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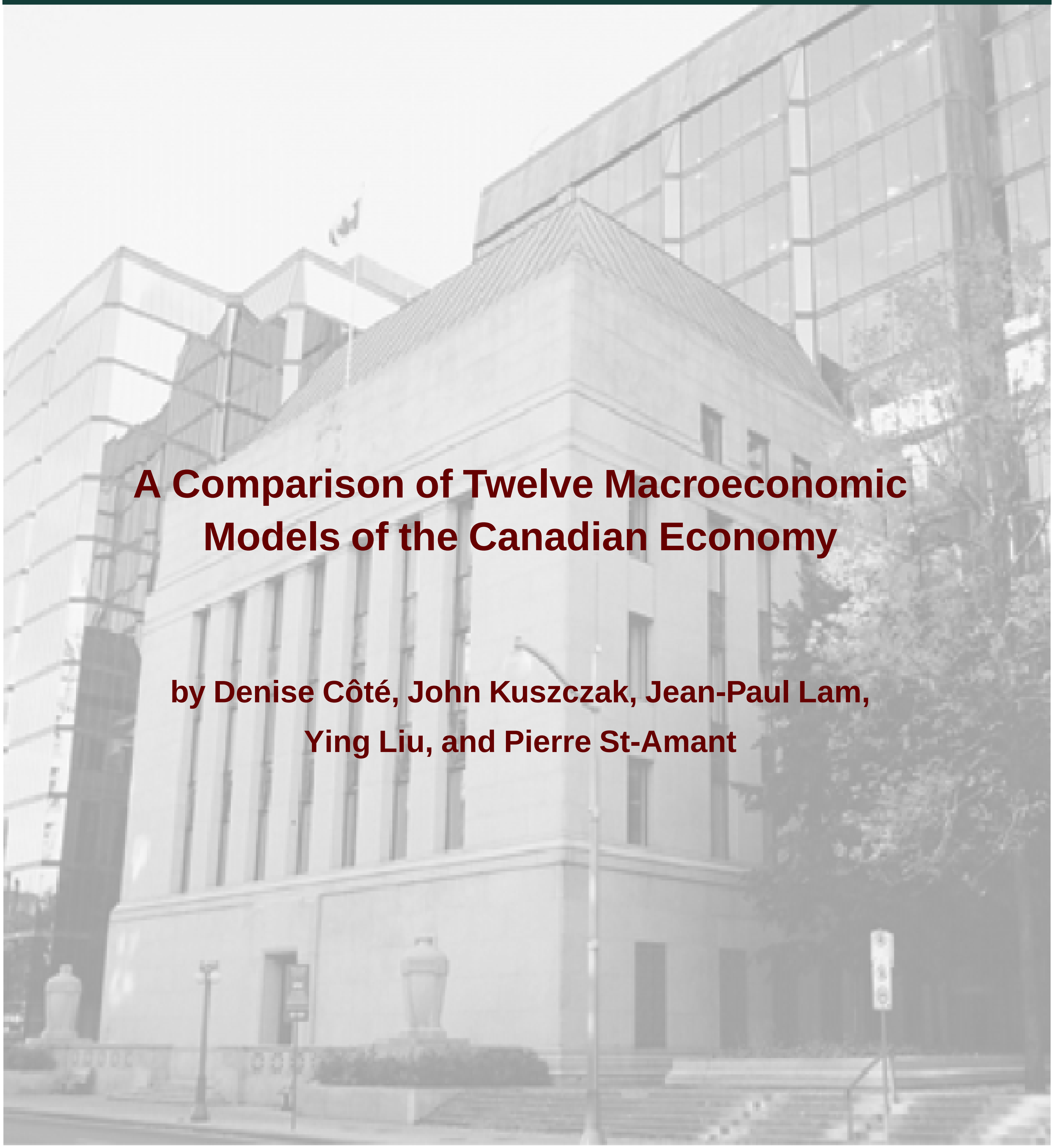

A Comparison of Twelve Macroeconomic Models of the Canadian Economy

by Denise Côté, John Kuszczak, Jean-Paul Lam, Ying Liu, and Pierre St-Amant

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Abstract

In this report, the authors examine and compare twelve private and public sector models of the Canadian economy with respect to their paradigm, structure, and dynamic properties. These open-economy models can be grouped into two economic paradigms. The first is the "conventional" paradigm (or Phillips curve paradigm) and the second is the "money matters" paradigm. Under the conventional paradigm, inflation is determined by price adjustments in response to inflation expectations and by factor disequilibrium in labour or product markets. Under the money matters paradigm, inflation is determined mainly by monetary disequilibrium. Although most models are based on the conventional paradigm, there are nevertheless important differences within that paradigm. In particular, there are differences in the inflation process (linear/non-linear Phillips curve), the expectation processes (backward-looking and/or model-consistent expectations), the channels through which monetary policy affects the economy (short-term interest rates or the yield curve), and the sensitivity of output and inflation to changes in interest rates and the exchange rate. The authors also examine the dynamic properties of the various models when those models use the simple monetary reaction function proposed by Taylor (1993). The eight deterministic shocks considered in this report reveal significant differences in the dynamic properties of the participating models. A comparison of the models' impulse-response functions with those of a vector autoregression suggests that some models do better than others in reflecting the typical response of the Canadian economy to certain shocks.

JEL classification: C5, E52, E58
Bank classification: Economic models; Uncertainty and monetary policy

Résumé

Dans leur étude, les auteurs analysent douze modèles de l'économie canadienne élaborés par des organismes des secteurs privé et public et en comparent les paradigmes, la structure ainsi que les propriétés dynamiques. Ces modèles d'économie ouverte reposent sur l'un ou l'autre des deux paradigmes suivants : le paradigme « traditionnel » (dit de la courbe de Phillips) et le paradigme fondé sur la monnaie. Le premier postule que la dynamique de l'inflation dépend des modifications de prix liées à l'évolution des attentes d'inflation et du déséquilibre des facteurs sur le marché du travail ou des biens. Le second attribue un rôle central au déséquilibre monétaire dans la détermination de l'inflation. Le paradigme traditionnel, sur lequel se fondent la plupart des modèles retenus, présente toutefois plusieurs variantes sensiblement différentes : 1) selon que le processus d'inflation est formalisé au moyen d'une courbe de Phillips linéaire ou non linéaire;

2) selon que les attentes sont rétrospectives ou conformes au modèle; 3) selon que la politique monétaire a pour canal de transmission les taux d’intérêt à court terme ou la pente de la courbe de rendement; 4) selon la sensibilité de la production et de l’inflation aux variations des taux d’intérêt et du taux de change. Les auteurs examinent également le comportement dynamique des divers modèles lorsqu’on intègre à ceux-ci la fonction de réaction monétaire simple proposée par Taylor (1993). Les huit chocs déterministes qui sont simulés font ressortir de profondes différences dans les propriétés dynamiques des modèles. Si l’on compare les profils de réaction qui se dégagent de ceux-ci et d’un modèle vectoriel autorégressif, on constate que certains modèles reproduisent mieux que d’autres la réaction type de l’économie canadienne à certains chocs.

Classification JEL : C5, E52, E58
Classification de la Banque : Modèles économiques; Incertitude et politique monétaire

1. Introduction

In the fall of 2000, we began a research project to determine whether we could find a simple monetary policy rule that would give good results in models of the Canadian economy.[1] We wanted our approach to differ from that used in previous studies in three respects. First, while most previous studies had used models of the U.S. economy, we wanted ours to focus on Canada's small open economy. Second, we wanted our analysis to incorporate a large number of models that differ significantly from each other, to address criticisms by authors such as Hetzel (2000) and Svensson (2002) that previous studies did not reflect a large enough spectrum of models and consequently did not constitute a good test of the robustness of simple monetary policy rules. Third, because the models are all used either for forecasting key variables of the Canadian economy and/or for policy analysis, we wanted to emphasize models designed to be consistent with the data. Sims (2001) argues that existing studies that use models to evaluate monetary policy rules have not paid enough attention to how well those models fit the data.

The results of our research project, concerning the robustness of simple monetary policy rules in models of the Canadian economy, are described in Côté et al. (2002). In that report, we examine several simple monetary policy rules in twelve private and public sector models of the Canadian economy. Our results indicate that none of the seven simple policy rules examined is robust to model uncertainty, in that no single rule performs well in all models. In fact, our results show that the performance of some of the simple rules, particularly interest-rate-smoothing rules and rules that have a high coefficient on the inflation gap, can deviate substantially from the optimal rule and can even be unstable in some models.[2] Our results are thus very different from those of Levin, Wieland, and Williams (1999), who argue that simple policy rules are not only robust but also generate essentially the same policy frontier as more complicated rules or rules that respond to a large number of variables. Unlike Ball (1999), we find that open-economy rules do not perform well. Although it is not robust, we find that a simple nominal Taylor-type rule that has a coefficient of 2 on the inflation gap and 0.5 on the output gap outperforms the other simple rules in a certain class of models.[3] But even in these models the loss-function value of this simple rule can deviate substantially from the optimal or base-case rule.

The objective of our current report is to examine and compare the paradigm, structure, and dynamic properties of the twelve private and public sector models of the Canadian economy that we used in our evaluation of the different simple monetary policy rules. To our knowledge, no

1. The results of our research effort were the subject of a Bank of Canada day-long conference on Taylor rules (see the Bank's Web site at http://www.bankofcanada.ca/workshop2001/).
2. The inflation gap is the difference between actual inflation and the target rate of inflation.
3. The output gap is the difference between actual output and potential output.

recent studies exist on the structure and properties of models of the Canadian economy used in policy analysis and projections as well as cross-model comparisons. The last time a large-scale study of that nature was conducted was in 1982, when the Bank and the Department of Finance held a day-long seminar on the structure and properties of nine major Canadian econometric models (O'Reilly, Paulin, and Smith 1983).

Since 1982, a number of institutions and private forecasters have built new models of the Canadian economy or made major improvements to their models. New research on economic theory, development of new algorithms to solve large non-linear systems of equations, and advancements in computer hardware and software have led to richer and more complex models. Our report describes the current state of the Canadian macroeconomic models used in policy analysis and projections and is a source document for research studies in macroeconomic modelling in Canada.

In this report, the description of the structure and dynamics of models of the Canadian economy, as well as the analysis of their key properties, is based on official publications, discussions that we had directly with the participants of our research project, responses to a questionnaire on model properties (Appendix A), and model responses to deterministic shocks provided by the participants. It is important to remember, however, that the models involved in this research project are subject to ongoing modification. With time, the versions described may change.

This study considers twelve private and public sector models of the Canadian economy. Five of them are maintained by private sector organizations. The models are:

- CEFM: Canadian Economic and Fiscal Model, Department of Finance Canada
- DRI: Data Resources Inc. of Canada[4]
- FOCUS: Policy and Economic Analysis Program (PEAP), Institute for Policy Analysis, University of Toronto
- FOCUS-CE: a version of FOCUS that incorporates model-consistent expectations
- INTERLINK: Organisation for Economic Co-operation and Development (OECD)
- LPM: Limited-Participation Model, Monetary and Financial Analysis Department, Bank of Canada
- M1-VECM: Vector-Error-Correction Model, based on the M1 aggregate, Monetary and Financial Analysis Department, Bank of Canada
- MTFM: Medium-Term Forecasting Model, Conference Board of Canada

4. Data Resources Inc. of Canada and Wharton Economic Forecasting Associates merged in 2001 under the name DRI-WEFA.

- MULTIMOD: International Monetary Fund
- NAOMI: North American Open-Economy Macroeconometric Integrated Model, Department of Finance Canada
- QPM: Quarterly Projection Model, Research Department, Bank of Canada
- WEFA: Wharton Economic Forecasting Associates

Our examination and comparison of the twelve participating models reveal important differences. These open-economy models can be grouped into two economic paradigms. The first one is the “conventional” paradigm (or Phillips curve paradigm) and the second is the “money matters” paradigm (in which inflation is determined mostly by monetary disequilibrium). Although most models are based on the conventional paradigm, there are nevertheless important differences within that paradigm. In particular, there are differences in the inflation process (linear/non-linear Phillips curve), the expectation processes (backward-looking and/or model-consistent expectations), the channels through which monetary policy affects the economy (short-term interest rates or the yield curve), and the sensitivity of output and inflation to changes in interest rates and the exchange rate.

