) forecast error variance of an unweighted average of forecasts equals the average covariance of individual errors.[6] There is thus a gain from using a combined forecast as long as the individual forecast errors are unbiased and less than perfectly correlated. This theoretical argument suggests that the mean forecast in the SPF should be assigned a smaller uncertainty than the average individual uncertainty.

Example 3 *To continue the previous example, suppose that individual signals have the same variance and covariances. It can then be shown (see Appendix B) that the forecast error variance of the combined forecast is* $\sigma_i^2 - \mathrm{Var}\,(\mu_i)$*, which is the individual forecast error variance minus the cross sectional (across forecasters) variance of point forecasts. The combined forecast is thus better than individual forecasts, especially if forecasters disagree.*

As mentioned, the SPF combines the individual histograms into aggregate (or mean) probabilities, by taking the average (across forecasters) probability for each inflation interval. To see how this *aggregate distribution* is related to individual uncertainty and

[6] With n forecasters we have $\mathrm{Var}\,(\pi - \sum_{i=1}^{n} \mu_i/n) = \mathrm{E}\,\sigma_i^2/n + \mathrm{E}\,\gamma_{ij}\,(1 - 1/n)$, where $\mathrm{E}\gamma_{ij}$ is the average covariance of two individual forecast errors.

disagreement among forecasters, think of both future inflation and forecaster i's signal as random variables. Also, let $\mathrm{pdf}(i)$ be the density function of receiving the signal of forecaster i in that period. We then see that the aggregate distribution in that period, $\mathrm{pdf}_A(\pi)$, which averages $\mathrm{pdf}(\pi|i)$ across forecasters, amounts to calculating the "marginal" distribution of π

$$\mathrm{pdf}_A(\pi) = \int_{-\infty}^{\infty} \mathrm{pdf}(\pi|i)\,\mathrm{pdf}(i)di. \tag{4.1}$$

As before, let μ_i and σ_i^2 be the mean and variance in forecaster i's distribution, $\mathrm{pdf}(\pi|i)$. We know that (if the moments exist) the variance of the distribution in (1) is[7]

$$\mathrm{Var}_A(\pi) = \mathrm{E}(\sigma_i^2) + \mathrm{Var}(\mu_i), \tag{4.2}$$

so the variance of the aggregate distribution of π can be decomposed into the average of the forecasters' variances (average individual uncertainty) and the variance of the forecasters' means (disagreement). If we were to take one more step and integrate $\mathrm{pdf}_A(\pi)$ over the distribution of cross-sectional (across forecasters) means, then we would arrive at the unconditional distribution of inflation.

Example 4 *To continue the previous example, the aggregate distribution becomes a normal distribution with mean* $\mathrm{E}\,\mu_i$ *and variance* $\mathrm{Var}_A(\pi) = \sigma_i^2 + \mathrm{Var}\,(\mu_i)$. *In terms of the "deep" parameters, this is* $\mathrm{Var}_A(\pi) = s_{\pi\pi} - s_{\pi i}^2/s_{ii} - (s_{\pi i}/s_{ii})^2\,(s_{ii} - s_{ij})$, *where* s_{ij} *is the covariance of signal* z_i *and* z_j. $\mathrm{Var}_A(\pi)$ *is smaller than the unconditional variance,* $s_{\pi\pi}$, *since* $s_{ii} \geq s_{ij}$.

It is not obvious what the aggregate distribution represents. It is more "informed" (lower forecast error variance) than the unconditional distribution (when there is no signal at all) of π, but less informed than the individual conditional distributions. An appealing interpretation is that a reader of forecasts faces two sources of uncertainty:

[7] For any random variables y and x we have $\mathrm{Var}(y) = \mathrm{E}[\mathrm{Var}(y|\,x)] + \mathrm{Var}[\mathrm{E}(y|\,x)]$.

which forecast to trust and then that forecast's uncertainty. This is wrong, however, if the individual forecaster understands that he could make a more precise forecast if he had all the information of the other forecasters, that is, if he incorporates his individual uncertainty in the forecasting error variance he reports. The forecasters who calculate conditional expectations do.

This simple model of forecasting suggests a few things. First, combined forecasts are likely to be much better than individual forecasts only if disagreement is large compared to individual uncertainty. Second, it seems hard to justify the aggregate distribution from a pure forecasting perspective—unless we believe that individual forecasters underestimate uncertainty. Whether this is the case empirically is discussed in Section 5.3.

4.3.2 Individual beliefs and asset pricing

It has so far been difficult to motivate why we should care about SPF's aggregate distribution. This section presents a simple economic model, where this aggregate distribution turns out to be crucial for asset pricing, even if may be of no particular importance for forecasting. The basic idea is that the beliefs of an agent (forecaster) will influence his consumption and investment decisions, so the aggregate economy is likely to be affected by some kind of average beliefs.

To demonstrate this point, we consider the pricing of Arrow-Debreu (A-D) assets when agents have different beliefs (see, for instance, Varian (1985) and Benninga and Mayshar, 1997); A-D asset s has a payoff of one in state s and zero in all other states.

This is an endowment economy with n agents. Endowment in period 1 is known, but endowment in period 2 is random and may take any of S different values ("states") for each of the n agents. The agents have identical preferences, but may have different endowments and beliefs about the state probabilities. Agent i maximizes expected utility subject to the budget restrictions, that is, he solves

$$\max C_{i1}^{1-\gamma}/\left(1-\gamma\right)+\mathrm{E}\,C_{i2}^{1-\gamma}/\left(1-\gamma\right), \text{ subject to} \tag{4.3}$$

$$Y_{i1}=C_{i1}+\textstyle\sum_{s=1}^{S}p\left(s\right)B_{i}\left(s\right), \text{ and} \tag{4.4}$$

$$C_{i2}\left(s\right)=Y_{i2}\left(s\right)+B_{i}\left(s\right) \text{ for } s=1,..,S. \tag{4.5}$$

The period utility function has constant relative risk aversion γ. The budget restriction in period 1, (4), says that agent i's endowment is spent on consumption and purchases of the S different A-D assets at the prices $p(s)$. The budget restrictions for period 2, (5), says that i's consumption in state s equals his endowment in that state and the number of A-D asset s bought in the previous period.

Agent i's first order condition for A-D asset s is

$$p\left(s\right)=\Pr_{i}\left(s\right)C_{i1}^{\gamma}/C_{i2}^{\gamma}\left(s\right), \tag{4.6}$$

where $\Pr_i(s)$ is agent i's subjective probability assessment of state s, and $C_{i2}(s)$ his consumption in that state. Solve this equation for $C_{i2}(s)$, sum over all n agents and use the fact that aggregate consumption equals aggregate endowment, $Y_2(s)$, in every state. This gives the price of A-D asset s

$$p\left(s\right)=\left[\textstyle\sum_{i=1}^{n}C_{i1}\Pr_{i}\left(s\right)^{1/\gamma}\right]^{\gamma}/Y_{2}^{\gamma}\left(s\right). \tag{4.7}$$

When $\gamma=1$ (logarithmic utility), then this simplifies to $1/Y_2(s)$ times a weighted average of the agents' probabilities that state s will occur. The weights are proportional to the agents' consumption in period 1. If these are roughly equal, then this is an unweighted average similar to the aggregate distribution in the SPF. This can then be interpreted as the appropriate belief of a "representative agent."

To illustrate this, consider real and nominal bonds. A real bond pays one unit in all states, so its price is $\Sigma_{s=1}^{S}p(s)$. A nominal bond will require compensation for inflation. For simplicity, suppose there is no inflation in states $s=1,\ldots,S-1$, but inflation is π in state S. The price of a nominal bond is then equal to the price of a real bond minus $\pi p(S)$. In the simple case where all agents have log utility and equal first period consumption $C_{i1} = C_1$, we get that $p(S) = \Sigma_{i=1}^{n} \Pr_i(S) C_1 / Y_2(S)$.

We could compare this with a "risk neutral" pricing of the nominal bond, which simply sets the price equal to the price of the real bond minus average of agents' expected inflation, $\pi \Sigma_{i=1}^{n} \Pr_i(S)/n$. The risk premium on the nominal bond is then

$$\text{Inflation risk premium} = \pi \left[\sum_{i=1}^{n} \Pr_i(S)/n\right] \left[nC_1/Y_2(S) - 1\right]. \tag{4.8}$$

We can note several interesting things. First, investors will regard the nominal bond as risky and ask for a positive risk premium if the inflation state has a low endowment $Y_2(S)$, that is, if inflation and endowment are negatively correlated. Second, it is the average of investors probabilities that matter. Third, a mean preserving spread of inflation (increase π by a factor and decrease $\Pr_i(S)$ by the same factor so expected inflation is unchanged but the variance increased) does not necessarily give a larger risk premium. However, the risk premium increases if the larger inflation uncertainty is accompanied by a lower $Y_2(S)$, that is, a more negative covariance of inflation and endowment. Fourth, increased disagreement (with unchanged average) has an ambiguous effect on the risk premium. With log utility as in (8) it has no effect, and the effect can be both positive and negative depending on γ.[8]

4.4 Estimating uncertainty from survey probabilities

This section discusses how we estimate variances from SPF's histograms. It is always tricky to estimate moments from a histogram, but it is even trickier in this case since the width of SPF's inflation intervals has changed over time (1% for most of the sample, but 2% 81Q3-91Q4).

[8]With $\gamma > 1$, if the probabilities for state s is made more different between agents but with $\Sigma \Pr_i(S)$ unchanged, then $p(S)$ decreases. This implies that the risk premium of the the nominal bond becomes smaller. The opposite holds for $\gamma < 1$.

