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Abstract

A central bank's main concern is the general direction of future inflation, and not transitory fluctuations of the inflation rate. As a result, this paper is concerned with forecasting a simple measure of the trend of inflation, the eight-quarter CPI-inflation rate.

The primary objective is to improve the M1-based vector-error-correction model (VECM) developed by Hendry (1995), by imposing a set of equilibrium conditions to better anchor the long-run behaviour of interest rates, the exchange rate and the output gap in the model. These changes provide for greater confidence in the dynamic properties of the model, especially over a longer time horizon.

This extended-VECM is shown to provide considerable leading information about inflation, forecasting the eight-quarter inflation rate with relatively small errors. The authors also stress that, to be most useful for monetary policy, inflation forecasts should explicitly indicate the range of uncertainty inherent in forecasting inflation with a long lead. For example, forecasts should explicitly consider confidence bands around forecasted outcomes, which is illustrated with the extended VECM developed in this paper.

Finally, the paper emphasizes that monetary policy is probably best-served by an eclectic approach in which policy judgements are based on input from models that summarize different paradigms of the transmission mechanism, or that use different technical approaches.

Résumé

La banque centrale se préoccupe essentiellement de l'orientation générale que prendra l'inflation à l'avenir et non des fluctuations passagères qu'elle affiche. Les auteurs de l'étude ont donc choisi de se pencher sur la prévision d'une mesure simple de la tendance de l'inflation, le taux d'augmentation de l'IPC sur huit trimestres.

Leur objectif principal est d'améliorer le modèle vectoriel à correction d'erreurs fondé sur M1 et mis au point par Hendry (1995); ils imposent à cette fin une série de conditions d'équilibre visant à mieux ancrer le comportement à long terme des taux d'intérêt, du taux de change et de l'écart de production dans le modèle. Les modifications apportées augmentent la fiabilité des propriétés dynamiques du modèle, surtout lorsque l'horizon retenu est éloigné.

Le modèle ainsi élargi renferme une quantité considérable de renseignements sur l'évolution future de l'inflation. Il permet de prévoir le taux d'inflation sur huit trimestres avec une assez grande précision. Les auteurs soulignent également que, pour que les prévisions de l'inflation soient le plus utiles possible aux autorités monétaires, la marge d'incertitude inhérente à toute prévision de l'inflation à un horizon lointain devrait être indiquée de façon explicite. Par exemple, les intervalles de confiance entourant les prévisions devraient être donnés, ainsi que l'illustre le modèle présenté dans l'étude.

Enfin, les auteurs insistent sur le fait qu'en matière de politique monétaire, l'éclectisme est probablement la meilleure approche à adopter puisqu'il permet aux autorités de fonder leurs jugements sur les résultats de modèles représentant différents paradigmes du mécanisme de transmission ou faisant appel à des techniques variées.

CONTENTS

1. Introduction

Monetary policy actions affect prices only after a considerable lag, generally thought to be about 18 months to two years. As a result, decisions on the appropriate track for monetary conditions are influenced predominantly by the outlook for inflation over the next two years. At the Bank of Canada, among the distant-early-warning models used to forecast inflation is an M1-based vector-error-correction model (VECM).

This inflation-forecasting model follows from recent work by Hendry (1995) on the long-run demand for the monetary aggregate M1. That work estimates a four-equation VECM for M1, prices, output and interest rates. In this paper, we extend Hendry's original model by improving its equilibrium conditions. Section 2 provides a brief discussion of the measure of inflation that we focus on in this paper, the eight-quarter inflation rate. In Section 3, we review some of the highlights of past work on the VECM and related models.

In Section 4, we address some shortcomings of the model first developed in Hendry (1995). In that version of the VECM, some variables are exogenous or became unstable in simulations over the long run. In the extended version of the VECM developed here, we impose sensible long-run conditions that help determine the behaviour of the output gap, Canadian and U.S. interest rates, and the Canada–U.S. exchange rate. As result, we should be able to have more confidence in the long-run and dynamic properties of the model. In sum, with these innovations, the VECM becomes a better tool for the development of monetary policy advice.

In Section 5, we consider the forecast accuracy of the extended VECM in an unconditional, out-of-sample exercise. We also illustrate that a more informative way to present inflation forecasts than simply providing the point estimate of the model is to include as well a statement about the probability distribution of potential outcomes. By drawing on the model's estimated variance-covariance matrix, we generate confidence intervals around a set of n-step-ahead forecasts, with each forecast projecting the eight-quarter inflation rate one-quarter further into the future.

In this way — presenting a set of n-step-ahead forecasts bounded by estimated confidence bands — we can present an outlook that is more informative about the development of the general direction of prices, and one that explicitly recognizes the uncertainty inherent in forecasting inflation with a long lead.

We then briefly compare the VECM to some other inflation-forecasting models. However, we also argue that such contests should be kept in perspective. No single model, no matter how technically sophisticated, is likely to capture the transmission mechanism well in all respects. As a result, no single view or model is likely to be an adequate representation for the range of episodes that might confront a central bank.

Accordingly, we argue that monetary policy is probably best-served by drawing on models that summarize different paradigms of the transmission mechanism, or that use different technical approaches to represent the transmission mechanism. Taking such an eclectic, diversified approach to inform policy judgements is likely to reduce the risk of making serious policy errors.

Finally, Section 6 provides concluding remarks. There, we point to further work that should enable the M1-VECM to provide both early warnings of inflation, and a way to assess monetary policy actions needed to maintain price stability over time.

2. Measuring inflation: the two-year change in the CPI

A central bank's main concern is the future trend of inflation, and not transitory fluctuations of the inflation rate. As a result, we focus on a simple measure of expected trend inflation, the annual average CPI-inflation rate over the next two years (as in Armour et al, 1996). That is, we focus on the rate of change between the price level today (t) and eight quarters later (t+8), expressed at an annual rate. For simplicity, we call this the "eight-quarter inflation rate".

This measure should be distinguished from the (annualized) rate of inflation eight quarters hence, that is, the inflation rate in the eighth quarter (t+8). Our measure should also be distinguished from the year-over-year inflation rate between (t+4) and (t+8). These two rates are less useful than the eight-quarter inflation rate in measuring the main interest of a central bank — the trend of inflation.

The lag between monetary policy action and its effect on inflation might suggest that the central bank should focus on inflation expected between (t+4) and (t+8). However, such a focus has some drawbacks. For instance, focusing on the inflation rate between (t+4) and (t+8) can implicitly accept a greater degree of price-level drift. In this case, the central bank presumably would tend to react mainly to inflation forecasted for the fourth to eighth quarter ahead, and less to inflation expected over the first four quarters, between t and (t+4) — which would be treated as a bygone. Over time, this could lead to more price-level drift than would a focus on the eight-quarter inflation rate.

As well, focusing reactions on forecasted inflation from (t+4) to (t+8) seems unreasonably ambitious given the state of knowledge about the transmission mechanism. Put differently, this approach suggests a degree of fine-tuning that might seem unreasonable. Finally, as noted above, the fundamental concern of the central bank is the trend in inflation. This suggests that the annual inflation rate one year ahead could be a less useful measure than one which focused more squarely on the underlying direction of prices — the eight-quarter inflation rate.