To further understand the structure and properties of the twelve models of the Canadian economy (i.e., the way the models respond to different macroeconomic shocks), eight deterministic shocks (seven temporary and one permanent) are simulated in them. The seven temporary shocks are: a domestic demand shock, an external shock, a shock to commodity prices, a price-level shock, a wage growth shock, a shock to short-term interest rates, and a shock to the nominal exchange rate. The permanent shock is to long-term interest rates.

Because output and inflation dynamics depend in part on the specification of monetary policy, we have examined the dynamic properties of the various models when they use a common simple monetary authority reaction function, such as the one proposed by Taylor (1993). The simulation results of the eight deterministic shocks considered in our study reveal significant differences in the dynamic properties of the participating models. For example, the real GDP, CPI inflation, and exchange rate responses to a positive temporary commodity price shock differ largely across models. A positive commodity price shock leads to an increase in real GDP in the short term in DRI, FOCUS, FOCUS-CE, M1-VECM, MULTIMOD, NAOMI, QPM, and WEFA, but a decline in real GDP in INTERLINK and MTFM. The CPI inflation response to a commodity price shock is positive in most models, except for FOCUS. In response to that shock, the exchange rate appreciates in most models, with depreciation observed in CEFM, DRI, INTERLINK, MULTIMOD, and QPM.

The first four-quarter peak response of real GDP and CPI inflation in most models does not appear to be very sensitive to changes in interest rates, with CEFM and WEFA being the least sensitive to movements in interest rates. When the sensitivity of the exchange rate to movements in interest rates is considered, however, several models appear to be very responsive to changes in interest rates, except for DRI.

Interestingly, the exchange rate shock does not have a big impact on real GDP and CPI inflation in most models (except for QPM and, to a lesser extent, the M1-VECM, which are more responsive to this shock). Although most models have a well-developed external sector, the linkages between the exchange rate, output, and inflation may differ. Also, if most models are interpreting this shock not as a portfolio shock but as a fundamental shock, it is not surprising that the response of output and inflation is muted in those models.

Our comparison of the models' impulse-response functions with those of a vector autoregression (VAR) suggests that some models, especially MTFM, NAOMI, and CEFM, do a better job than the others in reflecting the typical response of the Canadian economy to shocks to real U.S. GDP and to commodity prices.

This report is organized as follows. In section 2, we examine the twelve models in detail, emphasizing the structure and dynamics of each. In section 3, we describe the properties of the various models when they are subjected to deterministic macroeconomic shocks. We compare some of the models' impulse-response functions with those of a VAR model in section 4. We conclude in section 5.

2. The Structure and Dynamics of the Models

2.1 CEFM

CEFM, a quarterly model, incorporates four sectors: households, firms, the government, and the external sector (Robidoux and Wong 1998; DeSerres, Robidoux, and Wong 1998). These sectors are described by a system of 113 estimated equations, using 61 economic and 52 fiscal variables. Consumers maximize utility over an infinite planning horizon subject to an intertemporal budget constraint. Consequently, consumption, which is disaggregated into purchases of consumer goods and residential investment, depends on aggregate wealth. As in MULTIMOD and QPM, some consumers are unable to borrow on the basis of future incomes because of liquidity constraints. Firms maximize profits and use labour, capital, and natural resources to produce goods with a Cobb-Douglas production technology. Demand for capital, in turn, determines investment in machinery and equipment and non-residential construction. The external sector consists of raw materials, finished products, and services that are exported and imported. The exchange rate is anchored by purchasing-power parity in the long run, and deviations from this value are determined by short-term uncovered interest rate parity. Compared with the other participating models, CEFM has an elaborate government sector, since one of the principal goals of the Department of Finance is to predict the federal government's revenue and spending prospects in considerable detail.

Inflation, in terms of wage increases, is modelled in CEFM using an augmented linear Phillips curve with backward-looking inflation expectations. A growth trend in total-factor productivity and an unemployment gap are added to those elements. The natural unemployment rate, in turn, is determined by an index of the generosity of the Employment Insurance Program and a variable approximating the level of unionization. The central bank's monetary policy instrument is the 90-day commercial paper rate. Other interest rates are determined through their term structure and they exert an influence on the economy's real variables, such as consumption and investment.

2.2 DRI

DRI is a large-scale quarterly econometric model of about 700 equations, with a large number of variables determined exogenously. It embodies several sectors, following closely the accounting framework of the National Income and Expenditure Accounts. The supply side of the DRI model is based on an explicit production function yielding potential output. The difference between actual and potential output is the primary channel through which demand and supply imbalances influence the adjustment of prices. The exchange rate is determined by the short-term uncovered interest rate parity condition and by movements in real commodity prices.

In DRI, the wage rate is determined in accordance with an extended Phillips curve specification as a function of backward-looking inflation expectations, productivity, and the gap between the actual and full-employment unemployment rate. Prices at the producer level are determined by industrial capacity utilization, the gap between the actual and full-employment unemployment rate, U.S. wholesale prices, and the exchange rate. The financial sector contains several interest rates and the money supply. The 90-day commercial paper rate is the monetary policy instrument. Longer-term interest rates are determined by the expectations hypothesis and they affect real variables such as consumption, housing, and investment.

2.3 FOCUS and FOCUS-CE

FOCUS is a quarterly macroeconomic model of the Canadian economy maintained by the Policy and Economic Analysis Program (PEAP) of the University of Toronto (Dungan 1998). The model consists of a system of 300 equations and identities. Like most of the other models we consider, FOCUS belongs to the neo-classical synthesis. This model's equations correspond to the IS-LM curve analytical framework and incorporate a non-linear Phillips curve with inflation expectations. Because of price/wage rigidity, there is a certain trade-off between price and quantity adjustment in the short term. In the long term, however, the model retains a neo-classical character, such that production depends on only real factors and not on variations in aggregate demand. Monetary policy is thus neutral in the long run. Given the large number of equations, the components of aggregate demand are modelled in considerable detail. Aggregate supply is formulated as a Cobb-Douglas production function with decreasing returns to scale. The model's LM curve defines equilibrium on the money market. Other financial markets are not modelled (Walras's Law). The foreign sector is described with the balance-of-payments curve, and short-term uncovered interest rate parity determines the exchange rate.

In FOCUS, wage changes are modelled using an augmented non-linear Phillips curve with backward-looking inflation expectations, to which productivity growth and the unemployment gap are added. Global inflation is thus determined as a markup added to the rate of wage growth. The consistent-expectations (CE) version of this model incorporates model-consistent expectations. The monetary policy instrument is the 90-day commercial paper rate.

2.4 INTERLINK

INTERLINK is the OECD's semi-annual model of the global economy (Richardson 1988). It follows the tradition of many other macroeconomic models of the neo-classical synthesis, combining short-term "Keynesian" features with long-term neo-classical properties. In particular, the presence of real and nominal rigidities in the wage- and price-setting behaviour generally implies that a protracted period of adjustment occurs before output and employment return to potential following a shock. The Canadian model has 26 equations and 280 identities. Aggregate demand is divided into twelve components: private and public consumption, investment in residential and non-residential construction, public sector investment, investment in stocks, and exports and imports of manufactured and non-manufactured goods and services. Aggregate supply is determined using a constant-returns-to-scale Cobb-Douglas production function, with capital and labour as production factors, with the exogenous trend growth rate of technical progress. The exchange rate is modelled by short-term uncovered interest rate parity.

In INTERLINK, the key price is the business sector GDP deflator, determined in an error-correction framework. In the long run, prices are determined as a constant markup over marginal costs, as calculated from the Cobb-Douglas production function. In the short run, however, prices are sensitive to demand pressures and may therefore deviate from trend unit costs. Demand pressures also enter through a capacity utilization term. There is also a short-run effect from import prices of non-manufactures, representing cost pressures from commodity prices. Wages (including non-wage compensation) come from a reduced-form bargaining model, and so depend on prices, the unemployment rate relative to the non-accelerating-inflation rate of unemployment (NAIRU), trend labour productivity, and the wedge between consumer and producer prices. Implicitly, NAIRU is a function of the growth rate of trend labour productivity. Most other prices feed off the business sector GDP deflator. For example, the consumption deflator depends on the business sector GDP deflator and import prices. Expectations are not specified anywhere in the model, except in the backward-looking exchange rate equation. Monetary policy operates through the 90-day commercial paper rate. Long-term rates have a slightly larger impact than short-term rates. Long-term interest rates affect business investment and short-term interest rates affect consumption. Money growth has no effect in the model and monetary policy does not have a permanent effect on either the level or the growth rate of real GDP.

2.5 LPM

The limited-participation model (LPM), based on the money matters paradigm, is a calibrated general-equilibrium quarterly model optimally derived from microfoundations (Hendry, Ho, and Moran 2001). It decomposes aggregate demand into consumption and investment. Both of these components derive from equations that incorporate purely model-consistent behaviour. In particular, households choose between three classes of consumption goods, two of which are domestic products (tradable and non-tradable), and the third produced abroad. Monetary policy actions affect the real economy through frictions generated by agents' portfolio decisions. More precisely, rigidities in adjusting money balances are the main source of the short-run non-neutrality of monetary policy. This is unlike most of the other participating models, in which the short-term impact of monetary policy on the economy's real variables works over some form of price or wage rigidity. In LPM, prices are perfectly flexible in the short run, implying that the aggregate supply function is vertical. Because firms incur debt to finance wages, however, variations in the interest rate alter supply conditions, causing the aggregate supply curve to shift.

2.6 M1-VECM

The vector-error-correction model (M1-VECM) is based on the money matters paradigm (Adam and Hendry 2000). This quarterly model comprises four key equations, in which variations in money, output, prices, and interest rates depend on the lagged values of these same variables, on a series of exogenous variables, and on the “money gap” (the difference between the money supply and the estimated long-term demand for money). The M1-VECM assigns an active role to money in the sense that changes in the supply of money, relative to the estimated long-term demand for it, cause variations in output and in prices in the short term, but only in prices in the long term. Although the external sector is not explicitly modelled, the exchange rate is determined by uncovered interest rate parity in the short run and anchored in the relative condition of purchasing-power parity in the long run.

In this model, inflation is measured by core CPI. The money gap in the previous period and lagged variables for the rate of monetary expansion increase inflation appreciably. This model also accounts for the lagged output gap, and previous variations in the interest rate, in inflation, in the exchange rate, and in U.S. interest rates. The monetary policy instrument is the overnight rate, and the actions of the monetary authorities are transmitted over the slope of the yield curve (the overnight rate minus the yield on bonds with maturities of 10 years).