We choose to fit normal distributions to each histogram. The mean and variance are estimated by minimizing the sum of the squared difference between the survey probabilities and the probabilities for the same intervals implied by the normal distribution. This can be thought of as a non-linear least squares approach where the survey probability is the dependent variable and the interval boundaries the regressors.

A straightforward, but crude, alternative way to estimate the mean and variance from a histogram (and used in a similar context by Lahiri and Teigland, 1987) is

$$\widetilde{\mathrm{E}}\pi = \textstyle\sum_{k=1}^{K} \bar{\pi}(k) \Pr(k) \text{ and } \widetilde{\mathrm{Var}}(\pi) = \textstyle\sum_{k=1}^{K} [\bar{\pi}(k) - \widetilde{\mathrm{E}}\pi]^2 \Pr(k), \tag{4.9}$$

where $\bar{\pi}(k)$ and $\Pr(k)$ are the midpoint and probability of interval k, respectively. The lowest and highest intervals, which are open, are taken to be closed intervals of the same width as the interior intervals.

The approach in (9) essentially assumes that all probability mass are located at the interval midpoints. However, the shape of the histograms in *Figure 1*, which often look fairly bell shaped, suggests that this approach overestimates the variance. It rather seems plausible that relatively more of the probability mass within an interval is located closer to the mean. This motivates our choice of fitting normal distributions.

Figure 2.a shows the aggregate survey probabilities once again, and *Figure 2.b* shows the difference between the aggregate survey probabilities and the probabilities implied by the fitted normal distributions. The normal distributions (with two parameters) seems to be able to fit most of the intervals (6, 10, or 15 depending on period) most of the time.

Figures 3.a-b show the aggregate standard deviation estimated in three ways: (*i*) from fitted normal distributions using SPF's intervals; (*ii*) as in the crude method in (9) using SPF's intervals; and (*iii*) from fitted normal distributions, but using 2% intervals throughout the sample. The general pattern is the same for all three methods, but there are some differences. In Figure 3.a, the crude method is consistently above the estimated normal and the difference is particularly large during the 1980s when

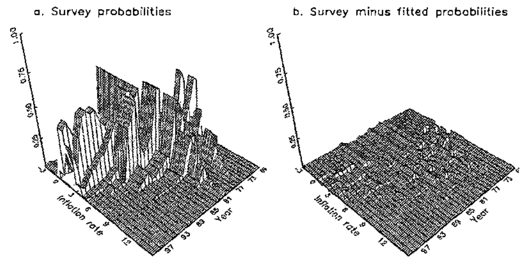

Figure 4.2: Aggregate probabilities and estimation error. Subfigure a shows the aggregate survey probabilities for every year 1969-2000. Subfigure b shows the difference between the survey probabilities and the implied probabilities from fitted normal distributions.

there were few and wide intervals.[9] In Figure 3.b, the 2% intervals give somewhat higher standard deviations. This suggests that the high estimates of the standard deviations during the 1980s may partly be due to the 2% intervals used by SPF at that time (this period is marked by vertical lines). However, the small difference between the two estimates during the 1970s and 1990s, when SPF used 1% intervals, suggest that this effect is small. In fact, none of our main results are affected by using 2% intervals throughout the sample.

[9] An alternative way of adjusting the crude variance, used by Ivanova and Lahiri (2000), is to apply Sheppard's correction (see Kendall and Stuart, 1963). It amounts to subtracting 1/12 of the squared interval width from the crude variance. For the standard deviations this means approximately 0.04 for most of the sample, and 0.12 for 1982-1991, which would not make much impact.

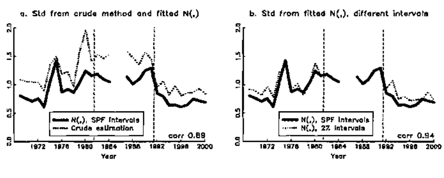

Figure 4.3: Aggregate standard deviation estimated in three different ways. Subfigure a compares standard deviations obtained fitting normal distributions with the crude method in (9). Subfigure b compares standard deviations from fitting normal distribution using either SPF's intervals or 2% intervals for the whole sample.

4.5 Empirical results

4.5.1 A decomposition of aggregate uncertainty

Figure 4.a shows the aggregate standard deviation and average individual standard deviation, $E(\sigma_i)$. Other measures of the central location, like the median σ_i, give similar results. The general pattern of the two series in Figure 4.a is that uncertainty was low before 1973 and after 1992 and fairly high in between with peaks in the early 1970s, late 1970s, and early 1990s. It is also clear that the aggregate standard deviation and the mean individual standard deviation are very highly correlated; the correlation coefficient is 0.90.

Figure 4.b shows the aggregate standard deviation and a measure of the cross-sectional dispersion of forecasters' point forecast μ_i (disagreement); a quasi-standard deviation, denoted qStd(μ_i), of u_i calculated as half the distance between the 84th and 16th percentiles of μ_i. If μ_i were normally distributed, then this would be the same

	$\text{Std}_A(\pi)$	$\text{E}(\sigma_i)$	$\text{qStd}(\mu_i)$	$\frac{\text{qStd}(\mu_i)}{\text{Std}_A(\pi)}$
$\text{Std}_A(\pi)$	1.00			
$\text{E}(\sigma_i)$	0.90	1.00		
$\text{qStd}(\mu_i)$	0.83	0.61	1.00	
$\text{qStd}(\mu_i)/\text{Std}_A(\pi)$	0.38	0.02	0.77	1.00

Table 4.1: Table Correlation of different measures of inflation uncertainy in SPF. The sample is 1969-2000, excluding 1985 and 1986. $\text{Std}_A(\pi)$ is the standard deviation of SPD's aggregate distribution; $\text{E}(\sigma_i)$ is the cross-sectional average individual standard deviation; $\text{qStd}(\mu_i)$ is a cross-sectional quasi-standard deviation of individual point forecasts

as the standard deviation.[10] The figure shows that disagreement and the aggregate standard deviation typically move in the same direction; the correlation coefficient is 0.83.

By comparing Figure 4.a and 4.b we see that disagreement and individual uncertainty typically move together: the correlation in *Table 1* is 0.61. However, disagreement fluctuates more. It is therefore not surprising that disagreement accounts for most of the movements in the aggregate uncertainty: Table 1 shows that the ratio $\text{qStd}(\mu_i)/\text{Std}_A(\pi)$ has a fairly strong positive correlation (0.38) with $\text{Std}_A(\pi)$. We interpret this evidence as indicating that disagreement is a good proxy for other measures of uncertainty that are more theoretically appealing, but less easily available. Bomberger (1996) reaches the same conclusion based on a comparison of disagreement and ARCH measures of the conditional variance.

[10]The traditional standard deviation is typically higher and much more volatile. A closer look at the data suggests that the standard deviation is affected by occasional outliers. We therefore focus on the quasi-standard deviation. Zarnowitz and Lambros (1987) use a traditional estimator of the cross sectional dispersion, which probably explains the very large time variation they get. The interquartile range divided by 1.35, which is another common robust measure of dispersion, gives very similar results.

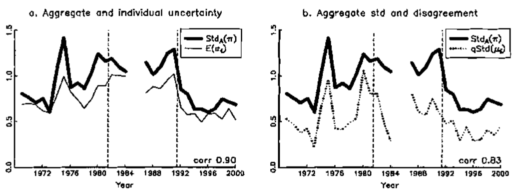

Figure 4.4: Individual and aggregate uncertainty. Subfigure a compares the standard deviation of the aggregate distribution with the average individual standard deviation. Subfigure b compares the standard deviations of the aggregate distributions with the quasi-standard deviations of individual point forecasts.

4.5.2 Inflation uncertainty and macro data

This section studies some simple facts about how inflation uncertainty is related to macroeconomic variables.

Table 2 shows that all three measures of uncertainty (aggregate standard deviation, average individual uncertainty, and disagreement), as well as the relative importance of disagreement, are strongly positively with inflation and the consensus point forecast of inflation. They are also strongly negatively correlated with GDP growth. This is consistent with previous findings based on other measures of inflation uncertainty.[11]

Most asset pricing models, including the one in Section 3, suggest that inflation uncertainty may contribute to a risk premium on nominal bonds, in particular if the

[11] See, among others, Levi and Makin (1980), Makin (1982), Mullineax(1980), Grier and Perry (2000), and Evans and Wachtel (1993) for evidence on the relation between inflation uncertainty and output and employment growth. Zarnowitz and Lambros (1987) found that average expected inflation and average individual uncertainty are positively correlated.

inflation risk cannot be diversified away. The implications for the relation between the risk premium and disagreement are less clear.

Table 2 shows that expected real return on a nominal bond is positively correlated with average individual uncertainty, but not correlated with disagreement. The first result is similar to the results for a shorter sample obtained by Lahiri and Zaporowski (1988), but the second result is different from Bomberger and Frazer (1981) and Makin (1983) who found a negative relation with the disagreement in the Livingston survey for the period up to the early 1980s. In fact, also our data show a negative correlation (-0.15) for 1969-1981, but this is outweighed by a stronger positive correlation (0.35) for 1982-1999.

The last four rows of Table 2 is an attempt to study possible ARCH/GARCH features. All three measures of uncertainty are strongly autocorrelated and positively correlated with recent volatility in inflation and GDP growth. This suggests that there are prolonged period of higher overall uncertainty of several macroeconomic variables. There are some fairly weak correlations between uncertainty and the absolute value of last year's forecasting error, so the evidence of ARCH effects is not very strong.