The specific index of prices that we use is the consumer price index (CPI), since this paper builds on previous work that is based on the CPI. The DEW model that we consider is a VECM based on Hendry (1995) which examines the long-run demand for M1. In that work, the most plausible long-run money-demand function was found when non-seasonally adjusted data were used in the estimation. (Note that seasonal-adjustment filters can distort estimates of long-run cointegrating relationships.) Since we use that basic function here, our VECM forecasts non-seasonally adjusted CPI inflation.[1]

3. Background on the M1-VECM and related work

Hendry (1995) uses the Johansen-Juselius (JJ) methodology to study long-run relationships among M1, the price level, output and interest rates, to determine if there is a stable cointegrating relationship that can be interpreted as long-run money demand. In particular, that work estimates a four-equation VECM for M1, the price level (CPI), output (GDP) and a short-term interest rate (CP90) from 1956 to 1993.

As a result of the JJ technique used, the information in both the levels and changes of the variables is exploited to estimate the coefficients of the long-run money-demand equation. As well, a number of exogenous variables are included to help model the short-run dynamics of the system, and to help identify a unique cointegrating vector among M1, prices, output and interest rates. These exogenous variables are the change in a short-term U.S. interest rate, the change in the Canada–U.S. exchange rate, a simple measure of the output gap, a GST dummy, and a permanent shift

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1. When we assess the forecast accuracy of the VECM (below), we compare its forecasts of the non-seasonally adjusted CPI inflation rate to the (more common) seasonally adjusted rate. (Strictly speaking, this way of measuring the forecast error itself would raise the observed forecast error, but by a trivial amount.)

dummy for the early 1980s to account for the financial innovations that occurred at that time.[2]

Money-demand relationships were estimated for a number of different data definitions, including raw and seasonally adjusted, nominal and real, and monthly and quarterly series. The best results were found with raw, quarterly data and nominal gross M1. The hypothesis of long-run unitary price elasticity was not rejected, and its imposition led to only marginal changes in the other coefficients.

The sign of the coefficient on the deviation of money from its long-run demand — the speed of adjustment — in each of the short-run dynamic equations also conformed to theory. In particular, when M1 is above its long-run demand, money will decrease and prices will increase to restore long-run equilibrium. The effects on output and interest rates of such a deviation are insignificant, implying the “weak exogeneity” of these two variables. Thus, the adjustment to return the economy to monetary equilibrium comes from fluctuations in money and prices. However, this does not preclude the possibility that changes in the stock of money can have short-run real effects. In fact, the short-run dynamic coefficients indicate that lagged values of ΔM1 do affect $\Delta M1_t$, ΔGDP_t, and $\Delta CP90_t$, but not ΔCPI_t.[3] In other words, M1 seems to be important for short-term changes in output and for the longer-term trend or movement in prices, but less so for short-run fluctuations of inflation.

Armour et al. (1996) show that the VECM developed by Hendry provides significant leading information about inflation, well in advance. In rolling out-of-sample forecasts of the eight-quarter

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2. The shift dummy is zero before 1980:1 and one after 1982:4, and it increases linearly between those dates. This is designed to approximate the slow introduction and dissemination of financial innovations. As regards the output gap, the measure used in the VECM is the residual from a regression of GDP on linear and quadratic time trends.

3. These short-run dynamic results are consistent with the findings of previous research conducted at the Bank of Canada on the short-term effects of changes to M1. See Muller (1990), for example.

inflation rate from 1978 through 1994, the model had a mean absolute error of about one percentage point, and a root-mean-squared error of about two. From the early 1980s on, the VECM had mean absolute errors and root-mean-squared errors both less than one percentage point. In addition, this model provided leading information about the turning points in out-of-sample experiments.[4]

Armour et al. point out that the model made some significant errors forecasting the sharp drop in the eight-quarter inflation rate in the early 1980s. In particular, it did not accurately anticipate the drop of inflation in 1982 with an eight-quarter lead. However, the model did provide accurate leading information about this break in inflation with a shorter lead, of about one year.[5]

The papers summarized above deal with the empirical foundation and basic forecasting properties of the M1-based VECM. Turning to more-detailed examination of its dynamics and interpretation of the model, Kasumovich (1996) and Fung and Kasumovich (1998) provide structural-VAR analyses of models very similar to the VECM.

Kasumovich (1996) examines the dynamic properties of a model very similar to the one developed by Hendry. He uses the parameter estimates of the cointegrating vectors in the data along with other (long-run) restrictions to identify the economic shocks in the data, and he examines the dynamic behaviour of the system in response to monetary policy shocks. Kasumovich's work, which

4. In future work, we can assess more formally the extent of the model's leading-indicator accuracy around turning points by considering a non-parametric test recently proposed by Pesaran and Timmermann (1992). For an example of an application of this procedure, see Amano and van Norden (1993).

5. As discussed in Armour et al. (1996), the errors in 1982 seem to be related to the very large interest-rate swings during 1980. Given the interest-rate sensitivity of M1 demand, large swings in short-term rates can temporarily influence the size of money disequilibria. The impulse-response functions in Kasumovich (1996) illustrate this very well; see especially Figure 3 of that paper.

An important implication here is that inferences from the VECM about future inflation during periods of large movements in short-term rates must be made carefully.

identifies monetary policy shocks in two different ways and in a variety of model specifications, suggests that the long-run demand for M1 is a robust feature of the data.

As well, Kasumovich's model suggests that a monetary policy shock disturbs the relationship between money and its long-run demand so as to create a long-lasting monetary disequilibrium.[6] Importantly, these "money gaps" are eliminated over time as prices adjust. His work also illustrates that monetary policy shocks clearly affect prices with a long lag, and the lag is variable across the range of models considered. Finally, the analysis suggests that a monetary-policy shock has an effect on output that may last several years, but that eventually fades out.

Fung and Kasumovich (1998) extend this analysis to the other G-6 countries and find results similar to those in Kasumovich (1996). They interpret their results as generally consistent with the view that central banks influence the money stock independently of other factors in the economy; that is, money has an active role in the transmission of monetary policy. In their work, in response to an unanticipated increase in money, it takes several quarters for agents to rebalance their portfolios. Since the price level is slow to adjust, the subsequent temporary increase in spending leads to an increase in real activity. As the price level adjusts, monetary equilibrium is restored, and interest rates and output return to their pre-shock levels.

In sum, this body of work identifies a reasonably stable long-run demand for M1.[7] This work also suggests that a vector-error-

6. Kasumovich (1996) identifies a monetary policy shock as either an orthogonolized innovation in the overnight rate, or as an orthogonolized innovation in the common trend shared by money and prices.

7. Hendry (1995) found evidence of only one shift in long-run M1 demand over the almost 40 years covered in his study. More recent evidence suggests that a second shift probably has been occurring in the last several years. (For a study on instability in the VECM, see Engert, Hendry and Yuan (1998).) This indicates that there have been at most two shifts in long-run M1 demand in 40 years, or one every 20 years. This degree of stability seems quite impressive. By comparison, for example, Fillion and Léonard (1997) estimate a Phillips curve with four (regime) shifts from 1968 to 1996, or one every six or seven years. However, it should also be noted that the Phillips curve is a dynamic adjustment equation, not a cointegrating relationship as is the long-run demand for M1.

correction model based on this long-run relationship provides good inflation forecasts with a long lead — which is important for monetary policy. As well, dynamic analysis of this type of model tends to suggest an active role for money in the transmission mechanism. That is, a monetary policy shock disturbs the relationship between the money stock and long-run money demand, setting in train a relatively long adjustment process in which changes in inflation are critical to restoring monetary equilibrium.