2.7 MTFM

The Conference Board of Canada’s MTFM is a large, quarterly, input-output model that comprises about 350 equations. It is estimated on a sample period beginning in 1981. In this model, aggregate demand consists of 70 components. Aggregate supply is not explicitly modelled, although market conditions can be extrapolated from capacity utilization rates by industrial sector. The exchange rate is explained by both uncovered short-term interest rate parity and by commodity price variations.

Global inflation is modelled in MTFM using a bottom-up approach based on more than 100 different prices, the weights of which are drawn from input-output tables. Inflationary pressures are established at three main stages of the goods-production process (raw materials, intermediate goods, and finished goods). Thus, three sets of prices are to be determined: the price of raw materials, the price of intermediate goods, and the price of finished goods or final demand. At each production stage, price is determined as a markup added to the costs of inputs (the marginal cost of labour, the cost of capital, materials, and changes to import prices). The markup, in turn, is influenced by market conditions; i.e., net aggregate demand as approximated by the utilization rate of production capacity or by the gap between aggregate output and its trend. Note that, in MTFM, inflation expectations are backward looking and, in general, inflation is more sensitive to changes in supply than to changes in aggregate demand. Finally, the central bank uses the treasury bill rate as its monetary policy instrument. Other interest rates (e.g., bonds, mortgages) are transmitted over the term structure of interest rates and also play a role, though short-term rates have the greatest impact on aggregate demand. Money is neutral in the long term.

2.8 MULTIMOD

MULTIMOD is the International Monetary Fund's annual model of the global economy (Laxton et al. 1998).[5] It includes individual models for each of the seven largest industrialized countries (including Canada), one model for the remaining fourteen industrialized countries, one model for developing countries, and one model for countries in transition. Like QPM, MULTIMOD consists of a set of dynamic relationships that trace the path leading from the starting conditions to the implicit steady-state, or long-term equilibrium, solution. In MULTIMOD, consumer behaviour is modelled on the Blanchard (1985)–Weil (1989)–Buiter (1988) paradigm, which assumes that economic agents plan within a finite time horizon. Consumers' lifespans are unknown, and they must plan their consumption and savings in light of this uncertainty. This paradigm is extended with the addition of remuneration profiles that vary across age groups and imply different marginal propensities to consume over the life cycle. Moreover, consumers are confronted with liquidity constraints that restrict their ability to borrow on the basis of future income. Thus, in MULTIMOD, aggregate consumption is obtained by summing consumption depending on permanent income with that depending on disposable income.

MULTIMOD models investment with Tobin's Q theory, which specifies that the desired level of investment may exceed the steady-state level to the extent that the expected marginal productivity of capital is greater than its replacement cost. The specification of the foreign sector is relatively conventional. Imports are determined by their relative prices and by a measure of domestic activity calibrated on the basis of input-output tables.[6] Exports are modelled to be compatible with other countries' imports. In the short term, exchange rates and interest rates are linked by uncovered interest rate parity adjusted for risk premiums. As in QPM, real domestic interest rates are connected to exogenous foreign values adjusted for risk premiums, while the steady-state real

5. The model is estimated for the 1970–2000 period.
6. MULTIMOD is a macroeconomic model of the world economy. The share of domestic demand supplied by foreign production is established on the basis of input-output tables specific to each country.

exchange rate is determined endogenously to generate the trade balance flows necessary for overall equilibrium in the economy's stock of assets.

MULTIMOD models fundamental inflation (defined as core CPI inflation) similarly to QPM, using a non-linear Phillips curve with inflation expectations that are both backward looking and forward looking, except that the disequilibrium factor is approximated by the unemployment gap.[7] Global inflation (that is, the overall increase in the CPI), includes changes in the prices of imported manufactured goods, the rate of growth of the price of oil, previous variations in global inflation, and the rate of increase in the core CPI. Expected inflation, in turn, is a linear combination of previous values of the growth rate of the CPI, the core CPI, and model-consistent values for those two measures. In MULTIMOD, monetary authorities act on the nominal short-term interest rate (i.e., the three-month treasury bill rate) to achieve their inflation-control target.

2.9 NAOMI

The North American Open-Economy Macroeconometric Integrated Model (NAOMI) includes six behavioural equations and 18 identities (Murchison 2001). For the sample period, 1973Q1–2000Q1, the equation system is estimated simultaneously using the full-information maximum-likelihood (FIML) procedure. The model's endogenous variables include output growth, inflation, the real exchange rate, the yield curve, and long-term interest rates. Variables exogenous to the model include potential output, U.S. variables, commodity prices, and the budget balance for the entire public sector. As with the M1-VECM, NAOMI defines aggregate demand in terms of a single equation (an IS curve). In particular, output growth is modelled on increases in potential output, output growth in the United States, and changes in the yield curve. Also incorporated are variations in the real exchange rate, relative non-energy commodity prices, and the ratio of the budget balance of the entire public sector to nominal potential GDP. Although the foreign sector is not explicitly modelled, the exchange rate is determined in the long run by the relative purchasing-power-parity condition and plays a leading role in the adjustment of the economy following external and domestic shocks.

NAOMI explains inflation by price-level adjustments in response to backward-looking inflation expectations, by the level and variation of the output gap, by changes to relative commodity prices, and by movements in the real exchange rate. Variations in the output gap are introduced to capture the predictive information it contains concerning the future level of potential output. As with QPM and the M1-VECM, the actions of the monetary authorities are transmitted over the

7. In MULTIMOD, the backward-looking and forward-looking elements are weighted 0.75 and 0.25, respectively.

slope of the yield curve. Monetary policy affects the real economy in the short run because of nominal rigidities, and price flexibility ensures its neutrality in the long run.

2.10 QPM

The Bank of Canada uses the Quarterly Projection Model (QPM) for policy analysis and to generate economic projections (Black et al. 1994; Coletti et al. 1996). QPM can be considered a system that consists of two calibrated models. The first—the steady-state or long-term equilibrium model (SSQPM)—is based on the Blanchard (1985)–Weil (1989) paradigm with overlapping generations. It is used to study the determinants of long-term equilibrium in the economy and the permanent effects of economic shocks or policy changes. The second model, QPM, consists of a set of dynamic relationships that trace the paths leading from the starting conditions to the implicit steady-state solution, or long-term equilibrium.

QPM is designed to explain the behaviour of households, firms, foreigners, government (all levels of the public sector), and the central bank. These agents' optimization decisions interact to determine the final levels of four key stocks: household financial wealth, capital, public debt, and net foreign assets. These stocks, in turn, are key determinants of related flows, such as consumption expenditure, savings, investment spending, government outlays and revenues, and the external balance. In this model, the exchange rate plays a key role in the monetary policy transmission mechanism by promoting equilibrium between aggregate demand and supply. In the short term, the exchange rate and interest rates are linked by uncovered interest rate parity. In the steady state, real domestic interest rates depend on their exogenous external analogues adjusted for risk premiums, and the real exchange rate adjusts endogenously to generate the trade-balance flows required for global equilibrium in the economy's stock of assets.

QPM describes inflation (in terms of core CPI inflation) using a non-linear Phillips curve with inflation expectations that are both backward looking and model-consistent.[8] This non-linearity endows QPM with the property that price adjustments are larger under conditions of excess demand on goods markets than under excess supply. The monetary policy instrument is the 90-day commercial paper rate, while actions of the monetary authorities are propagated over the slope of the yield curve, as in M1-VECM and NAOMI.

8. In QPM, the backward-looking and model-consistent elements are weighted 0.7 and 0.3, respectively.

2.11 WEFA

Like most other models, WEFA formalizes the behaviour of four groups of economic agents: consumers, firms, budgetary authorities, and monetary authorities. It disaggregates global demand into several components. There are about 10 equations for consumption and three for investment. A permanent income variable partially explains consumers' behaviour. As in FOCUS, MTFM, M1-VECM, and NAOMI, the concept of potential output is determined exogenously. As for the financial variables, interest rates and the exchange rate are linked in the usual manner to short-term uncovered interest rate parity. This is true of nearly all the models examined in this study.

As in MTFM, the WEFA model explains global inflation using a bottom-up approach based on numerous different prices. Inflationary pressures in the economy arise at various stages of the goods-producing process. Wage increases do not affect prices directly, but rather indirectly over variables for labour income. In WEFA, inflation expectations are of the backward-looking type. The central bank's monetary policy instrument is the three-month treasury bill rate. Other interest rates (e.g., bonds, mortgages) enter over the term structure of interest rates, but do not play a role in the determination of real variables. As in the case of the other models, money is neutral in the long term.

3. Deterministic Shocks with the Original Taylor Rule

In this section, we examine the dynamic properties that the various models display when they use a simple reaction function by monetary authorities, such as the one proposed by Taylor (1993). The Taylor rule is a behavioural rule that monetary authorities apply when inflation diverges from the inflation-control target and output diverges from its potential level. In another study (Côté et al. 2002), we examine a variety of alternative simple monetary policy rules. It is possible that the parameters of various models are not invariant to changes in monetary policy rules (Lucas's critique). Nonetheless, in our study we assume invariance of the parameters.

The original Taylor reaction function for a given inflation-control target, π_t^T, is defined by equation (1)[9]:

$$r_t = r_t^* + 0.5(\pi_t - \pi_t^T) + 0.5(y_t - y_t^p) , \tag{1}$$

where r_t is the real interest rate on 90-day commercial paper, r_t^* the equilibrium real interest rate on 90-day commercial paper, $\pi_t - \pi_t^T$ the inflation gap, and $y_t - y_t^p$ the output gap.[10]

9. The value of 0.5 for the coefficients was inferred by Taylor from the properties of large-scale models of the U.S. economy.

10. π_t is the year-over-year inflation rate, π_t^T is the corresponding inflation target, $(\pi_t - \pi_t^T)$ is the inflation gap, y_t is the log of real output, y_t^p is the log of real potential output, and $(y_t - y_t^p)$ is the output gap.

The immediate means, or instrument, whereby monetary authorities act on the economy is the nominal interest rate, i_t, which is determined by the Fisher equation. The original Taylor rule can thus be expressed in nominal terms using the following equation:

$$i_t = i_t^* + 1.5(\pi_t - \pi_t^T) + 0.5(y_t - y_t^P) , \qquad (2)$$

where i_t is the nominal interest rate on 90-day commercial paper and i_t^* = the equilibrium nominal interest rate on 90-day commercial paper.

Equations (1) and (2) represent the monetary authorities' reaction function, as proposed by Taylor (1993).

In our study, we seek to understand and compare the properties of the various models. Because output and inflation dynamics depend in part on the specification of monetary policy, we specify a common policy reaction function. The original Taylor rule is thus imposed as the baseline reaction function in each model. Within each of the models, the original Taylor rule implies that monetary authorities choose a nominal interest rate that includes a combination of the real interest rate and anticipated inflation.[11] This allows them to attain their target given the structure and dynamics of their model.

To further understand the structure and properties of the twelve models of the Canadian economy (i.e., the way the models respond to different macroeconomic shocks), eight deterministic shocks are simulated in the models: seven temporary and one permanent. We then run dynamic simulations to examine how equilibrium is re-established when the behaviour of monetary authorities is described by the original Taylor rule. The seven temporary shocks are: a domestic demand shock, an external shock, a shock to commodity prices, a price-level shock, a wage growth shock, a shock to nominal short-term interest rates, and a shock to the nominal exchange rate. The permanent shock is to long-term interest rates. These deterministic shocks are described in Table 1 and analyzed in detail in this section. Several of the shocks require explanation. The price shock, for example, represents a temporary change to firms' profit margins. The temporary shock to short-term interest rates represents a modification of the inflation-control target, and the permanent shock to long-term interest rates represents a permanent change in the term premium. The temporary shock to the exchange rate represents a temporary loss of confidence by investors in the Canadian economy.