It is also interesting to see if the positive correlation of uncertainty and inflation forecast holds also on the "micro level" in the sense that forecasters with a high point forecast tend to report high uncertainty in the same year. This correlation fluctuates substantially over time (in a non-systematic way), and is on average close to zero (0.12). Another possibility is that forecasters whose point forecasts are far from the medium also are more uncertain. This hypothesis is not supported by data either: the correlation between the individual standard deviation and the absolute deviation of the individual point forecast from the cross-sectional median fluctuates over time around zero (0.02).

	$\text{Std}_A(\pi)$	$\text{E}(\sigma_i)$	$\text{qStd}(\mu_i)$	$\frac{\text{qStd}(\mu_i)}{\text{Std}(\pi)}$
Consensus point forecast	0.68	0.60	0.67	0.33
Inflation_{t-1}	0.60	0.55	0.61	0.29
GDP growth_{t-1}	-0.44	-0.44	-0.50	-0.29
Expected real return on bond	0.11	0.30	-0.02	-0.19
Own lag	0.66	0.74	0.43	0.02
Std of recent inflation_{t-1}	0.45	0.50	0.23	-0.07
Std of recent GDP growth_{t-1}	0.38	0.42	0.23	-0.06
Absolute value of lagged forecast error	0.24	0.22	0.14	0.00

Table 4.2: Table Correlation of inflation uncertainty and macro series. The consensus point forecast is the average individual point forecast in SPF; Inflation and GDP growth are annual and measured in the last quarter of the preceeding year; the ex ante real interest rate is a one-year nominal interest rate minus the consensus point forecast; the own lag is the lagged value (one year) of the variables in the column headings; Std of recent inflation and GDP are the standard deviations of inflation and GDP growth over the last five years; the forecast error is the actual GDP deflator inflation minus the consensus forecast.

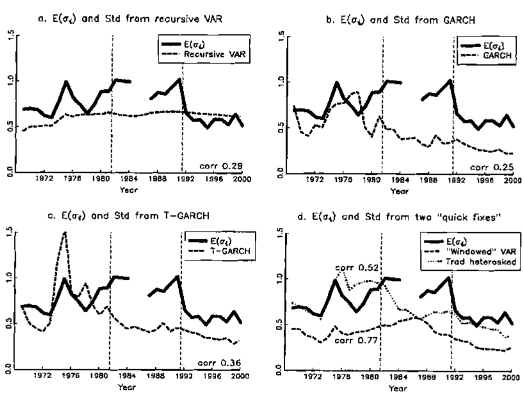

Figure 4.5: Uncertainty in survey and in time series models. Subfigure a compares the forecast error standard deviations from a VAR model estimated on longer and longer sample with the aggregate standard deviations from the SPF. Subfigure b compares with the average individual standard deviation instead.

4.5.3 Comparison with time series measures of uncertainty

We have argued that it sometimes makes sense to use a measure of uncertainty derived from survey data. Unfortunately, survey data is not always available—it is then tempting to use a measure of uncertainty derived from time series techniques instead. Whether some time series methods mimic the expectations of real agents and, if so, which methods come closer, is then a question of interest. We would also like to know if the time series models that come closer to the survey are also supported by the data. In other words, starting from a small group of commonly used models (homoskedastic VAR, GARCH, asymmetric GARCH, conditional variance as a function of past inflation), we would like to know whether the model that approximates the survey uncertainty best also is the model that we would select based on standard econometric criteria.

In carrying out the exercise we choose the average individual uncertainty, $E(\sigma_i)$, as a benchmark for comparison, but the main conclusions extend to the other survey measures of uncertainty.

We first examine a VAR with homoskedastic errors. We have strong prior expectations that this cannot be a good model of uncertainty, since it is firmly established that inflation errors are not homoskedastic, and the survey data clearly show that uncertainty is positively correlated with the forecasted inflation level. Nevertheless, since VARs are widely used for forecasting, it is instructive to see how bad the assumption of homoskedastic errors is in practice. We estimate a VAR(3) on quarterly US data. The included variables are GDP deflator inflation, log of real GDP, capacity utilization, the federal funds rate, and a 3-year interest rate for the period 1955Q1 to 1999Q4.[12]

[12]We use revised data. It would have made a lot of sense to use the preliminary data if we had focused on the point forecasts. In that case, the survey forecast in t should be compared with the forecast from an econometric model using the data available in t. The last few observations in that sample are preliminary, which is likely to affect the out-of-sample point forecast. In contrast, the estimated VAR model coefficients are probably not affected much (recall: only the last few observations are preliminary). Our measure of forecasting uncertainty is a function of the estimated VAR model parameters (coefficients and residual standard deviation), so this is unlikely to be an important

The VAR is first estimated up to 1968Q4, and a standard deviation for the forecast error of inflation is produced (inflation is defined as average price during 1969 over average price during 1968 minus one, as in the SPF). The VAR is then re-estimated with data up to 1969Q4 (a "recursive" VAR) and so on. The only reason for why the VAR std changes over time is that more and more data is used in the estimation (parameters estimates change). This recursive estimation procedure is adopted for all the models that follow, in an attempt to reproduce the information structure available to forecasters.

Figure 5.a shows the VAR series of standard deviations together with the average individual uncertainty. The VAR uncertainty increases after the first oil price shock, but is then almost flat for the rest of the sample. In particular, the VAR fails to capture the increase in uncertainty around the second oil price shock and the Volcker deflation as well as the decrease in uncertainty since the early 1990s (the correlation of the two series is only 0.29). The result is not surprising, since in a VAR all residuals are equally weighted in forming the standard error of a forecast. A quick fix for this poor performance is to compute the standard deviation using a subsample that has similar average inflation as the current one. Therefore a "windowed" VAR is estimated recursively on the latest fourteen years of data, so the sample size is fixed rather than progressively larger. In our case this gives good results, as illustrated in *5.d* (the correlation with $E(\sigma_i)$ is 0.77).

GARCH models are strong candidates for modelling inflation uncertainty. In fact, both ARCH (Engle, 1982) and GARCH (Bollerslev, 1986) were first applied to quarterly inflation. Encouraged by the signs of GARCH effects in the previous section, we try several types of GARCH models, starting with a standard GARCH(1,1).

There are reasons to believe that the standard GARCH model is not a good model of inflation uncertainty, since it implies that uncertainty is uncorrelated with the inflation

consideration in our application. The GARCH/T-GARCH models are potentially more vulnerable to data revisions, but these are relatively small for price data.

level (at odds with the findings in the previous section) and that an unforecasted fall in inflation produces as much uncertainty as an unforecasted rise. In any case, we try the model since it is widely used.

We estimate a GARCH(1,1) for GDP deflator inflation (same definition as in SPF) in the same recursive fashion as the VAR. The mean is modelled as an AR(4) and the sample is the same as in the VAR. There are now two reasons for why the model standard deviation changes over time: as in the VAR more and more data is used (parameters estimates change), but more importantly, the GARCH model produces time-varying standard deviations due to lagged forecast errors. *Figure 5.b* shows the result. The time profile of the GARCH results is quite different from the survey (the correlation is only 0.25). In particular, the GARCH uncertainty peaks too late in the mid 1970s and fails to capture the increase in uncertainty around the second oil price shock and the Volcker deflation.

An asymmetric GARCH could potentially solve the problems of the standard GARCH model. We therefore try a T-GARCH(1,1) (see Zakoian, 1994). Table 3 shows the coefficients of the conditional variance equation from an estimation on the whole sample 1955-1999. The coefficient of the lagged squared error can be safely set to zero, while the coefficient of the asymmetric component is significant and quite sizeable. This characterization of forecast uncertainty is different from that produced by the standard GARCH: uncertainty increases following an positive inflation surprise, while negative inflation surprises make uncertainty decline.

Figure 5.c shows the results from a recursive estimation of the T-GARCH model. The implied standard deviation of the forecast error is somewhat more correlated with the survey than the standard GARCH model (the correlation is 0.36 compared to 0.25), but the time profile is still far off. In particular, it diverges substantially from the survey uncertainty in the early 1980s.[13]

[13]Ivanova and Lahiri (2000) also estimate GARCH and T-GARCH for inflation. Our results differ from theirs in some respects (for example we find that the the T-GARCH has higher correlation with the survey uncertainty than the GARCH), due to the fact that we use a longer sample and we

	Coefficient (se)
Constant	0.05 (0.06)
Lagged squared error	0.03 (0.10)
Lagged conditional variance	0.81 (0.13)
Max of lagged error and 0	0.20 (0.10)

Table 4.3: Results of T-GARCH. The data is quarterly GDP deflator inflation for the period 1955Q1 to 1999Q4. The estimated model is an AR(4) with error $\varepsilon_t \sim N(0, \sigma_t^2)$, where the conditional heteroskedastcity is modelled as $\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \theta \max(\varepsilon_{t-1}, 0)$. Standard errors within parentheses

Ivanova and Lahiri (2000) argue that uncertainty in the SPF depends on the level of inflation, but not on the lagged forecasting errors. This suggest modelling inflation uncertainty in the same way. We therefore try to model quarterly inflation variance as a function of the average inflation in the previous four quarters (as before, the mean in modelled as an AR(4)) and use the estimates to construct the standard deviation of the inflation forecasts. *Figure 5.d* shows the results. The resulting series mimics the SPF uncertainty better than the GARCH and T-GARCH models (the correlation is 0.52). This suggests that we should add the inflation level to the variance equation in the GARCH and T-GARCH models. However, this model would not be selected based on standard econometric criteria, since lagged inflation turns out to be insignificant in the variance equation.