4. Additional equilibrium conditions

The fundamental equilibrium condition in the VECM is the long-run demand for M1. In this section, we add several other equilibrium conditions, with a view to improving the model's dynamic and steady-state properties. However, first, we note some minor adjustments that have been made in the specification of the original VECM introduced in Hendry (1995) and considered in Armour et al. (1996).

(a) The basic VECM

In the original specification of the VECM, the short-run inflation equation included a dummy variable to account for the introduction of the GST in the first quarter of 1991. In the current work, the estimated effects of the introduction of the GST in the first quarter of 1991 and the reduction of tobacco taxes in early 1994 have been removed from the CPI series. As a result, a GST dummy is no longer required.

Armour et al. also used a VECM in which the constant and the shift dummy variable were restricted to appear in only the cointegrating vector. However, this restriction has some undesirable implications for the equilibrium growth rates of the endogenous variables of the system. In particular, in the steady state of the original version of the model, the equilibrium growth rate for each of

M1, GDP, CP90 and the CPI is zero. Accordingly, all estimation now includes a constant and shift dummy which are unrestricted.[8]

Finally, as noted above, the output gap is measured in the VECM simply as the residual from a regression of output against linear and quadratic time trends. In forecasting with this model, the output gap is updated endogenously through the forecast period, given the predicted values of GDP from the VECM. Given the estimated coefficient on the quadratic term in the measure of potential output, the output gap becomes increasingly positive in out-of-sample simulations. Because of this, output and the other variables were never able to reach their equilibrium growth rates. To address this shortcoming, the output gap is forced to converge to zero out-of-sample by applying a linearly declining weight to the estimated gap.

In sum, we start this analysis by noting three modifications to the original specification of the VECM developed in Hendry (1995): we have dropped the GST dummy in that formulation; left the constant and shift dummy unrestricted; and forced the output gap to converge to zero in five years out-of-sample. We call this version of the model the “basic VECM”. In the rest of this section, we present an additional set of modifications to further extend the VECM.

(b) Extending the VECM: the interest rate

The basic VECM has a number of drawbacks. First, the endogenous variables are all assumed to be I(1) with drift. This assumption is reasonable for money, prices and output but is unsatisfactory for the interest rate. As indicated in footnote 8, the

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8. For a detailed discussion of the constant term in the VECM and the associated shift dummy, see Hendry (1995), especially pages 27 to 29. With an unrestricted constant and shift dummy, the steady-state annual growth rates of the endogenous variables are estimated to be 7.4% for M1, 3.0% for GDP, -24 basis points for CP90, and 3.1% for the CPI.

The continuous decline of interest rates in this steady state is a major motivation for the extra conditions developed in this paper for the extended VECM. (The steady state growth rates in the extended VECM — explained below — are 4.4% for M1, 1.9% for GDP, and 3.2% for CPI. The equilibrium interest rate is 7.6%.)

basic VECM model has an equilibrium rate of change for the interest rate but no equilibrium interest rate level. This does not seriously affect the model's ability to forecast over the near-term, but it does influence longer-term performance and the steady state. Here, we introduce some (theoretical) equilibrium conditions for the level of the interest rate to improve the long-run properties of the model. (The Appendix provides a detailed, technical description of the extensions to the VECM summarized here.)

To determine an equilibrium level for the Canadian interest rate, a cointegrating relationship was estimated between the Canadian 90-day interest rate and a comparable U.S. interest rate. (In sub-section (d) below, we discuss the long-run behaviour of the U.S. interest rate). The results show that the Canadian interest rate converges in the long run to the U.S. rate plus a component which is assumed to be a measure of the risk premium. (See equation (6) in the Appendix for more detail on this relationship.)

A disequilibrium implied by this cointegrating vector forces the Canadian interest to fall whenever it is above the level given by the U.S. rate and the estimated risk premium. Conversely, CP90 will rise when below its long-run equilibrium. When added to the larger forecasting model, this equilibrium relationship ensures that CP90 has a long-run equilibrium level instead of an equilibrium rate of change as in the basic VECM.[9]

(c) Extending the VECM: the exchange rate

In past forecasting exercises with the VECM (as in Armour et al.), we assumed that the exchange rate and the U.S. treasury bill rate was fixed over each eight-quarter forecast horizon. However, when forecasting, these assumptions might seem less plausible than

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9. The interest-rate condition implies that, in the long run, nominal Canadian interest rates would converge toward nominal U.S. rates (plus a premium). However, Canadian and U.S. inflation can differ in the model, which implies that real interest rates can differ in the long-run. A difference in the inflation rates across Canada and the U.S. is reflected in a steady-state movement of the exchange rate. (Future work will consider equilibrium relationships between real Canadian and U.S. interest rates.)

some other expected behaviour for these variables, especially over a longer period. That is, it seems implausible that the levels of these variables would remain fixed over any reasonably long period of time.[10]

In the extended VECM, the exchange rate is assumed to be governed by a relative purchasing power parity condition between Canada and the U.S. (see equation (4) in the Appendix). This ensures that the change in the Canada–U.S. exchange rate will converge in equilibrium to a rate consistent with the difference between the steady-state U.S. and Canadian inflation rates.

The evidence in support of relative purchasing power parity between Canada and the U.S. is actually rather weak (Johnson, 1990; Turtle and Abeysebera, 1996; and Flynn and Boucher, 1993). It is quite dependent on the inflation series used and the sample of data. However, it is an appealing theoretical condition which does help at least to slightly improve the overall fit of the model. A condition of absolute purchasing power parity between Canadian and U.S. price levels would yield a long-run equilibrium level for the exchange rate, instead of a growth rate. However, the empirical evidence in support of such a level-based relationship is even more tenuous.

(d) Extending the VECM: the U.S. inflation rate and interest rate

Instead of simply assuming random walks for the two remaining exogenous variables, the extended model fits autoregressive processes for the U.S. inflation rate and the U.S. interest rate. While not very sophisticated, these equations do enrich the model by improving the near-term forecasting of these variables and by setting equilibrium values for these variables that depend on more history than simply the last single observation.

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10. As well, with the basic VECM, one cannot derive a plausible path for monetary conditions, namely short-term interest rates and the exchange rate, consistent with (future) price stability, since the exchange rate is fixed over the forecast horizon. Moreover, for analysis with impulse-response functions, it would probably be useful to model these variables more explicitly.

(e) Extending the VECM: the output gap

Finally, as noted above, in the basic VECM, the output gap is forced to zero over the first five years out-of-sample. This implies that potential output is a weighted average of actual output and the estimated quadratic time trend. The extended VECM changes this somewhat by assuming that out-of-sample potential output is a weighted average of the estimated quadratic time trend and a term which grows at the equilibrium output growth rate. The weight on this second component converges to one over the first five out-of-sample years.

While this does not represent a substantial change in the model (from the basic VECM), it is theoretically more appealing. As well, this feature sets up a framework in which the growth rate of potential can be imposed on the model more easily. This will be a topic for future work.

(f) Extending the VECM: a summing up

While these various additions to the basic VECM are an improvement of the long-run properties of the model, they are not the only conditions that can be used. Indeed, more work remains to be done. In future research, we will consider equilibrium relationships between real Canadian and U.S. interest rates instead of between nominal rates. Separate Fisher equations could then be added to govern the movements of nominal rates in the model. As well, the equilibrium condition for potential output could be set in level terms instead of in terms of its growth rate, as above.