11. The definition of the monetary policy instrument differs across models. In some models, the 90-day commercial paper rate is used, whereas other models define it by the three-month treasury bill rate. This difference has, however, no implications for the analysis of dynamic model properties.

Table 1: Model Shocks

Shock	Description	Details
1. Domestic demand	A 4-quarter transitory increase in the levels of consumption and investment at the same time.	Shock to consumption and investment: Q1: 1.00%, Q2: 0.75%, Q3: 0.50%, Q4: 0.25%; i.e., the levels of consumption and investment increase by 1 per cent at the 1-quarter horizon and then progressively come back to control (there is no permanent increase in the level of output).
2. External demand	A 4-quarter transitory increase in the level of real U.S. output with endogenous responses of U.S. inflation and interest rate, and world commodity prices.	Shock to U.S. GDP: Q1: 1.00%, Q2: 0.75%, Q3: 0.50%, Q4: 0.25%. Endogenous response of U.S. inflation. Endogenous response of U.S. short-term interest rate. Endogenous response of world commodity prices.
3. Commodity prices	An 8-quarter transitory increase in the level of real commodity prices with endogenous responses of U.S. output, inflation and interest rate.	Shock to commodity prices: Q1: 4.00%, Q2: 3.50%, Q3: 3.00%, Q4: 2.50%, Q5: 2.00%, Q6: 1.50%, Q7: 1.00%, Q8: 0.50%. Endogenous response of U.S. output. Endogenous response of U.S. inflation. Endogenous response of U.S. short-term interest rate.
4. Consumer price	A 4-quarter transitory increase in the level of CPI excluding food, energy, and indirect taxes.	Shock to CPI: Q1: 1.00%, Q2: 0.75%, Q3: 0.50%, Q4: 0.25%.
5. Wage growth	A 4-quarter transitory increase in nominal-wage growth.	Shock to wage growth: Q1: 1.00 percentage point, Q2: 0.75 of a percentage point, Q3: 0.50 of a percentage point, Q4: 0.25 of a percentage point.
6. Short-term interest rate	A 4-quarter transitory increase in the short-term interest rate.	Shock to short-term interest rate: Q1: 100 basis points, Q2: 75 basis points, Q3: 50 basis points, Q4: 25 basis points.
7. Long-term interest rate	A permanent change in the term premium.	Shock to long-term interest rate: Permanent increase of 100 basis points.
8. Nominal exchange rate depreciation	A 4-quarter temporary increase in the risk premium on the exchange rate (a depreciation).	Shock to exchange rate: Q1: 1.00%, Q2: 0.75%, Q3: 0.50%, Q4: 0.25%.

We asked each participant in our project to generate a new control solution for their model when the monetary authorities' behavioural rule is approximated by the Taylor rule. The shocks are run on the models initiating from this new control solution. This allows us to evaluate the impact of the shocks in isolation. The shocks are introduced into the dynamic simulations when the economy is in steady-state equilibrium. Keep in mind that the temporary shocks being examined have no impact on the long-run equilibrium of the models. These dynamic simulations thus allow us to see how equilibrium is re-established subsequent to temporary shocks and to use the observed responses to better understand the behaviour and dynamic structure of the various models. They also allow us to see how the original Taylor behavioural rule determines policies under these conditions.

3.1 A temporary domestic demand shock

We first introduce a temporary shock to aggregate demand into eleven of the twelve models.[12] Over four quarters, the level of consumption and investment increases by 1.00, 0.75, 0.50, and 0.25 per cent, respectively. Figures C.1a to C.1d in Appendix C illustrate the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate in the eleven models for 24 quarters following the beginning of the dynamic simulation.[13]

As expected, the domestic demand shock causes inflation to increase in the short term. In CEFM and MTFM, however, the price increases are particularly small. To the extent that inflation increases above the target trajectory and output remains greater than potential output, monetary authorities raise the short-term interest rate by about 25 basis points during the first quarter. CEFM and WEFA show negligible interest rate hikes during the first four quarters, while these increases are particularly high in QPM, DRI, INTERLINK, and NAOMI during that same period. The greater interest rate increases in QPM, DRI, INTERLINK, and NAOMI are consistent with the particularly strong responses of inflation (and the persistence of the output response in DRI) in those models. The non-linearity of the Phillips curve in QPM, as well as the large currency depreciation, may explain the strong increase in inflation in that model. As for NAOMI and INTERLINK, the cause may be the steeper slope of the Phillips curve in those models.

In certain models, the impact of the temporary demand shock on output extends beyond the fourth quarter, either by creating secondary cycles (NAOMI and QPM) or by generating quasi-

12. The dynamic properties of LPM are omitted because that model does not handle the shocks considered in this study.

13. In our study, the exchange rate is defined as the nominal bilateral Can$/US$ exchange rate (Canadian dollar per U.S. dollar). Therefore, an increase in the exchange rate means a depreciation of the Canadian currency vis-à-vis the U.S. currency.

permanent effects (WEFA and DRI). Owing to the interest rate increase and the appreciation of the currency, real GDP and inflation eventually return to their reference values between the twelfth and sixteenth quarters, on average, except in the DRI and WEFA models for real GDP and, in the WEFA model only, for inflation.

3.2 A temporary external shock

The second shock we introduce into the eleven models is a temporary external shock. Real U.S. GDP is increased by 1 per cent, 0.75 per cent, 0.50 per cent, and 0.25 per cent, respectively, during the first four quarters. Note that this temporary shock incorporates the endogenous response of some U.S. macroeconomic variables, such as inflation and short-term interest rates, as well as the endogenous response of commodity prices.[14] Figures C.2a to C.2d in Appendix C show the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate in the eleven models for 24 quarters following the beginning of the dynamic simulation (the figures also show the impulse-response functions of the VAR model, described in detail in section 4).

As with the domestic demand shock, this positive external shock stimulates the Canadian economy, though to a lesser extent, given that our exports to the United States represent only a fraction of the demand for Canadian output. We notice that the temporary external shock's impact on domestic output dissipates soon after the fourth quarter. This shock is particularly persistent in DRI and INTERLINK, and generates secondary cycles in the other models. The temporary increase in foreign demand exerts upward pressure on domestic inflation. Monetary authorities react by increasing the short-term interest rate by about 10 to 20 basis points over the first year, except in QPM, NAOMI, and INTERLINK, where the increases are much more pronounced. As a result of a large increase in inflation, the interest rate increase is particularly steep and persistent in QPM. The magnitude of the direct and indirect impact on prices of the pronounced depreciation and the characteristics of QPM's Phillips curve contribute to the persistence of inflation in that model when the original Taylor rule is used. In the other models, inflation returns to the target trajectory around the twelfth quarter. The strength of the CPI inflation response in the case of WEFA is surprising, considering that this model shows little response in the case of real Canadian GDP.

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14. As a result of a temporary increase in U.S. GDP, the U.S. VAR model predicts an increase in U.S. output up to eleven quarters and an increase in inflation and U.S. interest rates during the first eight quarters. The endogenous variables gradually revert to their steady-state values afterwards. See Appendix B for more information on the U.S. VAR used to generate the endogenous responses.

3.3 A temporary shock to commodity prices

The third shock we introduce into the eleven models is a temporary shock to commodity prices over eight quarters. During the first quarter, commodity prices increase 4 per cent, during the second 3.5 per cent, during the third 3 per cent, and so on, until during the eighth they increase 0.5 per cent, returning to their initial value by the ninth quarter. This shock incorporates the endogenous VAR response of several U.S. macroeconomic variables, such as real GDP, inflation, and short-term interest rates.[15]

The short-term impact on real Canadian GDP could be positive, since this shock implies an improvement in Canada's terms of trade that boosts the value of exports and, through its positive impact on wealth, stimulates consumption. This assumes, however, that the increase in commodity prices is not offset by declines in the volume of our commodity exports to the United States. Indeed, real U.S. GDP tends to decline in response to an increase in commodity prices. Ultimately, the net effect on the Canadian economy remains an empirical question.

This shock may also have a positive impact on inflation, directly entering into the CPI and indirectly affecting prices because of the expansion of economic activity, and possibly contributing to inflation expectations. The effect on inflation should only be temporary, however, since monetary authorities will act to counter the shock's impact on inflation.

Figures C.3a to C.3d in Appendix C show the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate to a temporary increase in commodity prices in the eleven models for 24 quarters following the beginning of the dynamic simulation (the figures also show the impulse-response functions of the VAR model, described in detail in section 4). This shock generates a moderate increase in real GDP through eight quarters in most of the models, while MTFM and INTERLINK show a decline. This shock drives a temporary increase in inflation in all but the FOCUS model. We also notice that, in general, this shock has a greater impact on prices than on quantities.

In the short term, monetary authorities respond by raising the interest rate and then gradually lowering it as the inflation and output gaps close. The interest rate increases vary substantially from one model to the next, reflecting differences in inflation and output gaps among models. Overall, the output and inflation gaps close between the twelfth and sixteenth quarters, except in the INTERLINK and WEFA models for output. In fact, the response of GDP is particularly

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15. Subsequent to a temporary increase in commodity prices, the U.S. VAR model predicts a fall in U.S. output for the first 16 quarters and an increase in inflation and U.S. interest rates during the first 10 quarters. The endogenous variables gradually revert to their steady-state values afterwards. See Appendix B for more information on the U.S. VAR used to generate the endogenous responses.

persistent in these models. Moreover, in contrast to the other models, DRI, INTERLINK, and QPM predict a large depreciation of the Canadian currency. In QPM, the depreciation of the Canadian currency is particularly persistent, because real U.S. GDP tends to decline in response to this shock, and in QPM the Canadian dollar must depreciate to stimulate enough Canadian exports to sustain the Canadian foreign debt at a constant level in steady state.

3.4 A temporary shock to price levels

The price-level shock is a temporary increase in the CPI, excluding food, energy, and the effect of indirect taxes. The price index increases by 1 per cent, 0.75 per cent, 0.50 per cent, and 0.25 per cent, respectively, during the first four quarters, returning to its original level in the fifth quarter. Figures C.4a to C.4d show the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate in the eleven models for 24 quarters following the beginning of the dynamic simulation.

This shock can be interpreted as a temporary increase in firms’ profit margins. Although this shock is temporary, it may have repercussions on inflation expectations, driving inflation away from its target trajectory. Monetary authorities must therefore act to counter the shock’s impact on inflation expectations and to attenuate secondary upward pressures on prices originating from the currency depreciation.

Over the course of the first quarter, this shock causes an increase in inflation of about 3–4 percentage points (except in QPM and MULTIMOD) and a fall in output (only the M1-VECM yields a short-term increase in output). Monetary authorities react by raising interest rates as of the first quarter between 50 to 275 basis points, depending on the models. In the M1-VECM and MULTIMOD, interest rates remain practically unchanged over the horizon of the simulation, though they increase considerably in QPM and WEFA. The rise in interest rates puts downward pressure on output and inflation. The fall-off in real GDP from its potential level and the decline in inflation result in interest rate reductions as of the fourth quarter. Eight quarters after the beginning of the shock, inflation and interest rates have practically returned to their control levels, while output fluctuates somewhat before returning to its initial path.