All time series models we have considered fail to capture the increase in uncertainty in the early 1980s. Our opinion is that the large uncertainty in the early 1980s was reflecting an announced change in regime, namely the Volcker deflation, and is therefore unlikely to be picked up by any time series model in which the conditional variance is a function of past data. Indeed, one may see this as a strong argument in favor of using survey measure of uncertainty in period of suspected structural breaks.

estimate the models recursively rather than on the entire sample (our definition of SPF uncertainty is also different).

4.5.4 Do forecasters underestimate uncertainty?

The last issue we study is if the survey uncertainty is "rational" in the sense of generating measures of uncertainty that correspond roughly to the objective uncertainty. In particular, we are interested in studying if forecasters underestimate the objective uncertainty, as is often claimed. For instance, Thaler (2000) writes

> "Ask people for 90 percent confidence limits for the estimates of various general knowledge questions and the answers will lie within the limits less than 70 percent of the time."

The natural way of approaching this question is to use the survey data to construct confidence intervals around the point forecasts, and then study if actual GDP deflator inflation falls within the $x\%$ confidence interval $x\%$ of the time (as it should in a large sample). To make this operational, we assume that the forecast errors are approximately normally distributed and construct different confidence bands around both individual point forecasts and the consensus point forecast.

Table 4 shows the results. Individual forecasters seem to underestimate uncertainty: the actual GDP deflator inflation falls inside the 90% confidence bands in only 72% of the observations (indeed close to Thaler's assertion) and inside the 80% confidence intervals in only 61% of the observations.[14]

We get similar results for the consensus point forecast. Our theoretical forecasting model in Section 3 suggests that the variance for the consensus point forecast should be the average individual variance minus disagreement, $\mathrm{E}(\sigma_i^2) - \mathrm{Var}(\mu_i)$. Actual inflation falls inside such a 90% confidence band only 62% of the time.

These results suggest that forecasters underestimate the actual inflation uncertainty. There are several caveats, however. First, it is possible that the results are driven by small sample problems, for instance, in the point forecast used as the mid-point of

[14]To account for the fact that the number of forecasters has changed over time, we normalize the number of forecasters to one for each year, so that each year is given the same weight.

Type of confidence band	Confidence level (x%): 90%	80%	66%
Around individual point forecasts, with std from:			
σ_i	0.72	0.61	0.47
Around consensus point forecasts, with std from:			
"Combined Std" $\sqrt{\mathrm{E}(\sigma_i^2) - \mathrm{Var}(\mu_i)}$	0.62	0.48	0.28
$\mathrm{Std}_A(\pi)$	0.90	0.90	0.72
$\mathrm{E}(\sigma_i)$	0.90	0.79	0.62
$\mathrm{qStd}(\mu_i)$	0.59	0.45	0.34

Table 4.4: Comparison of confidence bands and actual inflation. This table shows the fraction of years when actual inflation is inside the x% confidence bands. The confidence bands are calculated assuming a normal distribution and are calculated as: mean inflation forecast ± the critical value times the standard deviation. Actual inflation is measured as the percentage change in the GDP deflator (annual-average). The sample is 1969-1999, excluding 1985 and 1986.

the confidence intervals. We do not believe that this alone can account for the result. It is true that most forecasters missed the inflation surge directly following the first oil price shock, but the results go through even if we disregard this episode. Second, the forecast errors could be very far from normal. Once again, we do not believe that this is strong enough to overturn the results. The evidence of non-normality is mixed, and perhaps more importantly, some of the numbers in the table actually violate Chebyshev's inequality—so the fraction inside the band is too low for any distribution (with finite variance).[15]

If it is true that forecasters underestimate the true uncertainty, how should we then use the survey data? In many cases, it is probably the actual beliefs of economic agents that matter, for instance, for understanding investment decisions, asset pricing, and price/wage setting (including monetary policy credibility). However, from a pure fore-

[15] Chebyshev's inequality says that $\Pr(|x - \mathrm{E}\,x| \geq C\sigma) \leq 1/C^2$ where σ is the (finite) standard deviation of x. For instance, the gaussian 90% confidence level uses $C = 1.645$, so the probability of being inside the band is at least 0.63. This is violated by the "Combined Std."

casting perspective, it may be reasonable to adjust the numbers. The remaining lines in Table 4 therefore give results for consensus point forecast, but using the other survey measures of uncertainty. The results indicate that both the aggregate standard deviation, $\text{Std}_A(\pi)$, and the mean individual uncertainty, $\text{E}(\sigma_i)$, work fairly well, while the disagreement across forecasters, $\text{qStd}(\mu_i)$, generates too narrow confidence intervals.

4.6 Summary

This paper investigates survey measures of forecast uncertainty: why survey uncertainty matters, how to measure it, how it differs from time series estimates and what factors that seem to drive it.

Extracting a measure of uncertainty from survey data is not an uncontroversial task, and several alternatives have been proposed. Concentrating on inflation uncertainty, we argue that the relevant measure depends on its intended use, giving as examples a model of forecasting and a model of asset pricing. Though the correct measure of uncertainty is not the same in the two models, information on both the average of forecasters' individual uncertainty and their disagreement (on the point forecast) is found to be useful in both models.

Using data on inflation forecast distributions from the Survey of Professional Forecasters (1969-1999), we discuss how these alternative measures of uncertainty relate to one another in practice. Disagreement as a stand-alone measure of uncertainty is not supported by any model we are aware of, yet it has been widely used because of availability and ease of computation. We find that disagreement has a fairly high correlation with other measures of uncertainty, and may thus be a good proxy in some applications.

Our estimates of inflation uncertainty differ somewhat from those in the previous literature. In particular, our estimates are less volatile. The main reasons are that we try to correct for the bias that the discrete nature of the data (histograms) creates and that we adopt robust estimation techniques when there are indications of extreme outliers.

We use our estimates to study how inflation uncertainty is related to other macro variables and how well time series methods of conditional volatility can capture the changes of the survey uncertainty since the late 1960s. We find, among other things, that inflation uncertainty is negatively correlated with GDP growth, which, using a simple model of asset pricing, yield the prediction that the real interest rate should be positively correlated with inflation uncertainty. There is some support for this prediction in our estimates. We also find that inflation uncertainty is strongly correlated with the inflation level and recent volatility in inflation and output growth.

We assess the performance of some common time series methods (homoskedastic VAR, GARCH, asymmetric GARCH, conditional variance as a function of past inflation) in reproducing the survey uncertainty. Several of them fail since they do not account for the positive correlation of inflation uncertainty and the level of inflation (and inflation expectations). Starting from this consideration, we find that quarterly US inflation is better described by an asymmetric GARCH that by a standard GARCH. In fact, inflation under-prediction leads to increased uncertainty, but over-prediction does not (a sequence of over-predictions is accompanied by decreased uncertainty). In spite of this, the survey measures seem to carry more information than can be incorporated in any of the time series models. In particular, time series methods perform poorly when the survey incorporates forward looking behavior and uncertainty about events that are possible but may not materialize, as in the case of the Volcker deflation.

4.7 Appendix: Data

This appendix presents the data sources.

Real GDP and the GDP deflator series (1955Q1to 1999Q4 for quarterly data and 1968-1999 for annual data) are from the Bureau of Economic Analysis (available

Period	No. of intervals	Intervals, %					No. of forecasters
68Q4-73Q1	15	<-3	-3 – -2.1	...	9 – 9.9	10+	53 – 65
73Q2-74Q3	15	<-1	-1 – -0.1	...	11 – 11.9	12+	59 – 59
74Q4-81Q2	15	< 3	3 – 3.9	...	15 – 15.9	16+	26 – 47
81Q3-85Q1	6	< 4	4 – 5.9	...	10 – 11.9	12+	29 – 34
85Q2-91Q4	6	< 2	2 – 3.9	...	8 – 9.9	10+	14 – 34
92Q1-	10	< 0	0 – 0.9	...	7 – 7.9	8+	27 – 36

Table 4.5: Inflation intervals in SPF

at http://www.bea.doc.gov/), the capacity utilization rate from the Federal Reserve Board (available at http://www.stls.frb.org/fred/data). The Federal funds rate and the 3-years Treasury Note rate (constant maturity) are aggregated to quarterly from monthly data by taking the average of the data at FRED (www.stls.frb.org/fred/data).

The data from the Survey of Professional Forecasters is available at the web site of Federal Reserve Bank of Philadelphia (http://www.phil.frb.org/econ/spf/index.html). Some details of the inflation probability survey are summarized in Table 5.