To summarize, the extended-VECM forecasting model is a seven-equation model for M1, the CPI, output, the short-term interest rate, the exchange rate (or the deviation from relative purchasing power parity), the U.S. inflation rate, and the U.S. short-term interest rate. The parameters of the long-run demand for money used in this model are estimated from a four-variable auxiliary VECM using only M1, the CPI, output, and CP90. The interest rate condition is estimated from a second auxiliary model using only CP90 and the U.S. T-bill rate.

5. Inflation forecasts, uncertainty and multiple models

In this section, we consider the forecast accuracy of the VECM described above, that is, the basic VECM, modified with the additional equilibrium conditions discussed in Section 4. We also discuss the likelihood of the forecasts from the extended VECM. Then we briefly compare the VECM's forecast accuracy to that of other common inflation models. Finally, we discuss the role of multiple models in formulating policy advice.

(a) Forecast accuracy of the VECM

In conducting our out-of-sample forecast exercise, the VECM inflation forecasts are conditional only on information that would have been known at the time the forecast would have been made. That is, eight-quarter-ahead inflation forecasts made at time t are conditional on an information set available up to and including period t, but do not draw on data available only after period t.[11]

Therefore, to generate our out-of-sample forecasts with the VECM, we start by estimating the model over a subsample beginning in 1956 and ending with 1983:Q1. Then we forecast the (annualized) inflation rate over the next eight quarters. That is, we forecast the inflation rate over the eight quarters from 1983:Q2 up to and including 1985:Q1. Then we add a quarter of data, re-estimate the entire model, and then forecast the next eight-quarter inflation rate, in this case, the inflation rate from 1983:Q3 to 1985:Q2. Another

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11. Our intention is to simulate, as much as practically possible, the use of the VECM through earlier periods, as if we were actually living through those periods. This would seem to give the most realistic and meaningful assessment of the forecast accuracy of the model. Of course, this goal is not perfectly achievable. It is impractical not to "look at" future data in two respects. First, there is the benefit of data revisions that might not have been available at past periods. And second, analysis of long-run M1 demand (as in Hendry, 1995), which was critical to the development of the VECM, was conditioned on a data set that spanned 1956 to 1993.

quarter of data is then added to our sample, we again re-estimate the model, and the next eight-quarter inflation rate is forecasted. In this way, we generate a quarterly series of out-of-sample, unconditional inflation forecasts for eight-quarter periods from 1985:Q1 to 1996:Q4.

Armour et al. (1996) showed that the original formulation of the VECM provides good forecasts of the eight-quarter inflation rate. As shown in Table 1, the inclusion of the additional equilibrium conditions in the VECM, as well as enhancing the long-run properties of the model, does not seem to erode the forecast accuracy of the model. Over the 12-year horizon considered in our out-of-sample experiment, the root-mean-squared-error (RMSE) of the VECM falls from 1.0 to 0.9 with the inclusion of the additional equilibrium conditions. As well, the mean-absolute-error declines from 0.8 to 0.7.

Table 1 also shows the in-sample forecast accuracy for two of the versions developed here, that is, the basic VECM and VECM4, which includes all of the extensions discussed in Section 4. (We show only these two for the sake of simplicity — all these models fit the data very similarly.) By in-sample forecast, we mean the rolling forecast over the same 1985-1996 sample period, but based on the full-sample parameter estimates. Notably, there is little decline in forecast accuracy when moving from the in-sample to the more demanding, and more meaningful, out-of-sample exercise.

(b) Uncertainty over the forecast horizon and the likelihood of potential outcomes

Figures 1 and 2 illustrate the eight-quarter inflation forecasts of the basic VECM and VECM4. Figure 3 provides the eight-quarter inflation forecasts one-year ahead from the VECM4. In this case, the model is forecasting our measure of inflation only four steps (quarters) from the current quarter, instead of eight quarters, as above. That is, the model is forecasting one-year ahead, instead of two years. One can think of this as forecasting the trend of inflation one year ahead.[12]

Not surprisingly, the model performs better in this less-demanding exercise: the root-mean-squared-error of the unconditional out-of-sample forecast in Figure 3 is 0.4 and the mean-absolute-error is also 0.4.[13] Figure 3 also shows that the model predicted the turning points in 1991 and 1993 with a one-year lead, although it overshot somewhat the decline in 1993.[14] Generally, of course, our confidence in predicting such turning points with a two-year lead must be lower; on this point, compare Figure 3 to Figure 2.

This illustrates that a more informative way to present inflation forecasts than simply providing the point estimate of the model is to include as well a statement about the probability distribution of potential outcomes. By drawing on the model's estimated variance-covariance matrix, we can generate confidence intervals around a set of n-step-ahead forecasts from any given quarter, with each forecast projecting the eight-quarter inflation rate one-quarter further into the future.

Figure 4 illustrates this for a series of inflation forecasts looking ahead from 1994. More specifically, Figure 4 provides a set of eight-quarter inflation rate forecasts from the VECM4 estimated up to 1994:Q4. The forecast first steps out only one-quarter to

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12. We formulate the results in terms of the eight-quarter rate, instead of the four-quarter rate, in this case for two reasons. First, as argued in Section 2, the eight-quarter rate seems to be a better measure of the general direction that prices are taking. Second, a consistent measure of inflation makes it simpler to calculate confidence intervals (discussed below) around the point estimate.

13. The root-mean-squared error in forecasting the four-quarter inflation rate (from t to t+4) is 0.8 and the mean-absolute error is 0.7.

14. In particular, as shown in Figure 3 and Figure 2, the model forecast that inflation would fall below the bottom of the inflation-control band (1 per cent) in 1993. Such forecast errors raise an interesting question of model assessment: It might be the case that the central bank reacted to an outlook that suggested such a result, and acted to avoid that. In other words, the implied reaction function of the model is inappropriate in this case, or, there was a policy innovation (shock) which the model could not anticipate.

1995:Q1, then two quarters ahead, then three quarters ahead, and so on, until the last forecast, at 1996:Q4, is the eight-quarter-ahead forecast. This set of forecasts is bounded by the 90 per cent and 50 per cent confidence intervals estimated from the model. It shows, of course, that as the forecast horizon increases, the confidence band also widens.[15]

In this way — presenting a set of n-step-ahead forecasts bounded by estimated confidence bands — we can present an outlook that is more informative about the development of the general direction of prices, and one that explicitly recognizes the uncertainty inherent in forecasting inflation with a long lead. The model could also be used in a similar way to generate a band for the future growth of M1 conditional on a given future profile for inflation.

(c) A comparison with forecasts from other inflation models

We now turn to a brief comparison of the VECM's recent forecast accuracy to two other popular ways of forecasting inflation; a simple autoregressive model (including four lags of past inflation), and a Phillips curve.

The Phillips curve considered here is very similar to that developed by Fillion and Léonard (1997). Inflation is measured as the change in the CPI excluding food, energy and the effect of indirect taxes — a measure of the "core" inflation rate, which is a smoother series than total CPI. As explanatory variables, the model includes lagged inflation, a measure of import-price changes, a measure of oil-price changes and an output gap measure. (The

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15. Essentially, the VECM4 is used to simulate 1995-96 data in the presence of random shocks based on the estimated variance-covariance matrix. After 2000 replications, the simulations were ordered and percentiles calculated.

The Bank of England routinely includes bands of likelihood around their inflation projections in the *Inflation Report*. For example, see Bank of England, 1997, p. 48. As well, in a recent issue of Goldman Sachs' *Canadian Weekly Analyst*, Chandler and Kasumovich (1997) also put their medium-term inflation outlook in a probalistic context.

Appendix provides a detailed description of the Phillips curve we use.)