3.5 A temporary shock to wage growth

The fifth shock we introduce into the models is a temporary shock to the growth rate of nominal wages. During the first quarter, these increase 1 per cent, during the second 0.75 per cent, during the third 0.50 per cent, and during the fourth 0.25 per cent. Figures C.5a to C.5d illustrate the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate in the nine models for 24 quarters following the beginning of the dynamic simulation.[16]

This shock can be interpreted as a standard Keynesian “wage-push” shock, in which wage dynamics generate inflation. We assume that this shock raises real wages beyond the marginal productivity of labour (i.e., the equilibrium condition). After a short lag, this wage-push shock generates an increase in inflation and a fall in output in all models. Monetary authorities react by raising the short-term interest rate, which increases by about 25 basis points during the first quarter and continues to rise thereafter. It eventually peaks 75 basis points above the control value in MULTIMOD and 225 basis points higher in QPM. Over the second year of the simulation, the interest rate gradually begins to converge towards its starting value, to the extent that inflation and output return to their initial paths. After 24 quarters, inflation returns to the steady-state value in nearly all models. We observe, however, that the response of inflation is particularly persistent in FOCUS, QPM, and MTFM, while output continues to move away from the steady-state solution in WEFA.

3.6 A temporary shock to nominal short-term interest rates

The sixth shock we introduce into the eleven models is a temporary increase in nominal short-term interest rates, which increase by 100 basis points, 75 basis points, 50 basis points, and 25 basis points, respectively, during the first four quarters. Figures C.6a to C.6d illustrate the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate for the eleven models over a 24-quarter time horizon.

Table 2 presents the peak response in the first four quarters of real GDP, CPI inflation, and the exchange rate following a temporary increase in short-term interest rates. As the table shows, the peak response of real GDP and CPI inflation in most models does not appear to be very sensitive to changes in interest rates, with CEFM and WEFA being the least sensitive to movements in interest rates. When the sensitivity of the exchange rate to movement in interest rates is considered, however, several models appear to be very responsive to changes in interest rates, except for DRI.

16. The impulse-response functions of NAOMI and the M1-VECM are omitted because they do not include wages.

Table 2: Peak Response to a Transitory Change in Short-Term Interest Rates

	Least sensitive (Peak response in the first four quarters is less than 0.25%)	**Moderately sensitive** (Peak response in the first four quarters is between 0.25% and 0.5%)	**Most sensitive** (Peak response in the first four quarters is more than 0.5%)
Real GDP	CEFM, WEFA, FOCUS-CE	INTERLINK, NAOMI, MULTIMOD, QPM, M1-VECM, DRI	FOCUS, MTFM
CPI inflation	CEFM, DRI, QPM, INTERLINK, MTFM, MULTIMOD, WEFA	FOCUS, FOCUS-CE, NAOMI	M1-VECM
Exchange rate	DRI	CEFM, QPM, WEFA	FOCUS, FOCUS-CE, INTERLINK, MTFM, MULTIMOD, NAOMI, M1-VECM

Note: Short-term interest rates are increased by 100 basis points, 75 basis points, 50 basis points, and 25 basis points, respectively, during the first four quarters. Results for the LPM were not available.

This shock can be interpreted as a temporary reduction of the inflation-control target. The increase in the real interest rate has a negative impact on the output gap and on inflation. The reaction of monetary authorities, which is artificially maintained over the course of the first year, accelerates the decline in output and in inflation. After approximately four quarters, the fall in inflation, combined with the excess supply generated by the initial shock, prompts monetary authorities to reduce interest rates below their initial level. Between the twelfth and sixteenth quarters, output, inflation, and the interest rate have returned to their control values on average, except in INTERLINK and the M1-VECM (note the substantial appreciation of the Canadian currency in these models at the end of the simulation horizon).

3.7 A permanent shock to long-term interest rates

This shock is a permanent increase of 100 basis points in the long-term interest rate for the duration of the simulation. Figures C.7a to C.7d illustrate the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate for the nine models.[17]

17. The impulse-response functions of NAOMI and the MI-VECM are omitted because this shock has no effect in these models: short-term interest rates respond one-for-one to changes in long-term interest rates, leaving the slope of the yield curve unchanged.

This shock can be interpreted as a permanent increase in the term premium, attributable to an increased risk of inflation that may result from uncertainty surrounding the probability that a part of the central government's debt will be monetized.[18]

Despite the fact that short-term interest rates are below their control values, the increase in the long-term interest rate causes real GDP to fall in all models. After a short delay, inflation drops relative to its steady-state value, except in the case of MTFM. Monetary authorities react with additional reductions to interest rates. The most pronounced declines occur in models that show the greatest fall in real GDP and in inflation, such as QPM, FOCUS, and FOCUS-CE. It is of interest that the substantial appreciation of the Canadian currency within QPM and FOCUS after the eighth quarter of simulation explains a large share of the apparently permanent decline in real GDP in QPM, and in inflation in FOCUS and FOCUS-CE. After a 24-quarter simulation, the output gap has practically closed in all models except QPM and CEFM. The fall in inflation relative to its control value does not seem to be absorbed within the simulation time frame in FOCUS and FOCUS-CE.

3.8 A temporary shock to the nominal exchange rate

The final shock we introduce into the eleven models is a temporary exchange rate shock over four quarters. During the first quarter, the Canadian currency depreciates by 1 per cent relative to that of the United States, during the second by 0.75 per cent, during the third by 0.50 per cent, and during the fourth by 0.25 per cent, finally returning to its original value during the fifth quarter. Figures C.8a to C.8d show the impulse-response functions of real GDP, inflation, the nominal short-term interest rate, and the nominal exchange rate, within the eleven models for 24 quarters following the beginning of the dynamic simulation.

Table 3 presents the peak response in the first four quarters of real GDP and CPI inflation following a temporary depreciation in the exchange rate. As the table shows, the exchange rate shock does not have a big impact on real GDP and CPI inflation in most models (except for QPM and, to a lesser extent, the M1-VECM, which are more responsive to this shock).

18. The reasons why the term premium may increase are complex. According to the liquidity-preference theory, the term premium primarily reflects inflationary risks (second moment).

Table 3: Peak Response to a Transitory Change in the Exchange Rate

	Least sensitive (Peak response in the first four quarters is less than 0.25%)	**Moderately sensitive** (Peak response in the first four quarters is between 0.25% and 0.5%)	**Most sensitive** (Peak response in the first four quarters is more than 0.5%)
Real GDP	CEFM, DRI, FOCUS, INTERLINK, WEFA, MULTIMOD, NAOMI, FOCUS-CE	MTFM	QPM, M1-VECM
CPI inflation	DRI, FOCUS, INTERLINK, MTFM, MULTIMOD, NAOMI, M1-VECM	CEFM, FOCUS-CE, WEFA	QPM

Note: The Canadian currency relative to that of the United States depreciates by 1 per cent in the first quarter, by 0.75 per cent in the second, 0.50 per cent in the third, and 0.25 per cent in the fourth. Results for the LPM were not available.

This shock can be interpreted as a temporary loss of confidence by investors in assets denominated in Canadian dollars. Since this shock represents a change in investors' preferences, and not a change in economic fundamentals, monetary authorities need to increase the interest rate to counter the effects of the depreciation of the Canadian dollar on domestic prices. Depending on the model, the impact of the depreciation will most likely be transmitted over two channels. The first, a direct effect, works over an increase in import prices and the second, indirect, works over an increase in net exports.

In all models, the temporary depreciation of the Canadian currency induces an increase in real GDP and inflation over the course of the first year of the simulation. As monetary authorities raise the interest rate, the stimulative impact of the depreciation is quickly dampened. During the first year, interest rates rise by less than 25 basis points, diluting the stimulus created by the shock. Between the twelfth and sixteenth quarters, real GDP, inflation, interest rates, and exchange rates nearly regain their initial level, except in the case of output and the exchange rate in WEFA and in all variables in QPM.

This temporary exchange rate shock suggests output and inflation responses that vary widely between the models. The response of the exchange rate, in particular, is higher in QPM and WEFA. These two models, however, show very different responses for output, inflation, and the interest rate. The direct and indirect impact of the currency depreciation on prices appears particularly pronounced in QPM relative to the other models. In QPM, non-linearity and forward-looking expectations in the Phillips curve may partially explain these results.

4. Comparison of the Models' Impulse-Response Functions with those of a Vector-Autoregressive Model

Ideally, we would be able to subject each model to a rigorous and detailed examination to determine how much weight to assign the information it yields for our evaluation of monetary policy rules. The number and diversity of the models, however, impose severe constraints on what is achievable in that area. Nevertheless, to explore the extent to which the models under consideration reflect some of the characteristics of the Canadian economy, we calculate the distance by comparing some of the impulse-response functions of the models with those generated by a simple VAR model. We then use this calculation to rank the various models. The ranking is used to perform a robustness check on the results of our evaluation of the monetary policy rules (Côté et al. 2002).

We use the VAR model to estimate the historical response of CPI inflation, real Canadian GDP, and the Can$/US$ exchange rate to a shock to real U.S. GDP and a shock to commodity prices. We select these shocks because their identification is relatively uncontroversial. It is generally acknowledged that these variables can be assumed exogenous with respect to the Canadian economy. That is the hypothesis we retain for identification.[19] The advantage of using a VAR model as the benchmark for comparison is that it is relatively unconstrained and can thus better reflect the characteristics of the data than models that have more structure built in to yield more theoretical interpretations. To facilitate comparison of the VAR model's responses with those of the other models, we assume, as in section 3, that short-term interest rates are determined by the original Taylor rule.

Vectors of the model's endogenous and exogenous variables, respectively, can be written as follows:

$$Z_t = \begin{bmatrix} \Delta r_t \\ \Delta y_t \\ \Delta p_t \\ \Delta e_t \end{bmatrix} \text{ and } X_t = \begin{bmatrix} \Delta y_t^{US} \\ \Delta pcom_t \end{bmatrix},$$

where r_t is the real interest rate on the 90-day commercial paper rate, y_t is the logarithm of real Canadian GDP, p_t is the log of the Canadian consumer price index, e_t is the log of the Can$/US$

19. The results of exogeneity tests that we ran confirm this assumption. These results are available on request.

exchange rate (Canadian dollar per U.S. dollar), y_t^{US} is the log of real U.S. GDP, and $pcom_t$ is the log of the Bank's commodity price index. Δ indicates that we have taken the first differences of these variables. The data are from Statistics Canada and the Bank. Our sample ends in the fourth quarter of 2000 and starts in the first quarter of 1965, the beginning of the period that covers our series of commodity prices.[20]

The model we estimate can be written as follows:

$$Z_t = cst + \sum_{i=1}^{q} \beta_i Z_{t-i} + \sum_{i=1}^{q} \Pi_i X_{t-i+1} + \varepsilon, \tag{3}$$

where cst is a vector of constants, β_i and Π_i are vectors of coefficients, and ε_t is a vector of error terms. The number of lags, q, is determined using a likelihood-ratio test applied to a model that has a long-lag structure (maximum of eight lags), from which we eliminate one lag at a time, retaining four lags.

We simulate the response of Z_t to shocks to the variables contained in X_t. The variables y_t^{US} and $pcom_t$ are assumed exogenous with respect to Z_t, but cannot be assumed to be independent of each other. For example, we expect that, typically, an increase in real U.S. GDP will put upward pressure on commodity prices. To account for the endogenous response of one of these variables to a shock that affects the other, we run simulations on the VAR, described in Appendix B. These shocks are of the same magnitude as those run with the other models. We generate a 95 per cent confidence interval around the VAR's estimated responses to the various shocks using bootstrapping-type simulations.