4.8 Appendix: Proof of result in Section 3

The forecast error variance of the combined forecast equals the (average) covariance of individual forecast errors. The covariance of the forecast errors of agent i and j is

$$\begin{aligned} \mathrm{E}(\pi-\mu_i)(\pi-\mu_j) &= \mathrm{E}\left[\pi-(s_{\pi i}/s_{ii})z_i\right]\left[\pi-(s_{\pi j}/s_{jj})z_j\right] \\ &= s_{\pi\pi} - s_{\pi j}^2/s_{jj} - s_{\pi i}^2/s_{ii} + (s_{\pi i}/s_{ii})(s_{\pi j}/s_{jj})s_{ij}, \end{aligned}$$

where s_{ji} is covariance of z_i and z_j. We assume $s_{\pi j} = s_{\pi i}$ and $s_{jj} = s_{ii}$, which simplifies the expression to

$$\begin{aligned} \mathrm{E}(\pi-\mu_i)(\pi-\mu_j) &= s_{\pi\pi} - 2s_{\pi i}^2/s_{ii} + (s_{\pi i}/s_{ii})^2 s_{ij} \\ &= \sigma_i^2 - (s_{\pi i}/s_{ii})^2(s_{ii}-s_{ij}), \end{aligned}$$

Year	Std_A	$E(\sigma_i)$	$\text{qStd}(\mu_i)$	Year	Std_A	$E(\sigma_i)$	$\text{qStd}(\mu_i)$
1969	0.80	0.69	0.53	1985			
1970	0.76	0.70	0.47	1986			
1971	0.70	0.68	0.38	1987	1.14	0.81	0.81
1972	0.75	0.62	0.42	1988	1.02	0.88	0.61
1973	0.61	0.60	0.22	1989	1.09	0.86	0.58
1974	1.05	0.78	0.67	1990	1.24	0.95	0.75
1975	1.42	1.00	0.95	1991	1.29	1.02	0.60
1976	0.87	0.82	0.43	1992	0.85	0.66	0.48
1977	0.92	0.74	0.41	1993	0.80	0.58	0.51
1978	0.86	0.65	0.49	1994	0.64	0.58	0.30
1979	1.03	0.74	0.53	1995	0.64	0.49	0.44
1980	1.24	0.89	1.06	1996	0.61	0.59	0.29
1981	1.16	0.89	0.81	1997	0.64	0.59	0.30
1982	1.19	1.01	0.80	1998	0.75	0.53	0.41
1983	1.10	1.00	0.50	1999	0.71	0.64	0.36
1984	1.05	1.00	0.28	2000	0.69	0.52	0.45

Table 4.6: Estimation results

where σ_i^2 is the individual forecast error variance. We therefore have to show that the last term is the cross sectional (across agents $i = 1, 2, \dots$) variance of μ_i, $\text{Var}(\mu_i)$. Note that $(s_{\pi i}/s_{ii})^2$ is the square of the individual projection coefficient. We therefore only have to show that the cross sectional variance of z_t is $s_{ii} - s_{ij}$.

Let $\bar{z}$ be the cross sectional sample mean of z_i. It is clear that $\text{E}z_i|\bar{z} = \bar{z}$, and that $\text{Var}(z_i|\bar{z}) = s_{ii} - \text{Var}(\bar{z})$. The variance of $\bar{z}$ is

$$\text{Var}\left(\sum_{j=1}^{n} z_j/n\right) = \frac{1}{n^2}\left[n s_{ii} + n\left(n-1\right) s_{ij}\right],$$

so the limiting value, as $n \to \infty$, is s_{ij}, and the proof is done.

4.9 Appendix: Some estimation results

Table 6 summarizes our main estimation results.

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Chapter 5

Constitutions and Central-Bank Independence: An Objection to McCallum's Second Fallacy

with Giancarlo Spagnolo

Abstract:

Most of the literature on monetary policy delegation assumes that the government can credibly commit to the delegation contract or that renegotiation involves a cost. This paper provides some foundations for the assumption that renegotiating a delegation contract can be costly by illustrating how political institutions can generate inertia in recontracting, reduce the gains from it or prevent it altogether. Once the nature of renegotiation costs has been clarified, it is easier to see why certain institutions can mitigate or solve dynamic inconsistencies better than others. The paper points to institutions which give Western democracies the technology to make credible delegation commitments, and argues that the ECB is an example of credible delegation.

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Quis costodiet custodes?

5.1 Introduction

Since Kydland and Prescott (1977), and Barro and Gordon (1983) underlined the potential time-inconsistency problem in monetary policy, a vast literature has investigated institutions designed to moderate or solve it. Starting with Rogoff (1985), the literature has focused on delegating control of monetary policy to an independent, 'conservative' central banker. In this framework, the credibility of delegation is usually (implicitly) assumed. However, this assumption is far from compelling. In an influential paper, McCallum (1995) comments on the literature on optimal delegation contracts for central bankers (e.g. Persson and Tabellini, 1993; Walsh, 1995), and concludes that this literature is flawed in that delegation merely relocates the dynamic inconsistency problem. In his words

> [...] Under the proposed arrangement, the government has to enforce the contract (...), but the government has exactly the same incentive not to do so as identified by the Kydland-Prescott (1977) and Barro-Gordon (1983) analysis. Indeed, if the absence of any precommitment technology is actually a problem, then it must apply to the consolidated central-bank-government entity just as it would to an entirely independent central bank. If the technology does not exist, then it does not exist. Nor is this problem overcome by saying that the objective function must be specified at the "constitutional stage" of the political process. [...] No constitutional amendment has ever taken the United States off of the metallic standard that is clearly implied by Sections 8 and 10 of the Constitution.

While McCallum's intention was to argue that an independent central bank does not need performance-related incentives[1], his words raised the more fundamental question of what guarantees independence in the first place. If the government is free not to "enforce the contract" (with or without performance incentives) through which it delegates control of monetary policy to the central bank, then it can regain such control at will. Then delegation indeed relocates the time-inconsistency problem, from the promise not to overinflate to the promise not to violate/change the delegation contract (in order to overinflate).

The purpose of this paper is to show that – on the contrary – in modern democracies legal institutions, and constitutions in particular, do provide delegation contracts and analogous institutional devices with sufficient credibility to mitigate (and possibly eliminate) many time inconsistencies, among which the inflation bias.

To deal with McCallum's criticism and make delegation matter, part of the most recent literature on monetary delegation, in particular Jensen (1997), assumes that renegotiating the delegation contract is costly (see also Lohmann, 1992). The assumption of exogenous costs and the assumption that the size of the costs can be set by the government (once and forever) have both been used, and in both cases the nature of these costs is not completely clear (see the discussion in Section 3). Since the outcome depends crucially on the size of renegotiation costs and on whether they are exogenous or not, it is indeed unfortunate that their nature is unclear.

Another strand of the literature (e.g. Al-Novaihi and Levine, 1996 and Herrendorf, 1998), shows that delegation can be relevant in a repeated game framework with asymmetric information, where it is not clear to the public whether inflation is due to bad shocks or bad policy. Then delegation can improve the equilibrium outcome by making the government's policy more transparent.[2]

[1]This is clarified in McCallum (1997).
[2]A point also raised by Canzonieri (1985).

But everybody - with the exception of Persson and Tabellini (e.g. 2000, Ch. 17) - seems to have acknowledged that with symmetric information and no exogenous renegotiation costs delegation is irrelevant.

Instead, we show here that even in the standard framework with complete information and per se costless renegotiation, in stable democracies the inflation bias can be mitigated, and possibly eliminated, by appropriately specifying the process required to modify the delegation contract/law at the constitutional stage – thereby endogenously generating lags and costs of renegotiating. More broadly, we point out why in modern democracies institutions do matter and commitment technologies are not exogenous.

5.2 Contracts, constitutions and commitment

5.2.1 The enforcement of contracts

We are not convinced by McCallum's first quoted statement, namely that "*the government has to enforce the contract*". The literature on monetary delegation focuses on modern constitutional democracies where, fortunately, governments do not enforce contracts (courts do). This division of powers is of course never complete and it varies from time to time and from country to country. Nevertheless, separation of powers, which implies that the government does not enforce contracts, is a good approximation for certain countries. Constitutions with separation of powers emerged as means to constrain rulers' discretion and opportunism, which brought as a by-product an increase in rulers' ability to commit through contracts (North and Weingast, 1989). Borrowing a quotation from Laffont's recent book (2000),

> "A society in which the guarantee of rights is not assured, nor the separation of powers provided for, has no constitution". (Article 16, French Declaration of Rights of Man, 1789)

A sufficiently independent and benevolent judiciary, customarily assumed in political economy, constrains the government to respect certain constitutional rules and the contracts it signs or bear the legal penalties from infringement. This assumption is of course more reasonable for some countries than for others, and often clearly unreasonable. We do not deny that everywhere in the world governments maintain the ability to exercise pressure on the judiciary. Our argument can accommodate different degrees of separation of powers, in the sense that the probability that the judiciary will be swayed by the government can go from zero to one. In the end, differing degrees of separation of powers will imply different abilities to mitigate the inflation bias (and dynamic inconsistencies more generally).

A contract is commonly defined as a "legally binding agreement" (Oxford Advanced Learner's Dictionary 1990, p. 255) between two or more parties. An agreement, before being written down as a contract, is nothing else than a couple (or more) of reciprocal promises. Therefore, we can say that enforceable written contracts are legal instruments that add credibility to promises, that allow contracting parties to credibly commit to certain future courses of actions. They increase the costs of violating the contractual promise by the threat of legal penalties. The time-inconsistency problem in monetary policy consists of a suboptimal outcome reached because the government's promise not to overinflate lacks credibility. McCallum argues that the presence of a delegation contract makes no difference regarding the credibility of a government's promise. On the contrary, we maintain that contracts have the precise purpose of making promises credible, and therefore that the time-inconsistency problem is more easily solvable through a contract.[3]

5.2.2 Commitment technologies

McCallum's statements "if the absence of any precommitment technology is actually a problem..." and "If the technology does not exist, then it does not exist" have been interpreted as suggesting that contractual delegation cannot help governments to com-

[3] Of course, while we will assume that a government may bear costs if acting against the provisions of a contract while the contract is legally valid, we allow for the fact that the delegation contract, if part of a law, can be changed by the government through a new law.

mit. However, one reason why delegation may matter is that the normal situation is *not* the absence of *any* precommitment technology. Rather, we typically have technologies that allow us to commit to certain actions (e.g. not to suddenly or secretly renegotiate/cancel/amend a contract/law/constitution), but no technology to commit to certain other actions (e.g. not to inflate when we retain control on monetary policy). This is what contract theorists' distinction between verifiable and merely observable actions (or states) is meant to capture. Suppose the institutional technology for enforcing explicit (written) contracts, a well functioning independent judicial system, does exist. Basic contract theory defines only *observable* (or *non verifiable*) the actions that – although observable for contracting parties – cannot be observed/verified (at reasonable cost, or with reasonable precision) by a third enforcing party like a court, so that they cannot be explicitly contracted upon. *Verifiable* actions are observable by the parties and can also be observed/verified by third parties, so that contracts on these variables can be enforced by courts.