As with the VECM, our Phillips curve is estimated on quarterly data, and we use it to forecast eight steps ahead, as in the exercise in Section 5(a). Also, as in Fillion and Léonard (1997), to obtain an estimate of the unobservable output gap, we use the Bank of Canada's "extended multivariate filter" (EMVF) measure of potential output.[16]

Before considering the forecast results, a few words on this measure of the output gap are in order. The EMVF effectively adds terms to a Hodrick-Prescott filter (which measures trend output) to reflect elements of economic structure that are seen to be related to potential output. More precisely, the EMVF-measure of the output gap is conditioned on a set of economic relationships consistent with the structure of the Bank's Quarterly Projection Model (QPM). In this way, the EMVF efficiently incorporates a wide range of information and prior theory to extract a sensible estimate of the output gap from the data. Part of that set of conditioning information is an error term from a Phillips curve relationship. That is, the measure of the output gap from the EMVF is conditioned in part on minimizing near-term forecast errors of a Phillips curve.

As well, historical time-series estimates of the EMVF-based output gap at any time t are conditioned on information from both before and after time t, since the EMVF is a two-sided filter. That is, estimates of the output gap at time t are conditioned on information spanning (t-n) to (t+n). Nevertheless, as Laxton and Tetlow (1992) and Butler (1996) stress, there is considerable uncertainty surrounding historical point estimates of potential output. Moreover, when policy makers confront the current inflation

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16. For a detailed discussion of the EMVF, see Butler (1996). A very brief summary of that approach can also be found in the May 1995 Bank of Canada *Monetary Policy Report* (p. 8). A more general review of research on measuring the output gap at the Bank of Canada can be found in St-Amant and van Norden (1997).

outlook, information beyond the current period t of course is not available. As a result, these authors note that uncertainty around this measure of the output gap is greatest precisely when the estimate matters most to policy makers.[17]

As regards the historical, in-sample fit of the Phillips curve then, Table 2 and Figure 5 show that this model (not surprisingly) performs very well in fitting the eight-quarter inflation rate — and somewhat better than the VECM over this sample period (Table 1).

Turning to an out-of-sample experiment for the Phillips curve, again, we sequentially estimate the model over a series of sample periods, the first ending in 1983:Q1, and generate a series of forecasts of the eight-quarter inflation rate — as measured by the CPI excluding food, energy and indirect taxes in this case. However, an important difference in this case concerns the conditional nature of this exercise. The Phillips curve forecast draws on the actual values for the exogenous variables in the model. That is, the forecast is conditional on the actual (future) values for import-price changes, oil-price changes and the EMVF-measure of the output gap. Of course, this implies a considerable (and unrealistic) degree of future information available to the Phillips curve model.

Nevertheless, the forecast accuracy of the Phillips curve falls notably from its in-sample performance. As well, the model does not forecast as well as the VECM, despite the informational advantage provided by the conditional nature of this exercise and a smoother variable to forecast (CPIXFETAX).

One important reason for the relatively poorer performance of the Phillips curve in this exercise is a shift, which is estimated by Fillion and Léonard (1997) to have occurred between 1982 and

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17. In the quarterly projection exercise at the Bank of Canada, the EMVF-estimate of potential output used for the projected quarters is determined by the internal structure of QPM together with the starting point estimate for potential output and the exogenous assumptions that underlie the projection, such as the projected rates of population and productivity growth (Butler, 1996).

1984.[18] Accordingly, starting the forecast exercise one year later notably reduces the errors of the Phillips curve. The root-mean-squared-error falls to 1.1 and the mean-absolute error falls to about 0.9, which are comparable to (but still larger than) those of the VECM shown in Table 1.

Fillion and Léonard (1997) argue that the four shifts in the Phillips curve over the last two-and-a-half decades are related to changes in the way that inflation expectations are formed. They also suggest that shifts in inflation expectations appear to have been influenced by monetary policy developments, or put differently, by changes in the policy regime. Accordingly, to the extent that the current monetary policy regime — characterized by targeting low inflation — is expected to stay in place, a Phillips curve could be expected to provide good leading information about inflation.

(d) Multiple paradigms, contests and advice

The results presented here suggest that the VECM forecasts inflation well, and that it performs well compared to other inflation models. Contests between different respectable models that are based on different views of the world and different technical approaches to the data are informative. However, our considerable ignorance about the monetary transmission mechanism suggests that such contests should be kept in perspective. No single model, no matter how technically sophisticated, is likely to capture the transmission mechanism well in all respects. As a result, no single view or model is likely to be an adequate representation to handle all episodes that might confront a central bank in the future.

Accordingly, monetary policy is probably best-served by drawing on models that summarize different views, or paradigms, of the transmission mechanism, or that use different technical

18. In conducting our rolling conditional forecasts with the Phillips curve, we account for a new regime, as identified in Fillion and Léonard (1997), only after the estimated probability that there is a new regime reaches one. However, given the number of variables in the model identifying each regime, even more data than this procedure allows for is needed to obtain good estimates of the model's parameters following each shift.

approaches to represent the transmission mechanism — in this case, a “passive-money” view (the Phillips curve) and an “active-money” view (the VECM). Such an eclectic, diversified approach would likely lower the risk of making serious policy errors.[19]

6. Concluding remarks

In this paper, we have made five points.

First, since we are most concerned with persistent changes in inflation (as opposed to transitory fluctuations), we emphasized a simple measure of the general direction or trend that prices are taking, the eight-quarter CPI-inflation rate.

Second, we imposed a set of equilibrium conditions in the VECM to better anchor the long-run behaviour of interest rates and the exchange rate in the model. As well, a more reasonable equilibrium condition for the output gap was imposed. With these modifications, we should be able to have greater confidence in the dynamic properties of the model, especially over a longer time horizon. As well, our analysis suggests that the establishment of these conditions might improve the VECM’s distant-early-warning properties for inflation.

The third point is that our analysis indicates that the VECM provides considerable leading information about the trend of inflation, forecasting the eight-quarter inflation rate with relatively small errors. However — our fourth point — we also stressed that, to be most useful for monetary policy, inflation forecasts should take account of the uncertainty — and errors — inherent in forecasting inflation with a long lead.

Fifth, in this paper we emphasized that monetary policy is probably best-served by an eclectic approach in which policy judgements are made by drawing on models that summarize

19. Engert and Selody (1998) elaborate on the motivation that uncertainty provides to consider both these paradigms of the transmission mechanism when considering the outlook and the development of monetary policy advice.

different paradigms of the transmission mechanism, or use different technical approaches to represent the transmission mechanism.

The next stage of the M1-VECM project involves further improvements to the long-run properties of the model. In particular, as noted above, equilibrium relationships between real Canadian and U.S. interest rates (instead of between nominal rates) will be developed. Separate Fisher equations then can be added to govern the movements of nominal rates in the model. As well, the equilibrium condition for potential output could be set in level terms.

Following that stage, we can identify the shocks driving the model, and based on that analysis, we can interpret monetary policy shocks and assess their impact, that is, provide dynamic analysis of monetary policy action.[20] As well, the VECM could be used to calculate bands for M1 growth conditional on a given future inflation profile. Such a calculated path for M1 would be a form of indicator model, where movements of M1 outside of the band *might* signal a need for a monetary policy response, depending on the assessment of the reasons for M1 leaving its band.[21]

20. In principle, identification of policy shocks could be made either with contemporaneous identification restrictions, as in Armour, Engert and Fung (1996), or through long-run restrictions, as in Kasumovich (1996), or Fung and Kasumovich (1998). (The so-called M-shocks of the latter papers seem especially promising.) For a straightforward exposition of the use of VAR-based models in this way, see Cecchetti (1996).