Our approach has several limitations. First, even though the VAR is a good approximation of the historical relationship between the affected variables, it is an approximation. Second, while it is calibrated to closely reflect the importance of the various components to the Canadian economy, the commodity price index we use may differ from that used in the other models. For example, some models contain several prices, or price indexes, for commodities, which may appear in different equations. The shock to real U.S. GDP is not affected by this problem. Third, we consider only two types of shocks and three variables in the comparison. It is possible that our conclusions would have been different had other shocks and other variables been examined.

20. The frequency of this series is annual for the period from 1965 to 1973. We transformed it to quarterly for this exercise.

Figures C.2 and C.3 in Appendix C compare the impact of real U.S. GDP and commodity price shocks on real GDP, CPI inflation, and the Canadian exchange rate in the various participating models with the corresponding responses from the VAR model. The red dashed line indicates the confidence interval associated with the VAR.

4.1 A temporary external shock

Real U.S. GDP is increased by 1 per cent, 0.75 per cent, 0.50 per cent, and 0.25 per cent, respectively, during the first four quarters. Note that this temporary shock incorporates the endogenous response of some U.S. macroeconomic variables, such as CPI inflation and short-term interest rates, as well as the endogenous response of commodity prices.

It is interesting that the response of real Canadian GDP to a shock to real U.S. GDP is often smaller, in the very short run, in the participating models than in the VAR model. In particular, it responds much less in CEFM, FOCUS, FOCUS-CE, M1-VECM, MULTIMOD, and WEFA than in the VAR model. It is also interesting that NAOMI (in the short term) and QPM overestimate the response of inflation compared with the VAR and other models.

In several models, the response of the exchange rate is quite different from, and, indeed, often outside the (wide) estimated confidence interval of, that yielded by the VAR. Incidentally, several models yield responses of a different sign from the VAR, especially in the short term. For example, although, in the VAR model, an increase in real U.S. GDP causes a short-term depreciation of the Canadian dollar, the opposite is predicted in FOCUS, FOCUS-CE, INTERLINK, M1-VECM, MTFM, MULTIMOD, and WEFA. Furthermore, whereas the VAR model predicts that the exchange rate should return to control following the temporary U.S. GDP shock, INTERLINK, NAOMI, and QPM predict large long-run depreciations of the Canadian dollar in response to that shock.

4.2 A temporary shock to commodity prices

During the first quarter, commodity prices increase 4 per cent, during the second 3.5 per cent, during the third 3 per cent, and so on, until during the eighth they increase 0.5 per cent, returning to their initial value by the ninth quarter. This shock incorporates the endogenous response of several U.S. macroeconomic variables, such as real GDP, CPI inflation, and short-term interest rates.

In several models, the response of real GDP to commodity price shocks resembles that generated by the VAR model. MTFM, in the short term, and INTERLINK, in the short and the longer term, differ most from the VAR. These two models are, in fact, the only ones to predict a short-term fall in real GDP in Canada in response to a positive commodity price shock.

As in the case of the VAR, the response of inflation to this shock is generally positive in the short term, except in the FOCUS model with backward-looking expectations. Several models, however, especially FOCUS-CE and WEFA, show much stronger responses than the VAR in the short term. MTFM and MULTIMOD are the closest to the VAR model in this respect.

We find great variation in our results for the exchange rate. DRI, INTERLINK, and QPM are particularly divergent from the VAR (and the other models) with respect to this variable. While the VAR predicts that an increase in commodity prices causes a short-term appreciation of the Canadian dollar, CEFM, DRI, INTERLINK, MULTIMOD, and QPM forecast a depreciation.[21]

We calculate the distance between the results generated by the impulse-response functions of the participating models and the VAR—computed as the sum of squares of the differences between the impulse-response functions of the models and the VAR. We then use this calculation to rank the various models in terms of the distance of their impulse-response functions from those of the VAR. Table 4 presents the results of these calculations for the two types of shocks and the three variables we consider, along with an aggregate ranking over all shocks and variables.[22] A minimum-rank criterion is used. The model that is ranked first is the one, on average, that has the lowest score for the two shocks and three variables (each ranked equally). The last-ranked model—that differing most from the VAR overall—is the one with the highest score.

21. The endogenous response of real U.S. GDP to the commodity price shock partially explains the effect it has on the exchange rate in QPM. Indeed, real U.S. GDP tends to decline in response to this shock, reducing Canada’s exports to the United States. To maintain foreign debt at a constant level in steady state, the Canadian dollar must depreciate to stimulate Canadian exports.

22. In the case of a positive shock, QPM’s response is biased upwards compared with the linear VAR, because QPM has a non-linear aggregate supply curve. We therefore took an average of QPM’s response to the positive and negative shocks to calculate the statistics presented in Table 4.

Table 4: Distance of the Models from the VAR

	Shock to real U.S. GDP			Shock to commodity prices			
Models	Real GDP	CPI inflation	Exchange rate	Real GDP	CPI inflation	Exchange rate	Aggregate measure
DRI	5	8	8	4	8	11	10
FOCUS	6	1	4	9	9	2	5
FOCUS-CE	4	4	3	6	11	8	6
INTERLINK	11	11	11	11	6	10	11
CEFM	9	3	2	1	5	7	3
MTFM	1	2	5	10	2	3	1
MULTIMOD	7	6	6	5	1	5	4
M1-VECM	8	7	10	8	4	6	9
NAOMI	3	9	7	2	3	1	2
QPM	2	10	9	3	7	9	8
WEFA	10	5	1	7	10	4	7

Our comparison of the models' impulse-response functions with those of a VAR comprising very little economic structure reveal that MTFM, NAOMI, and CEFM reflect relatively better than the other models the typical response of the Canadian economy to shocks to real U.S. GDP and to commodity prices. Some models yield results that are close to the VAR for certain variables and certain shocks, but are much further in other cases. No model is among the closest to the VAR for all variables and all shocks. Every model contains at least a few impulse-response functions that diverge significantly from those estimated by the VAR. The responses generated by MTFM, however, are closest to the VAR overall, followed by NAOMI and CEFM; those generated by M1-VECM, DRI, and INTERLINK are the furthest from the VAR model.

5. Conclusions

This report has examined and compared twelve private and public sector models of the Canadian economy with respect to their paradigm, structure, and dynamic properties. Although they are all "open-economy models," they are quite different. The twelve models can be grouped into two economic paradigms. The first one is the "conventional" paradigm (or the Phillips curve paradigm) and the second is the "money matters" paradigm.

Under the conventional paradigm, inflation is determined by price adjustments in response to inflation expectations and by factor disequilibrium in labour or product markets. While most models are based on the conventional paradigm, there are nevertheless important differences within this paradigm.

Under the money matters paradigm, inflation is mostly determined by movements in monetary aggregates. Two models are based on this paradigm: the M1-VECM, in which the money gap—the disequilibrium between the money supply and the estimated long-term money demand—influences inflation, while still allowing a role for the output gap, and the LPM, in which rigidities in adjusting money balances are the main source of the short-run non-neutrality of monetary policy.

Within the conventional paradigm, inflation is determined by a linear Phillips curve in five participating models: CEFM, DRI, INTERLINK, NAOMI, and WEFA. Although the M1-VECM is based on the money matters paradigm, the disequilibrium in the product market also plays a role in the adjustment of prices. Asymmetries in the inflation process are introduced in FOCUS, FOCUS-CE, MULTIMOD, and QPM. On the other hand, MTFM uses a very disaggregated approach to determining the adjustment of prices.

Eight of the twelve models assume purely backward-looking inflation expectations: CEFM, DRI, FOCUS, INTERLINK, MTFM, M1-VECM, NAOMI, and WEFA. The following three models also assume model-consistent inflation expectations: FOCUS-CE, MULTIMOD, and QPM. In MULTIMOD and QPM, in particular, the hybrid Phillips curve assigns more weight to backward-looking inflation expectations than to model-consistent inflation expectations. The LPM is the only model that incorporates purely model-consistent behaviour and is optimally derived from microfoundations.

The models can also be differentiated based on the channels through which monetary policy actions affect the economy. In most of the twelve models examined, monetary policy actions affect the economy through the level of short-term interest rates. This is the case with CEFM,

DRI, FOCUS, FOCUS-CE, INTERLINK, LPM, MTFM, MULTIMOD, and WEFA. In the M1-VECM, NAOMI, and QPM, the monetary policy transmission mechanism works through the slope of the yield curve. In all models, monetary policy affects the real economy in the short run because of wage and/or price rigidities (rigidities in adjusting the money balance in the LPM), but it remains neutral in the long term owing to price flexibility. There are also differences in estimation techniques and sizes. For example, NAOMI is a small estimated model, whereas QPM is a large-scale calibrated model. MTFM, on the other hand, is a fairly disaggregated model compared with most of the other models.

We have examined the dynamic properties of the various models when they use the simple monetary reaction function proposed by Taylor (1993). The eight standard shocks considered in our study reveal significant differences in the dynamic properties of the models examined. For example, the output, inflation, and exchange rate responses to a positive temporary commodity price shock differ largely across models. A positive commodity price shock leads to an increase in real GDP in the short term in DRI, FOCUS, FOCUS-CE, M1-VECM, NAOMI, MULTIMOD, QPM, and WEFA, but to a decline in output in MTFM and INTERLINK. The inflation response to a commodity price shock is positive in most models, except for FOCUS. In response to that shock, the exchange rate appreciates in most models, with depreciation observed in CEFM, DRI, INTERLINK, MULTIMOD, and QPM.

The first four-quarter peak response of real GDP and CPI inflation in most models does not appear to be very sensitive to changes in interest rates, with CEFM and WEFA being the least sensitive to movements in interest rates. When the sensitivity of the exchange rate to a movement in interest rates is considered, however, several models appear to be very responsive to changes in interest rates, except for DRI. Interestingly, the exchange rate shock does not have a big impact on real GDP and CPI inflation in most models (except for QPM and, to a lesser extent, the M1-VECM, which are more responsive to this shock).

Our comparison of the models' impulse-response functions with those of a VAR suggests that some models, especially MTFM, NAOMI, and CEFM, do a better job than the others in reflecting the typical response of the Canadian economy to shocks to real U.S. GDP and to commodity prices. Nonetheless, every model contains at least a few impulse-response functions that diverge significantly from those estimated by the VAR.

The comparison of the models' impulse-response functions with those of a VAR does not, of course, provide a definitive answer to the following question: How much weight should policy-makers assign to the information yielded by those models? A more thorough evaluation of the models is warranted to answer this question. That is left for future research.