An example relevant to our discussion is that of codified procedural rules, such as those required to change laws and constitutions. The conformity of an action to a procedural rule is usually easily verifiable. If procedural rules for changing laws are not followed, any such change is nullified by the competent (often specialized) court. If a procedural rule requires a minimum time lag or a public announcement before a given law can be chånged, as long as the procedural rule is in place governments are credibly committed not to suddenly or secretly change the law.

We think that the articles of the US Constitution that McCallum mentions are not an example of a verifiable statement prohibiting fiat money. We interpret them as aimed at giving monetary authority to the Federal Government alone and forbidding individual states from establishing their own currency rather than at preventing the Federal Government from printing fiat money. All clauses of section 10, article 1, start with "*No state shall...*".[4]

[4]We report the debated statements (Article 1, Section 8 and Section 10).

As another example of time-inconsistency problem in monetary policy, the respect of a law constraining the Treasury to "pursue good monetary policy" or "to keep inflation low" is hardly verifiable, as it is unclear what "good" and "low" means. On the other hand, consider a constitutional rule stating that the central bankers' contract can only be changed/cancelled through an "impeachment procedure" that must start with a given public act and must be completed a minimum of three months after the public act with the approval of at least two thirds of the members of each the two Houses of Parliament. Clearly, the compliance with such rule is easily verifiable by courts, which may make the promise not to suddenly or secretly change the central banker's incentives credible.

5.2.3 Renegotiation and constitutions

We have argued that governments are not completely free to decide whether to respect a contract or not, in the sense that the expected cost of violation is positive. Does this imply that any delegation contract between a government and an agent (e.g. the central banker) has commitment power towards other parties (e.g. the private sector)? Of course not. In all modern legal systems the (two or more) parties that signed a contract are left free to cancel or change the contract, if they all agree on doing so. Dewatripont (1988) and Katz (1991) proved that if a contract between two parties can be secretly and costlessly renegotiated, it cannot have commitment power toward a third party. In the monetary policy framework, the renegotiation need not even be secret: it can be done openly since agents are assumed unable to adjust to the changes until the next period. Then sudden and costless renegotiation deprives delegation of any commitment power.

"The Congress shall have power to (....) coin money, regulate the value thereof, and of foreign coin, and fix the standards of weights and measure".

"No state shall enter in any treaty, alliance or confederation; grant letters of marque and reprisal; coin money, emit bills of credit; make anything but gold and silver coin a tender of payment in debts (....)".

Here comes our third point of disagreement with McCallum's quoted statement, in particular with his words *"Nor is this problem overcome by saying that the objective function must be specified at the "constitutional stage" of the political process"*. It is true that when sudden renegotiation is feasible and per se costless a simple delegation contract between a government and a central banker (or a "delegation law" that can be easily modified) would not have the desired commitment effect in the standard framework: the private sector would foresee that once its expectations are formed (contracts are signed), government and banker could simply renegotiate the contract (change the law).[5] However, we will show in the next sections that embedding the delegation contract in the constitution *is* one way to mitigate or solve this problem. Most democratic constitutions require a public debate, a time lag, and a qualified majority to be amended. A delegation contract guaranteed by the constitution is therefore hard(er) to change, and cannot be suddenly or secretly renegotiated.

5.3 The standard framework

We will base our discussion on the standard model presented, for example, in McCallum (1995).

Log output is given by

$$y_t = \alpha(\pi_t - \pi_t^e), \ \alpha > 0 \tag{5.1}$$

The government (or the central banker) is assumed to control inflation directly. The government loss function is given by

$$E_t \sum_{i=0}^{\infty} \beta^i L_{t+i}, \text{ where} \tag{5.2}$$

[5]Using the term "renegotiation" when talking of monetary policy delegation implemented by law rather than by contract is perhaps confusing, since the government can change the status and objective of the central bank unilaterally. "Renegotiation" should then be read as "changing the terms of the delegation law."

$$L_t = \lambda(y_t - y^*)^2 + \pi_t^2, \ \lambda > 0, \tag{5.3}$$

where $y^* > 0$, while potential output is zero. The inflation bias does not arise if $y^* = 0$.

Monetary policy can be delegated to a central banker whose preferences and incentives are such that the inflation bias is eliminated if delegation is fully credible. For example, the central bank may have the same loss function as the government, but $y^* = 0$. In this framework, McCallum's statement implies that the government cannot commit (make delegation credible): it can change the delegation contract at will (say, through a law, if the delegation contract is written in a law) and therefore, absent renegotiation costs and asymmetric information, delegation is irrelevant.

Jensen (1997) augments this model by assuming that if the government delegates monetary policy, it then faces a given cost of renegotiation. We mentioned in the introduction that we find these exogenous renegotiation costs unclear. They cannot be reputational: inflating once, reputation is lost forever since the true preferences of the government are revealed, while Jensen's main argument relies on costs that must be faced each time that the government inflates.[6] If they are "transactions costs", then their size would be arguably too small to influence a government's policy.

In any case, if exogenous renegotiation costs are zero, the following protocols are equivalent:

1. No delegation.

2. No delegation, objective function constitutional but non verifiable.

3. Delegation, non-contractual.

4. Delegation, contractual, non constitutional.

By "contractual" we mean that the terms of the delegation are set forth in an explicit and enforceable contract.

[6] Reputation can arise only in an asymmetric information framework. The strandard references are Kreps and Wilson (1982) and Milgrom and Roberts (1982a, and 1982b).

We define delegation "constitutional" if the process through which the delegation contract is changed is specified in the constitution. The contract itself need not be part of the constitution; it suffices that the constitution states, for example, that "The status of the Central Bank and the compensation scheme for the central banker are modified following the same procedure needed to amend the constitution".[7]

In this framework, with no exogenous renegotiation costs nor reputation or punishments, (1)-(4) yield equivalent outcomes. In (3), no contract specifies the terms of delegation, which therefore can be changed at will by the government. In (4), breaking the contract involves an expected cost (assuming that the government does not completely control the judiciary), but the government can change the contract at no cost through a law, therefore we are back at (1). McCallum's statement that *"Nor is this problem overcome by saying that the objective function must be specified at the "constitutional stage" of the political process"* is assumed to hold for situation (2). For example, a constitutional law stating that "Monetary policy is conducted by the government in a way compatible with price stability" does not solve the problem. The reason is that the government retains control of monetary policy, and its intentions ex-post are hard to verify in a stochastic environment. Moreover, there is no clear consequence of not meeting the objectives. As long as McCallum's statement refers to cases (1)-(4), it is true in our framework. If, on the other hand, the statement is interpreted to mean that no constitutional norm can provide a commitment technology, the statement is definitely unconvincing. We see at least two ways in which a combination of delegation and commonly observed constitutional norms can solve or moderate the inflation bias: constitutional inertia and qualified majority.[8]

[7] Of course, the contract should be public and the central banker should not be allowed to undertake transactions that may generate conflicts of interest, as customary for high-ranking public servants.

[8] Note that with separation of power many contractual devices other than constitutional delegation can be designed to solve the same problem. For example, a well designed high-powered constitutional incentive scheme for the government itself, or a non constitutional multilateral contract between government, banker and representatives of the private sector.

5.4 Constitutional Inertia

5.4.1 Main result

Consider the case where delegation is contractual and constitutional, where changing the delegation contract requires the same procedure needed to amend the constitution. We make the following assumptions:

1. The delegation contract is such that the central banker has the right preferences/incentives to pursue a policy free of inflation bias.

2. The constitution can be legally changed only following the procedures set in the constitution itself. Constitutional changes operated in other ways and other violations of easily verifiable constitutional norms are punished with probability π and sanctions Σ, with $\pi\Sigma \geq 0$.[9]

3. The procedure of constitutional revision requires every amendment to be approved twice before becoming effective, with a minimum time span between the two deliberations or, alternatively, that a certain period of time passes before an approved amendment becomes effective.

4. Separation of powers guarantees that if the (risk-neutral) government does break the delegation contract – possibly by trying to corrupt the central banker – it receives the punishment S with probability p, with $0 \leq pS \leq \pi\Sigma$.[10]

Complete or partial commitment can be reached, depending on auxiliary assumptions, as illustrated in the following proposition.

[9] The first part of this assumption is clearly realistic, since compliance with procedural rules is easily verifiable (we do not need to assume that all constitutional rules are respected, but only that the easily verifiable ones are). Regarding the second part, it is sensible to assume $\pi\Sigma$ strictly positive in most cases, although its value varies wildly between different countries (otherwise, we should continuously observe incumbent Western governments illegally modifying the constitution - e.g. electoral rules - in their favor).

[10] Then when the government has complete control over the judiciary $p \simeq 0$, when separation of powers is complete $p \simeq 1$.