21. Another challenge to be considered in using this model to inform policy judgements is dealing with instability in the short-run dynamics of the model. For more on this point, see Engert, Hendry and Yuan (1998).

Table 1: VECM forecast results for the eight-quarter inflation rate from 1985:Q1 to 1996:Q4

Model	Unconditional Out-of-sample		In-sample	
	RMSE	MAE	RMSE	MAE
Basic VECM[a]	0.953	0.781	0.728	0.567
VECM2[b]	0.874	0.740		
VECM3[c]	0.884	0.748		
VECM4[d]	0.875	0.728	0.689	0.529

a. Estimated from 1956. Forecasts the total CPI excluding the estimated effect of the introduction of the GST in 1991 and the reduction of tobacco taxes in 1994.

The principal long-run condition in the basic VECM is the long-run demand for M1. The output gap is forced to zero over 20 quarters. (See the Appendix for a detailed description of the versions of the VECM considered here.)

b. As in the basic VECM, but adds a new output-gap equilibrium condition and an interest-rate equilibrium condition. The interest rate converges to equilibrium in 20 quarters and potential output growth converges to the model's equilibrium output growth rate in 20 quarters as well.

c. As in VECM2, but adds the spot PFX equation.

d. As in VECM3, but adds the U.S. interest rate and U.S. CPI equations.

Table 2: Forecast results for the eight-quarter inflation rate from 1985:Q1 to 1996:Q4: alternative models

Model	Out-of-sample[a]		In-sample	
	RMSE	MAE	RMSE	MAE
AR(4)[b]	1.184	0.871	1.070	0.777
Phillips curve[c]	1.414	1.122	0.543	0.444

a. The out-of-sample forecast for the AR model is unconditional, while the out-of-sample Phillips curve forecast is conditional.

b. Single-equation autoregression with four lags, estimated from 1956:Q1. Forecasts total CPI excluding the effect of the introduction of the GST in 1991 and the reduction of tobacco taxes in 1994. With inflation measured as the CPI excluding food, energy and indirect tax shocks, the out-of-sample RMSE rises to 1.30, and the in-sample RMSE rises to 1.03.

c. Estimated from 1968. Forecasts the CPI excluding food, energy and indirect tax shocks. Out-of-sample forecasts are conditional on future information through use of actual, historical values for the exogenous variables in the model. (Estimating from 1963 — the earliest date possible — would introduce a fifth shift in the Phillips curve, according to Fillion and Léonard, 1997.)

Table 3: Forecast results for the eight-quarter inflation rate from 1986:Q1 to 1996:Q4: alternative models

Model	Out-of-sample[a]		In-sample	
	RMSE	MAE	RMSE	MAE
AR(4)	1.152	0.819	1.059	0.744
Phillips curve[b]	1.141	0.942	0.553	0.447

a. The out-of-sample forecast for the AR model is unconditional, while the out-of-sample Phillips curve forecast is conditional.

b. Estimated from 1968. Forecasts the CPI excluding food, energy and indirect tax shocks. Out-of-sample forecasts are conditional on future information through use of actual, historical values for the exogenous variables in the model.

Appendix: Model Details

A. The Basic VECM Model

$$\Delta X_t = \Gamma(L)\Delta X_t + DZ_t + \alpha\beta' X_{t-1} \qquad (1)$$

where: X_t = [M1, CPI, Y, CP90]

Z_t = [constant, 3 seasonal dummies, output gap, Δexchange rate, ΔUS T-bill rate,1980 shift dummy]

Γ(L) = Matrix of parameters for a fourth-order lag process.

B. The Extended VECM Model

This section describes the seven equation expanded VECM forecasting model for M1, the CPI, output, CP90, the exchange rate, the U.S. inflation rate, and the U.S. 90-day T-bill rate.

Equations 1 to 3: M1, Price, and Output

$$\begin{bmatrix} \Delta M1_t \\ \Delta CPI_t \\ \Delta Y_t \end{bmatrix} = \Gamma_1(L)\begin{bmatrix} \Delta M1_t \\ \Delta CPI_t \\ \Delta Y_t \\ \Delta CP90_t \end{bmatrix} + D_1 Z_t + \alpha_1 MGAP_{t-1} \qquad (2)$$

where: Z_t = [constant, 3 seasonal dummies, output gap, ΔUS T-bill rate, 1980 shift dummy]

$MGAP_t$ = the money gap derived from the VECM described below.

Equation 4: The 90-Day commercial paper rate

$$\Delta CP90_t = \Gamma_2(L)\left[\Delta M1_t\ \Delta CPI_t\ \Delta Y_t\ \Delta CP90_t\right] + D_2 Z_t + \alpha_2 MGAP_{t-1} + \gamma_1 RGAP_{t-1} \qquad (3)$$

where: Z_t = [constant, 3 seasonal dummies, output gap, ΔUS T-bill rate at time t and with 3 lags, estimated monetary policy innovations, lagged expected rate of depreciation=(forward-spot rates)]

$RGAP_t$ = the interest rate gap derived from the model described below.

Equation 5: Relative purchasing power parity

$$RPPP_t = \Gamma_3(L)\left[\Delta M1_t \ \Delta Y_t \ \Delta CP90_t \ RPPP_t\right] + D_3 Z_t + \alpha_3 MGAP_{t-1} + \gamma_2 RGAP_{t-1} \tag{4}$$

where: $RPPP_t$ = ΔSPOT - ΔCPI +ΔUSCPI

Z_t = [constant, 3 seasonal dummies, output gap, ΔUS T-bill rate at time t and with 2 lags, estimated monetary policy innovations]

Equation 6: The US Inflation Rate

- An unrestricted AR(4) on the four-quarter US inflation rate.

Equation 7: The US 90-Day Treasury Bill Rate

- An AR(2) on the US 90-Day Treasury Bill Rate.

The money gap used in the above model is estimated from the following auxiliary VECM:

$$\Delta X_t = \Gamma(L)\Delta X_t + DZ_t + \alpha\beta' X_{t-1} \tag{5}$$

where: X_t = [M1, CPI, Y, CP90]

Z_t = [constant, 3 seasonal dummies, output gap, Δlog(exchange rate), ΔUS T-bill rate current and 3 lags,1980 shift dummy, estimated monetary policy innovations, lagged RGAP]

The interest rate gap used above, $RGAP_t$, is estimated from the following auxiliary ECM; (note that the US T-bill rate has been assumed to be strictly exogenous so that the current US rate can affect the current Canadian interest rate).

$$\Delta CP90_t = a\Delta USTB90_t + \Gamma(L)\begin{bmatrix} \Delta CP90_t \\ \Delta USTB90_t \end{bmatrix} + DZ_t + \alpha\beta'\begin{bmatrix} CP90_{t-1} \\ USTB90_{t-1} \\ \text{constant} \\ \text{shift} \end{bmatrix} \quad (6)$$

where: Z_t = [2 lags of Δlog(exchange rate), 2 lags of Δlog(forward rate), estimated monetary policy innovations]

Γ(L) = Matrix of parameters for a third-order lag process.

shift = a shift dummy with a value of one from 86Q1 to 92Q4 and zero otherwise to account for an apparently exogenous increase in the Canadian-U.S. spread.