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Appendix A: Questionnaire Responses

	CEFM	DRI	FOCUS	INTERLINK	LPM	M1-VECM	MTFM	MULTIMOD	NAOMI	QPM	WEFA
Expectations											
1. Backward looking; i.e., depend on only lagged values of variables.	Y[a]	Y	Y	Y	N	Y	Y	N	Y	N	Y
2. Combination of forward- and backward-looking components.	N	N	N[b]	N	Y[c]	N	N	Y	N[d]	Y	N
3. Do the inflation targets have an explicit role in the expectation process? If yes, describe how.	N	N	N	N	N	N	N	N[e]	N	N[f]	N
Asymmetry or non-linearities											
4. Interest rate increases have the same effect on demand as decreases.	Y	Y[g]	Y	Y	Y	Y	Y	Y	Y	Y	Y
5. Exchange rate appreciations have the same effect on demand as depreciations.	Y	Y[g]	Y	Y	Y	Y	Y	Y	Y	Y	Y
6. The exchange rate responds to the size of the interest rate differential and not to how quickly it opens.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7. Inflation responds differently to excess supply than to excess demand.	N	N	Y[h]	N	N	N	N	Y[h]	N	Y[h]	N
Other											
8. Do you have estimates of potential output?	Y	Y	N	Y	Y[i]	Y[j]	N	Y	Y[j]	Y	N
9. Do you have estimates of the equilibrium interest rate?	N	N	N	N	Y	N[k]	N	Y	N	Y	N
10. Do you have estimates of the equilibrium exchange rate?	N	N	N	N	Y	N	N	Y	Y	Y	N
11. When does the sample period of the model start?	70	61	65	NR[l]	NR	56	81	70	73	65	66
12. Frequency of data.	Q[m]	Q	Q	SA[n]	Q	Q	Q	A[o]	Q	Q	Q

a. Y = Yes.
b. N = No. Yes in the model-consistent-expectations version, FOCUS-CE.
c. Model-consistent expectations only.
d. Monetary policy is forward looking.
e. No explicit role in expectations, other than through the weight on the model-consistent lead of inflation in the expectation process.
f. Forward-looking expectations are model-consistent. If monetary authorities achieve their target, then this is taken into account.
g. Small changes have similar effects. The biggest non-linearities occur when the economy is in an excess-demand position.
h. The Phillips curve is non-linear.
i. For questions 8, 9, and 10, use either steady-state values or values arising in a model with no nominal rigidities.
j. Potential output is exogenous to the model.
k. A steady-state value is imposed.
l. NR = No response.
m. Q = Quarterly.
n. SA = Semi-annually.
o. A = Annually.

Appendix B: Endogenous Responses of Some U.S. Macroeconomic Variables

For the two external shocks—a shock to the real U.S. GDP and a shock to commodity prices—we calculate endogenous responses of some U.S. macroeconomic variables, as they are likely to play an important role in models of the Canadian economy. We derive these endogenous responses from a VAR model consisting of four variables: U.S. real GDP, U.S. CPI inflation, U.S. short-term interest rate, and world commodity prices.

The vector containing these variables can be written as follows:

$$Z_t = \begin{bmatrix} \Delta {y^{us}}_t \\ \Delta pcom_t \\ \Delta {p^{us}}_t \\ \Delta {r^{us}}_t \end{bmatrix},$$

where ${y^{us}}_t$ is the log of real U.S. GDP, $pcom_t$ is the log of the Bank of Canada's commodity price index, ${p^{us}}_t$ is the log of the U.S. consumer price index, and r^{us} is the U.S. 90-day commercial paper rate. The data are from Statistics Canada and the Bank of Canada. Our sample starts in the first quarter of 1970 and ends in the fourth quarter of 2000.

The model we estimate can be written as follows:

$$Z_t = cst + \sum_{i=1}^{q} \beta_i Z_{t-i} + \varepsilon_t, \tag{A1}$$

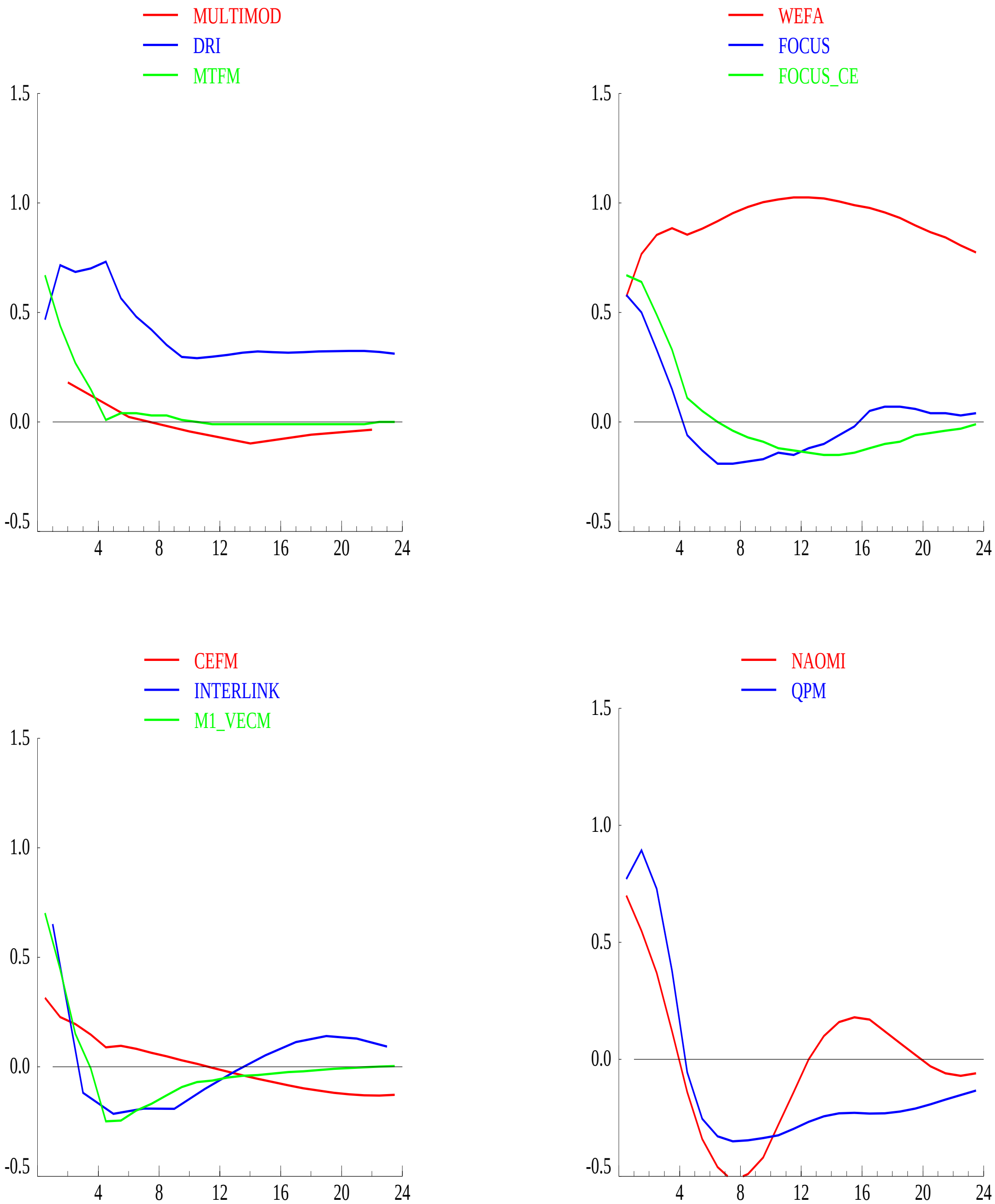
where cst is a vector of constants, β_i is a vector of coefficients, and ε_t is a vector of error terms. The number of lags, q, determined using a likelihood-ratio test, is equal to six.

We simulate the response of Z_t to the shocks to ${y^{us}}_t$ and $pcom_t$ outlined in Table 1. Because the variables in Z_t are likely to be serially correlated with each other, ε_t is orthogonalized using the Choleski factorization method. The order of the variables is as shown in vector Z_t. We assume that a shock to the real U.S. GDP affects all other variables in the same period, while a shock to world commodity prices affects U.S. output only in the next period.