Proposition 5 *In the standard model, if i) assumptions (1)-(4) hold, ii) the lag at point (3) is at least one period, iii) future (after the contract is renegotiated) options for the central banker are not enhanced if she inflates, and iv) pS exceeds the gains from inflating, then the inflation bias is completely eliminated.*

Proof. To change monetary conditions, the government needs to change the delegation contract because of iv) and (4). Changing the delegation contract requires a lag because of (3). Since this lag is at least as long as the time required for agents to update expectations (assumption ii), the gain from inflating is zero as long as the central banker behaves according to the incentives of the currently valid contract, as guaranteed by iii). ■

If the lag required to change the constitution (and hence the delegation contract) is smaller than one period, some gains from inflating will remain. The same is true if pS (the expected punishment from infringement) is smaller than the gains from inflating. Likewise, if the lag is sufficient, but the central banker may be in a more favorable situation once the contract is renegotiated if she inflates, the commitment solution is not reached. In all cases the equilibrium inflation will lie between zero and the discretionary level, so there is a partial gain from delegation. To model this situation, we introduce the parameter γ, with $0 \leq \gamma \leq 1$, where $1 - \gamma$ is the fraction of the period needed to change the contract (alternatively, γ reflects an inverse function of the expected punishment – pS – or the fact that the central banker may find herself in a better position when recontracting if she inflates). Then output follows

$$y_t = \alpha\gamma(\pi_t - \pi_t^e), \tag{5.4}$$

and the equilibrium inflation in the one-shot game is

$$\pi_t = \lambda\alpha\gamma y^*, \text{ implying } \frac{\partial \pi}{\partial \gamma} = \lambda\alpha y^* > 0. \tag{5.5}$$

Thus we obtain the intuitive results that each of the followings reduces the inflation bias monotonically in the one-shot game equilibrium:

a) Increased inertia.

b) Increased expected punishment of violating the delegation contract.

c) Improved exit options for the central banker that does not inflate.

These results are obtained when the government can modify the constitution without any support from the opposition. Section 5 discusses the implication of assuming, more realistically, that the constitution cannot be changed unilaterally by the ruling party.

5.4.2 Extension: repeated interaction

Modeling repeated games requires additional assumptions. We investigate the simple tit-for-tat strategy proposed by Jensen in a repeated (infinitely many times) game. The private sector strategy is assumed to be:

$$\begin{aligned} \pi_t^e &= 0 \text{ if } \pi_{t-1} = \pi_{t-1}^e. \\ \pi_t^e &= \lambda\gamma\alpha y^* \text{ otherwise.} \end{aligned} \tag{5.6}$$

The outcome $\pi_t = 0$ is an equilibrium if $\gamma = 0$ or if

$$\beta \geq \frac{1}{1 + \lambda\gamma\alpha^2}.$$

Therefore, as $\gamma \to 0$, the no-commitment outcome improves but the optimal policy becomes more difficult to sustain given this strategy. This result is the same obtained by Jensen with exogenous renegotiation costs. That is, larger renegotiation costs in Jensen's framework and smaller benefits of inflating in our framework generate the same results: the equilibrium inflation in the one-shot game decreases but the optimal rate of inflation is less likely to be the outcome of the simple proposed tit-for-tat strategy.

In Jensen's model the parameter determining renegotiation costs is taken as exogenous by the government designing the optimal delegation (incentive) scheme, reflecting the common interpretation of McCallum's words that a government cannot tie its own hands. Here, instead, we are trying to establish foundations for the assumption of positive renegotiation costs, and showing that these costs are typically not exogenous: they can be influenced by institutional arrangements, so that the commitment technology is not given prior to any political decision. If the lag can be chosen by the government (giving rise to endogenous renegotiation costs) and, as natural in our framework, it needs not be set once and forever but can be changed at every period, what process will arise in equilibrium for the lag level? Proposition 2 shows that the government will optimally choose lag$\geq$ 1.

Proposition 6 *Consider an infinite horizon model a la Barro-Gordon-Jensen, and let the time lag for (or the cost of) renegotiation be determined/modified by the government at the beginning of each period. Then, the unique equilibrium has lag$\geq$ 1 and (therefore) full commitment.*

Proof. If lag<1 and the government inflates, it cannot be punished in any way, since it can optimally set a lag$\geq$ 1 from the next period on. It follows that, for any discount rate, whenever lag<1 the government wishes to inflate. But since the private sector knows this, no surprise inflation is possible, and setting lag<1 is strictly dominated by setting lag$\geq$ 1. ■

As a theoretical result, Proposition 2 says that a government that can commit to delegation will do so. On an empirical level, it raises the question of why we do not universally observe such commitment. A first answer could be that in the last decades we have observed many moves towards such commitment. The statutes of the Italian and French central banks have recently been modified in this direction. The ECB is arguably the most important example: the statute of autonomy of the ECB and its goals are specified in the Maastricht Treaty. Modifying the Treaty, in turn, calls for an international conference where the unanimous vote of all signing states is required. There is a large dose of both inertia and qualified majority (see the next section) in this procedure.

But why have we not observed more credible delegation in the past? Possible explanations include:

- Politicians chose not to commit because they were using the wrong model; or thought that the private sector was either using the wrong model or forming expectations irrationally.[11]
- Inertia may imply a loss of flexibility (Lohmann, 1992), and politicians judged flexibility more important than low inflation.
- Politicians valued more authority on monetary policy than policy outcomes, and voters failed to punish them (e.g. because of the bundling of problems in general elections).
- For less stable democracies, lack of commitment technology. In our framework, this means that laws and constitutions were not sufficiently binding ($\pi\Sigma$ close to 0).

5.5 Qualified majority

5.5.1 Main result

We appeal to the literature on political business cycle in conjecturing that the inflation bias does not arise from the fact that a benevolent government is targeting a positive output gap because it believes that potential output is kept down by distortions. Rather, we assume that the government's loss function describes the probability of winning the next election, as in

$$\Pr(\text{re-election}_{t+1}) = c_t + \delta L_t^{-1}, \tag{5.7}$$

[11]For example, the government may have thought that the Phillips curve could be used to generate a long-run tradeoff between inflation and output.

where c_t depends on factors that are uncorrelated with output and inflation. We do not derive (5.7) from a model, but we believe that it gives a more plausible explanation of why a government may want to induce a positive output gap. If this is indeed the case, an increased aversion to inflation in public opinion would reduce the value of the parameter λ[12], thus reducing the inflation rate in the one-shot game (see equation 5.5). Then an inflation-averse public opinion can reduce the inflation bias independently of delegation, which seems realistic.

We keep assumptions (1)-(2) and (4), disregard constitutional inertia by assuming no lag for constitutional amendments, and add the following assumptions:

5. The expected utility of both government and opposition is equal to the probability of winning the next elections. The probability of re-election is given by equation (5.7).

6. The political system is bipartisan and the opposition votes compactly on issues that involve a change in the probability of success in the next elections.

7. Changing the constitution requires a share of the votes which cannot be reached if the opposition votes compactly against.

8. pS is larger than expected gains from inflating.

We then obtain the following result.

Proposition 7 *If assumptions (1)-(2) and (4)-(8) hold, the inflation bias is completely eliminated.*

Proof. To change the delegation contract, a constitutional reform is needed (the contract is not violated because of 8). This reform increases the chances that the party holding the government is re-elected. Let Pr(G) be the probability that the ruling

[12] The parameter associated with π^2 is normalized to one.

coalition will win the next election. Then the probability that the opposition will win the next election is given by Pr(O)=1-Pr(G), making elections a zero sum game (because of Assumption 5). In a zero sum game there is no scope for gain-splitting, therefore there is no Pareto superior outcome in which the opposition votes to pass the constitutional reform. ∎

5.5.2 Extension: multipartisan systems

Many existing democracies are not bi-partisan, majority and opposition are composed of coalitions of smaller or larger parties. It is therefore worthwhile to verify what happens to Proposition 3 if Assumption 6 does not hold. Suppose that assumption (8) holds but that the ruling majority can use side transfers to "buy" the number of additional votes it needs to modify the constitution. Let n be the number of seats in the parliament, $\frac{2}{3}n$ be the minimum fraction of votes required to amend the constitution, and m, with $\frac{2}{3}n > m > \frac{n}{2}$, be the number of seats held by the majority. Moreover, let $v > 0$ denote a parliament member's net value of winning the next elections, p the probability of the incumbent majority to win the next election without surprise inflation, and $\Delta p > 0$ the maximal increase in p it can achieve by inducing surprise inflation. The majority's gain from inducing surprise inflation is therefore $mv\Delta p$.

To obtain the $\frac{2}{3}n - m$ votes required for a constitutional amendment allowing for renegotiation and surprise inflation, the majority has to compensate $\frac{2}{3}n - m$ opposition members through side transfers. By being loyal, each opposition member expects a net reservation payoff included between $(1-p)v$, the payoff it obtains if strictly less than $\frac{2}{3}n - m$ opposition members vote with the majority (so that renegotiation is prevented), and $(1-p-\Delta p)v$, the payoff it obtains if at least $\frac{2}{3}n - m$ opposition members vote with the majority, so that renegotiation and surprise inflation take place. We assume that if an opposition member votes with the majority favoring renegotiation and surprise inflation, she is excluded from the next election.