Estimated interest rate policy innovations are the residuals from the following regression

$$\Delta RON_t = \Gamma(L)\left[\Delta RON_t \ \Delta M1_t \ \Delta Y_t \ \Delta CPI_t\right] + c + Innovations_t \quad (7)$$

The inclusion of these policy innovations in the CP90 equation is important for explaining a large portion of the increase in the Canadian-U.S. interest rate spread during the 1989 to 1991 period. The remainder of the increased spread during this time is attributed to a larger risk premium for Canada.

The output gap used in the VECM is the residual from the following regression

$$Y_t = a + bt + ct^2 + dQ2 + eQ3 + fQ4 + ygap_t \qquad (8)$$

The parameters of the model are estimated using the above equations but certain modifications are made when performing out-of-sample forecasts or simulations.

a. The output gap is modelled using the following equation:

$$\begin{aligned} ygap_t = Y_t - \{ & W1_t(a + bt + ct^2 + dQ2 + eQ3 + fQ4) \\ & + (1 - W1_t)(Y_{t-4} + gy)\} \end{aligned} \qquad (9)$$

where gy = the model's steady state four-quarter growth rate of output.

W1 = a weighting function that goes from one to zero over the first 20 out-of-sample quarters.

b. To ensure that CP90 is governed by only its equilibrium condition in the long run, a weighting function is applied to certain variables so that their influence disappears over time out-of-sample. These variables are: lags of ΔM1, ΔCPI, and ΔY growth, the money gap, the constant, and the seasonal dummies.

C. The Phillips Curve

The Phillips curve used in this paper is similar to that fitted by Fillion and Léonard (1997) and is given by equation (10). The variable π_t is the annualized one-quarter inflation rate of the seasonally adjusted CPI excluding food, energy, and indirect taxes. The variables D_1, D_2, D_3, and D_4 are shift dummies representing the regimes estimated by Fillion and Léonard (1997). Import-price inflation and the change in oil prices are represented by π_t* and $goil_t$, respectively. The output gap, $Ygap_t$, uses the “extended multivariate filter” estimate derived within the Bank’s QPM model. The one major change from Fillion and Léonard (1997) is that the second state, D_2, is left unrestricted instead of being restricted to have a unit root.

$$\begin{aligned}\pi_t = {} & a_1 D_1 + a_2 D_2 + a_3 D_3 + a_4 D_4 + D_1(a_5 \pi_{t-1} + a_6 \pi_{t-2}) \\ & + D_2(a_7 \pi_{t-1} + a_8 \pi_{t-2} + a_9 \pi_{t-3} + a_{10} \pi_{t-4}) \\ & + (D_3 + D_4)(a_{11} \pi_{t-1} + a_{12} \pi_{t-2}) \\ & + a_{13} Ygap_{t-1} + D_2(a_{14} \pi^*_{t-1} + a_{15} \pi^*_{t-2}) + a_{16} goil_{t-1} + a_{17} goil_{t-2} \\ & + a_{17} goil_{t-3} + a_{18} goil_{t-4}\end{aligned} \tag{10}$$

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Figure 1: Basic VECM: 8-Quarter Inflation In-Sample and Unconditional Out-of Sample Forecast

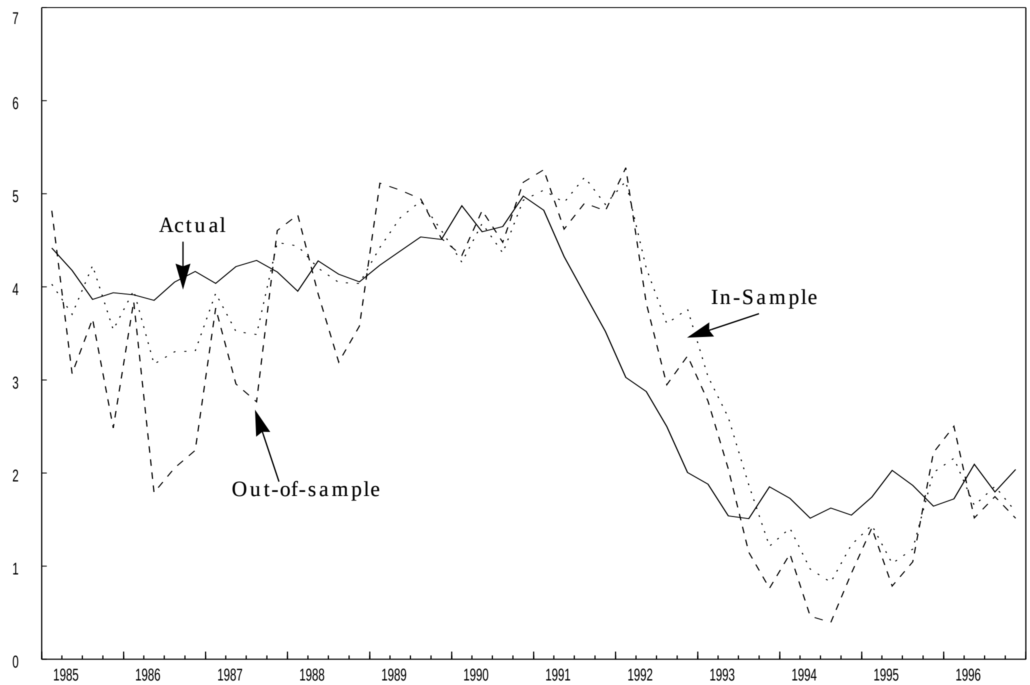


Figure 2: Extended VECM: 8-Quarter Inflation In-Sample and Unconditional Out-of Sample Forecast

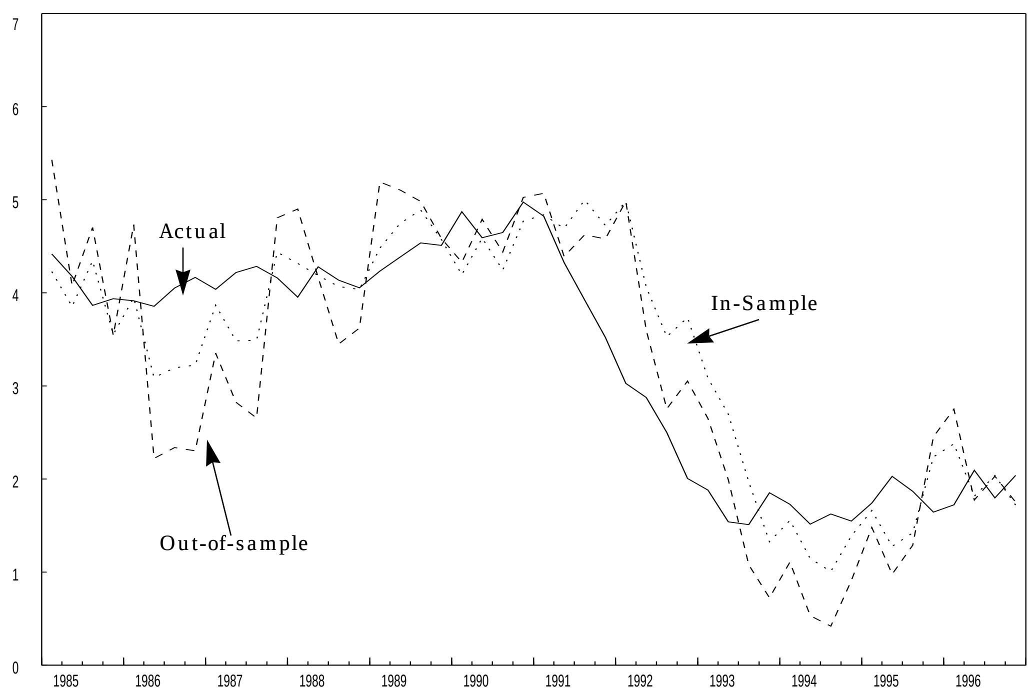


Figure 3: Extended VECM: 8-Quarter Inflation Unconditional Out-of-Sample Forecast Four Quarters Ahead

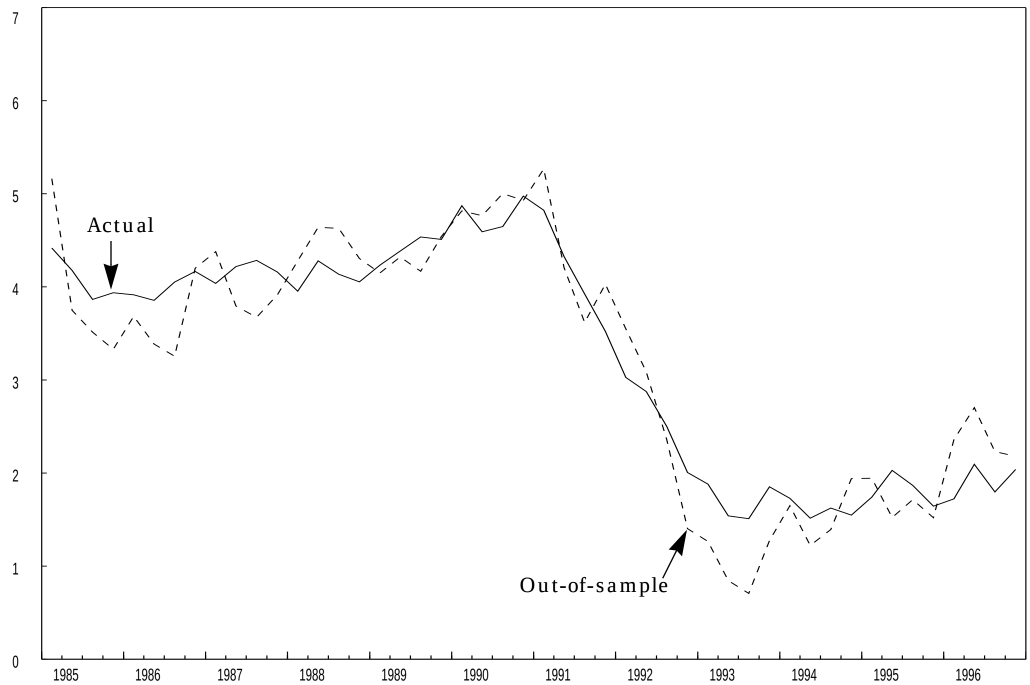


Figure 4: Extended VECM: N-step Ahead Inflation Forecast and Confidence Bands

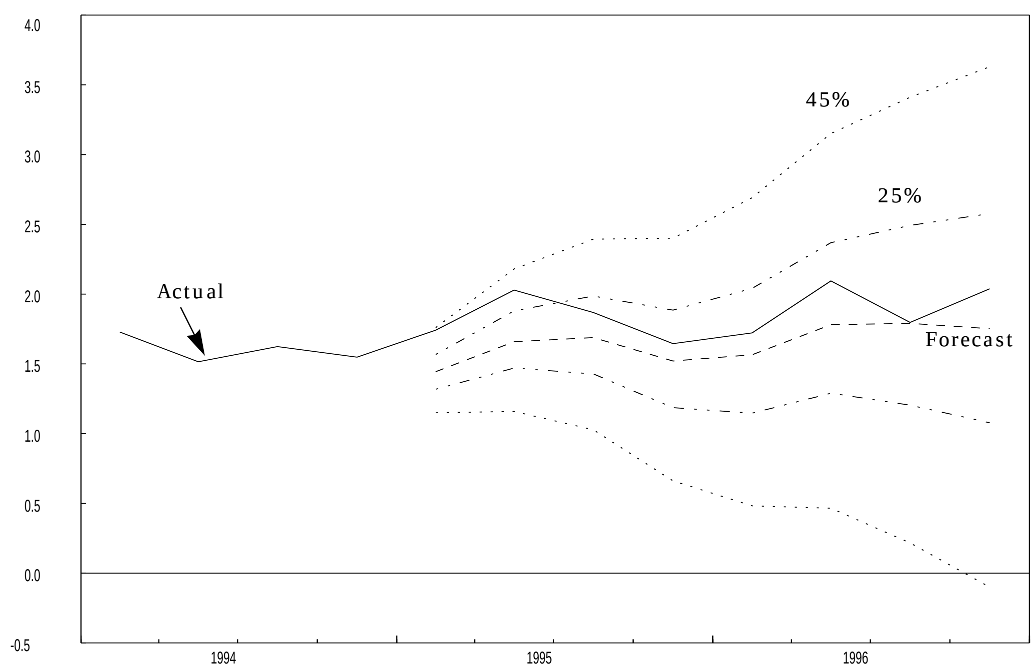
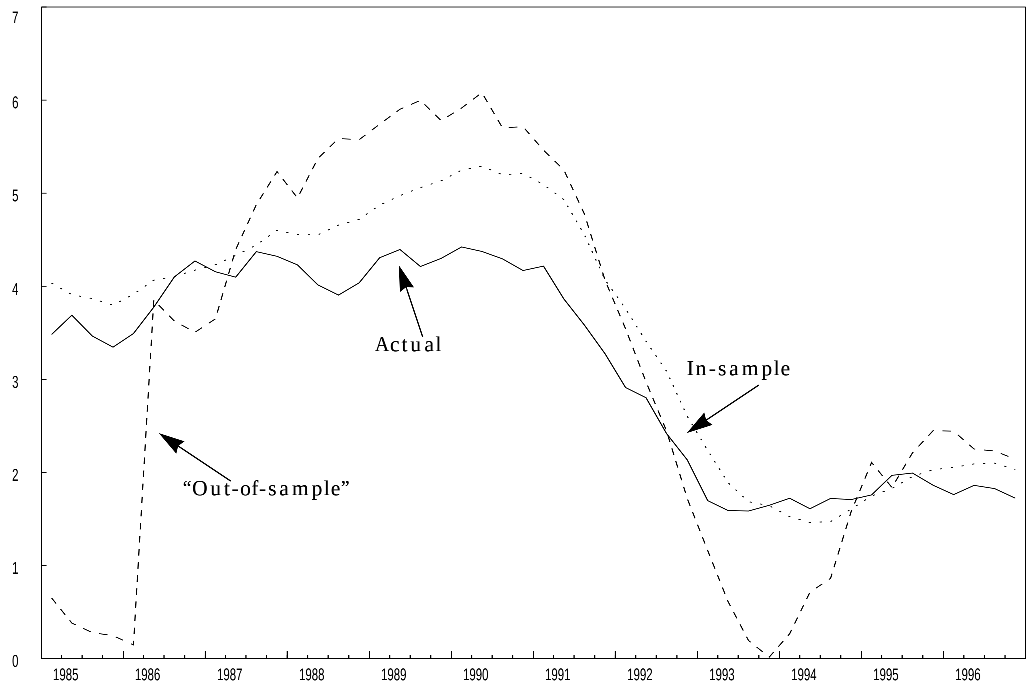


Figure 5: Phillips Curve Model: 8-Quarter Inflation In-Sample and Conditional Out-of Sample Forecast



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