As in the literature on takeovers, the per capita transfer t the majority must offer to capture a sufficient number of opposition members will depend on the details of the offer process: whether it is simultaneous or sequential, whether information on acceptance is private or public, whether offers can be conditional on success or not, and so on. The transfer required to persuade a sufficient number of opposition members will also depend on the details of the institutional framework. For example, if politicians at the extremes of the political spectrum have a strong aversion to vote with each other, so that the majority is restricted to make an offer to the $\frac{2}{3}n - m$ opposition members closer to the center, each of these less extreme opposition members is pivotal (or almost so), which means that all (or most) the majority's gains from surprise inflation are captured by the switching voters.

Whatever model one uses, a lower bound for the per capita transfer to an opposition member is $(1 - p - \Delta p)v$, which she can always obtain by not betraying her party. So the total transfer T that the majority has to offer to obtain the constitutional amendment and inflate must always be $T > (1 - p - \Delta p)v(\frac{2}{3}n - m)$. Therefore, given that $mv\Delta p$ is the majority's gain from surprise inflation, a minimal necessary (not sufficient) condition for renegotiation to take place is

$$mv\Delta p > (1 - p - \Delta p)v(\frac{2}{3}n - m) \tag{5.8}$$

or, equivalently,

$$\frac{\Delta p}{1 - p - \Delta p} > \frac{\frac{2}{3}n - m}{m}. \tag{5.9}$$

Since there is no reason to expect this condition to either hold or not hold in general, we can state the following proposition.

Proposition 8 *Suppose (1)-(2), (4)-(5) and (7)-(8) hold and that pS is larger than the gain from inflating. Then:*

1. As long as $\frac{\Delta p}{1 - p - \Delta p} \leq \frac{\frac{2}{3}n - m}{m}$ constitutional delegation completely eliminates the inflation bias.

2. When $\frac{\Delta p}{1-p-\Delta p} > \frac{\frac{2}{3}n-m}{m}$ *the inflation bias need not be completely eliminated by constitutional delegation; however, the cost for the ruling majority of renegotiating the delegation contract and induce surprise inflation is at least* $(1-p-\Delta p)v(\frac{2}{3}n-m)m$.

Since modern constitutions typically have a rigid structure requiring amendments to be passed by a qualified majority, Propositions 3 and 4 imply that inertia is not needed for constitutions to provide a credible commitment device. It is the sheer fact that the minority loses from inflation surprises to prevent them or reduce their gains.

At this point, a remark is in order.

Remark 9 *We have assumed that it is costless to change an ordinary law, which requires a simple majority. Relaxing this extreme working assumption strengthens our results and eliminates the equivalence of non-constitutional delegation and no delegation.*

This is another possible source of renegotiation costs. One could think of many reasons why passing such a law could be costly: for example, the opposition could delay its approval (oppositions do have means of delaying the approval of a law, for example by proposing hundreds of amendments), inducing inertia and therefore reducing gains from inflating.[13]

5.6 Discussion: assumptions and results

At a theoretical level, Propositions 1-4 provide a much needed foundation for the "*renegotiation costs*" used by Jensen (exogenous costs), Lohmann (costs set by government)

[13] We have also mentioned in the Introduction that reputational costs can arise in an asymmetric information, repeated game framework.

An example of the commitment power of a law is the Bundesbank, perhaps the most independent central bank, whose independence is guaranteed by a normal law (and a strong public opinion). German politicians resisted for ten years (between 1947 and 1957) to the Americans' pressing request for a law guaranteeing the Bundesbank's independence (see Buchheim, 2001). If laws and constitutions can be enforced or changed at will by governments, why did such a lengthy political fight take place?

and others. It is not, however, a foundation which delivers exactly the same object as the previously postulated one. In our framework "*renegotiation costs*" are not necessarily given exogenously to the government. Moreover, our foundation can give guidance as to the context-specific nature and size of these costs. At the level of application, Propositions 1-4 imply that constitutions do offer tools to mitigate the inflation bias, and that the effectiveness of these tools depend on the degree of separation of powers.

Long before Kydland and Prescott (1977), a primary function of constitutions has been to reduce dynamic inconsistencies. The inconsistencies arise because, once in power, each government has an incentive to pursue policies that increase its chances of maintaining power. We believe that the desire to engineer an output expansion has the same origin as the desire to manipulate the media, the judicial system and the electoral process, and that it can be disciplined in much the same way: by requiring the opposition to agree if certain rules are to be modified.

To iterate our point, Western-style constitutions have been designed (and can be modified) to generate costs able to mitigate dynamic inconsistencies arguably more severe (in terms of loss of welfare and of temptation for the ruling government) than those arising in monetary policy. The share of votes needed to change Western-style constitutions typically oscillates between 2/3 and 3/4, a percentage designed with the obvious purpose that a share of the opposition should agree on the change, reflecting the liberal principle that political minorities be guaranteed certain fundamental rights. In addition, many constitutions require a lag between two votes. The American Constitution (article 5) does so implicitly, requiring two thirds of all votes from both Houses and the ratification of three fourth of the legislatures of the states, a procedure that could hardly be carried out overnight. Similarly, the German Constitution (art. 79 and 82) requires two third of all votes from both Houses, then the signature of the President, and then the publication on the official journal. The Italian Constitution (art. 138) explicitly requires a lag of at least three months. The Swedish Constitution even calls for a general election between the two votes. Assumption 7 is also usually satisfied, together with Assumption 3, so that in reality the effects of inertia and of qualified majority reinforce each other.

The conclusion that constitutional inertia alone can completely eliminate the inflation bias depends on the central banker not having higher options, when the time of renegotiating the contract comes, if she has inflated. The applicability of this assumption varies from case to case. In economies with a well developed private financial sector, the central banker could find high paying jobs elsewhere. Public opinion may also play an important role, awarding prestige to bankers jealous of their independence. Increased public awareness of inflation may then reduce inflation through this simple mechanism, which grants popularity and respectability to independent central bankers. Finally, one also expects promises and threats from the government to be balanced to some extent by pressure and promises from the opposition, since the latter is assumed to be damaged by the engineered expansion.

Assumption 2 only excludes that an amendment to the constitution may, for example, be voted by a $1/2$ majority rather than by a $2/3$ majority. These highly verifiable procedural rules are respected in Western countries, and trying to break them would imply large expected costs when compared with the gains from surprise inflation.

Is the assumption of separation of powers (Assumption 4) a reasonable and useful one? It is, in our view, for certain countries. Of course there are countries in which power is absolute, so that the ruling government is not constrained to respect either contracts or procedural rules (and may not even face elections). Nothing is left of the relevance of delegation if the government is not constrained in any way by procedural rules nor by a judicial system (so that $pS = 0$). On the other hand, constitutional delegation has some degree of commitment – giving rise to renegotiation costs – as long as the judiciary is not completely controlled by the government (for any $pS > 0$). This implies that societies which have built an effective separation of powers are better able to deal with dynamic inconsistencies than societies which have not.

Finally, in our simple model the central banker is not facing any exogenous shock. If a model economy populated by forward-looking agents is hit by non-policy shocks, then even if the inflation bias is assumed away, a stabilization bias will generally be present if output is persistent (policy reacts less strongly to inflation deviations and more strongly to output deviations under discretion than it would under commitment). While the inflation bias can be solved or mitigated through a constitutional arrangement, we have said nothing about the stabilization bias. The literature has devised incentive schemes for the central banker aimed at solving the stabilization bias (see Persson and Tabellini (2000) for bibliography and a summary of the literature). Nothing of what we have said reduces the relevance of this literature. On the contrary, it could provide a foundation for it. In designing the appropriate contract for the central banker, this literature often assumes that the delegation contract is credible, that is, that it cannot be broken or renegotiated. McCallum's critique states that this assumption is a weak one, since the government cannot commit to any specific delegation contract. We see our contribution as clarifying some (sufficient, not necessary) conditions under which the assumption of a credible delegation contract is appropriate. We think we have gone some way in the direction suggested by Persson and Tabellini, who "*think that the premise of the literature* (which assumes that delegation is credible) *is generally appropriate*", but that "*It would be more convincing to derive the institutional inertia as the result of a well-specified non-cooperative strategic interaction between different actors, something the literature–so far–has failed to do.*"[14]

5.7 Conclusion

Most of the literature on monetary policy delegation assumes that the government can credibly commit to the delegation contract, or that renegotiation involves costs. This

[14]Persson and Tabellini (2000), p. 524. This research direction was also suggested by Lohmann (1992), who wrote: "*Another task for future research is to model explicitly the technology by which a sovereign, heterogenous policy-making body commits to an institution. [...] By analyzing the connection between political institutions and economic performance, one may come to a better understanding of why some countries cope very well with time-consistency problems, other very poorly.*"

paper provides foundations for this assumption by illustrating how political institutions can generate inertia in recontracting, reduce the gains from it or prevent it altogether. It argues that in modern democracies the commitment technology is not exogenous, focusing on two factors that help in solving dynamic inconsistency problems: inertia and qualified majority. Since amending Western constitutions typically requires both, those constitutions are clearly capable of providing credibility to monetary delegation. The delegation contract itself needs not be inserted in the constitution to ensure that there are gains from delegation, as long as changing the contract requires either inertia or qualified majority (both of which give rise to renegotiation costs).

By providing a better understanding of why delegation can be credible, we hope to have given a more solid background to the literature on optimal contracts for central bankers, which assumes credible delegation. In the end, monetary delegation should be seen as a new instance of the separation of powers: from the triple legislature-executive-judiciary, to the quartet legislative-executive-judiciary-monetary. And it is hard to see why legal institutions that often succeed in keeping the hands of governments away from the judiciary would not be able to do the same with respect to monetary policy.

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