Appendix C: Original Taylor Rule Results

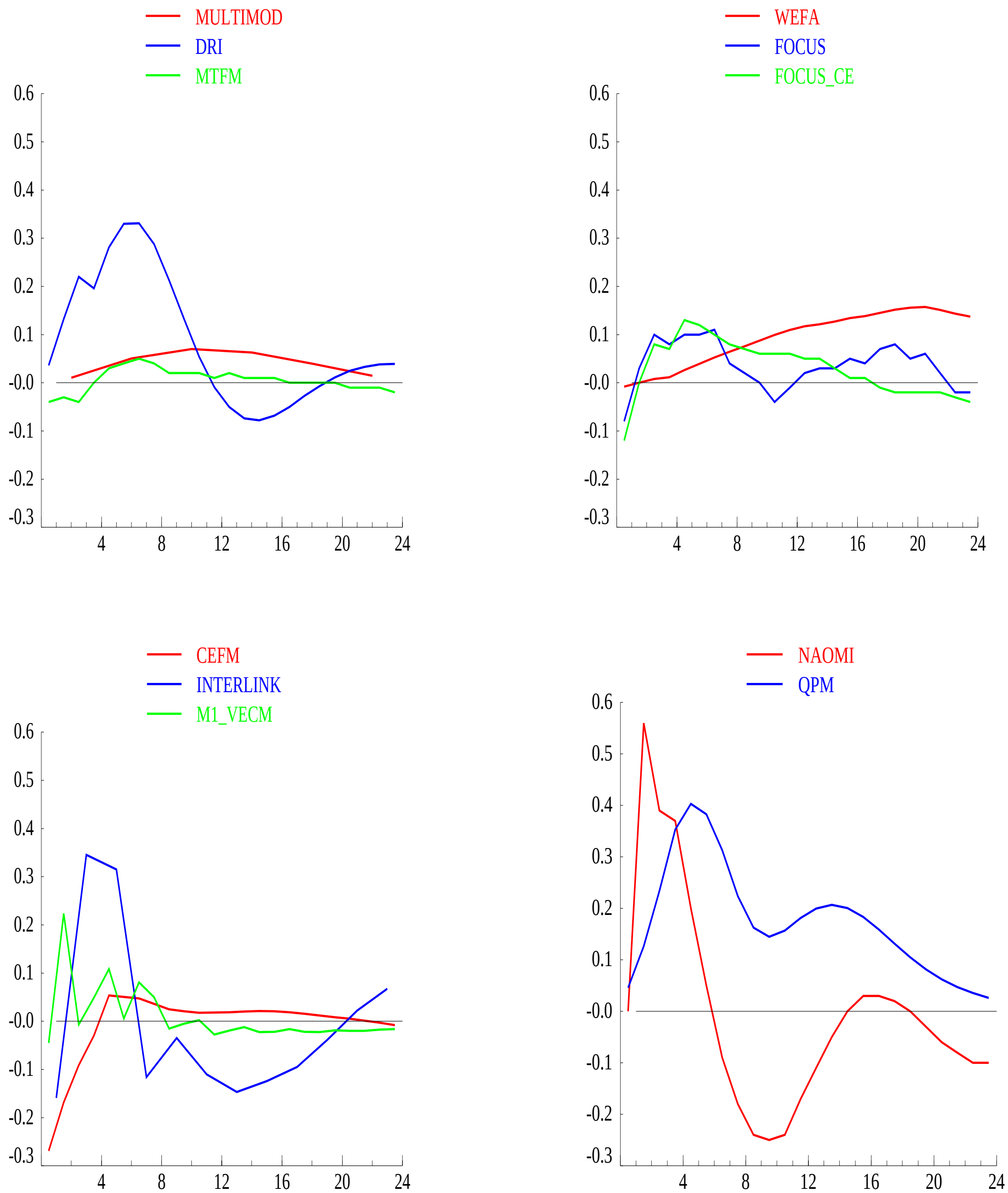
Domestic Demand Shock

Figure C.1a: **Real GDP**, Per cent, Shock minus Control



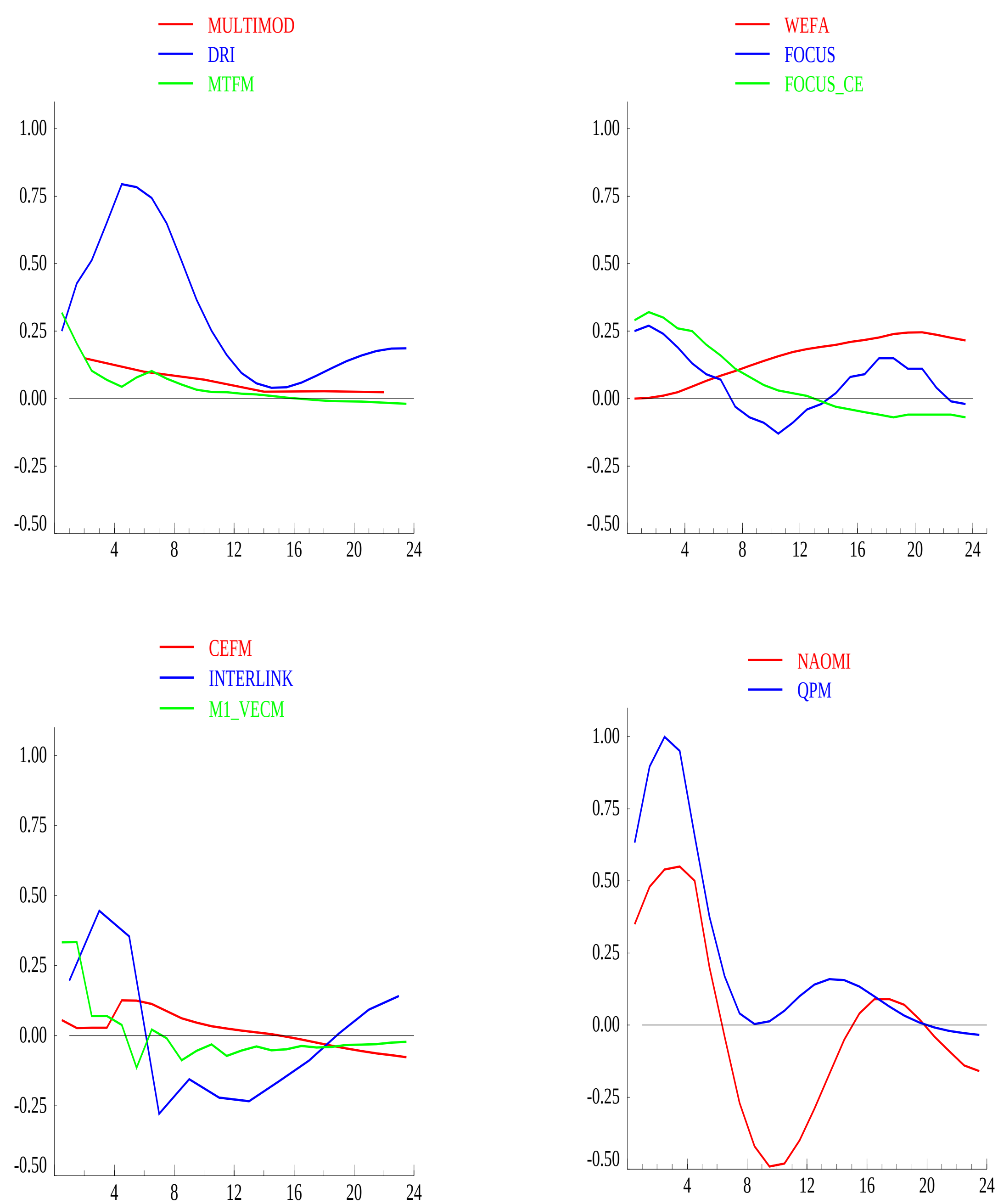
Domestic Demand Shock

Figure C.1b: **Inflation**, Percentage point, Shock minus Control



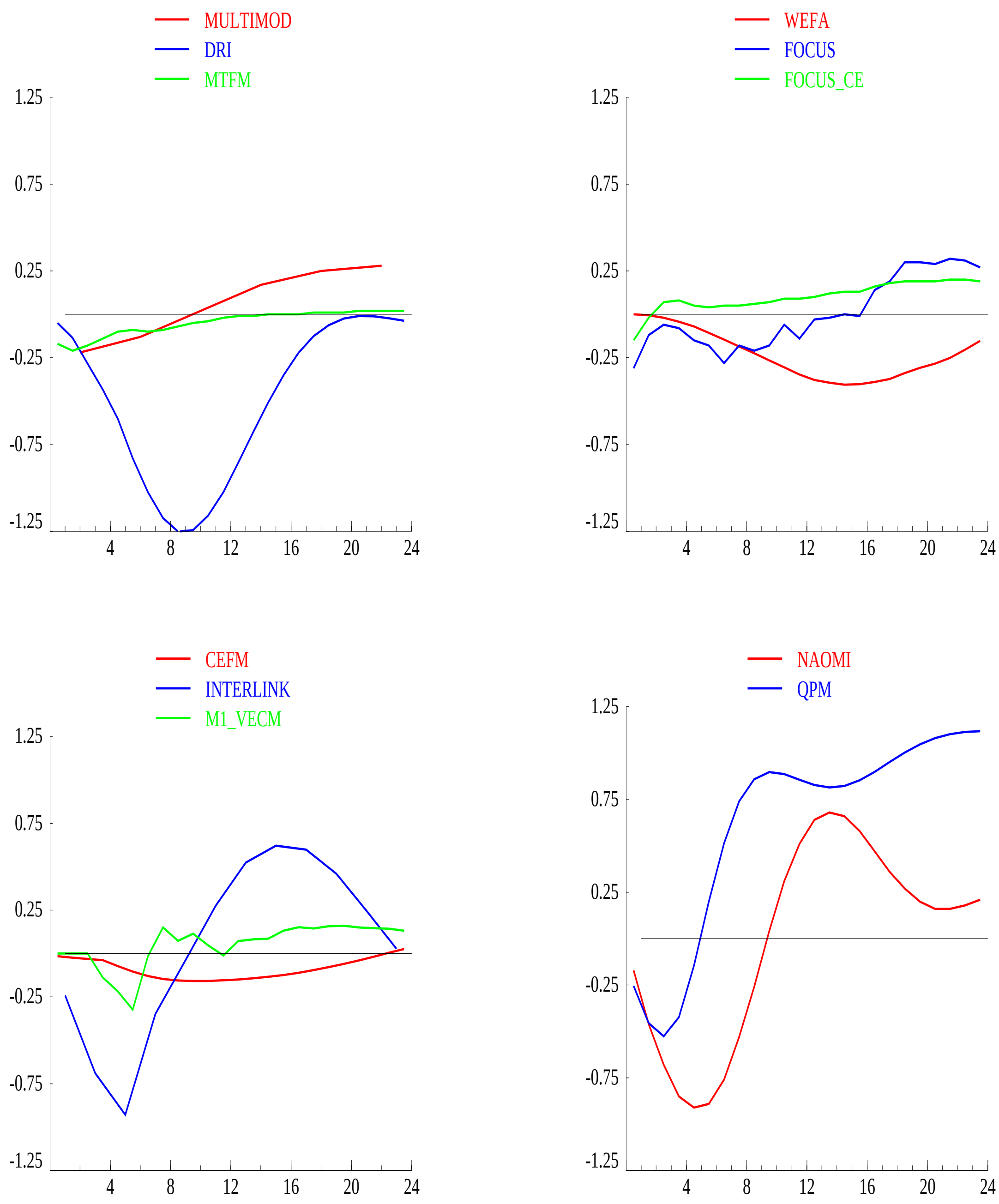
Domestic Demand Shock

Figure C.1c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



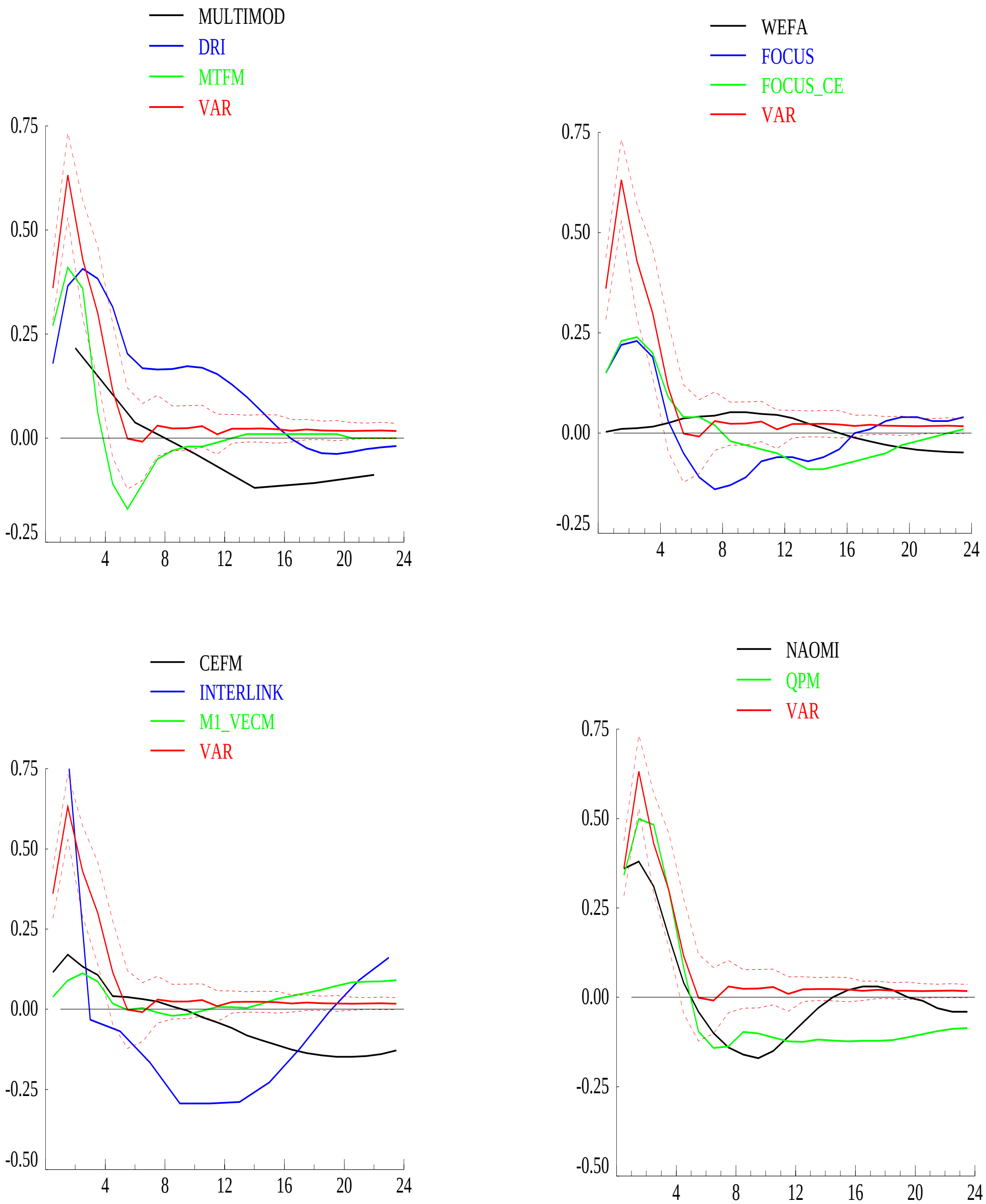
Domestic Demand Shock

Figure C.1d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



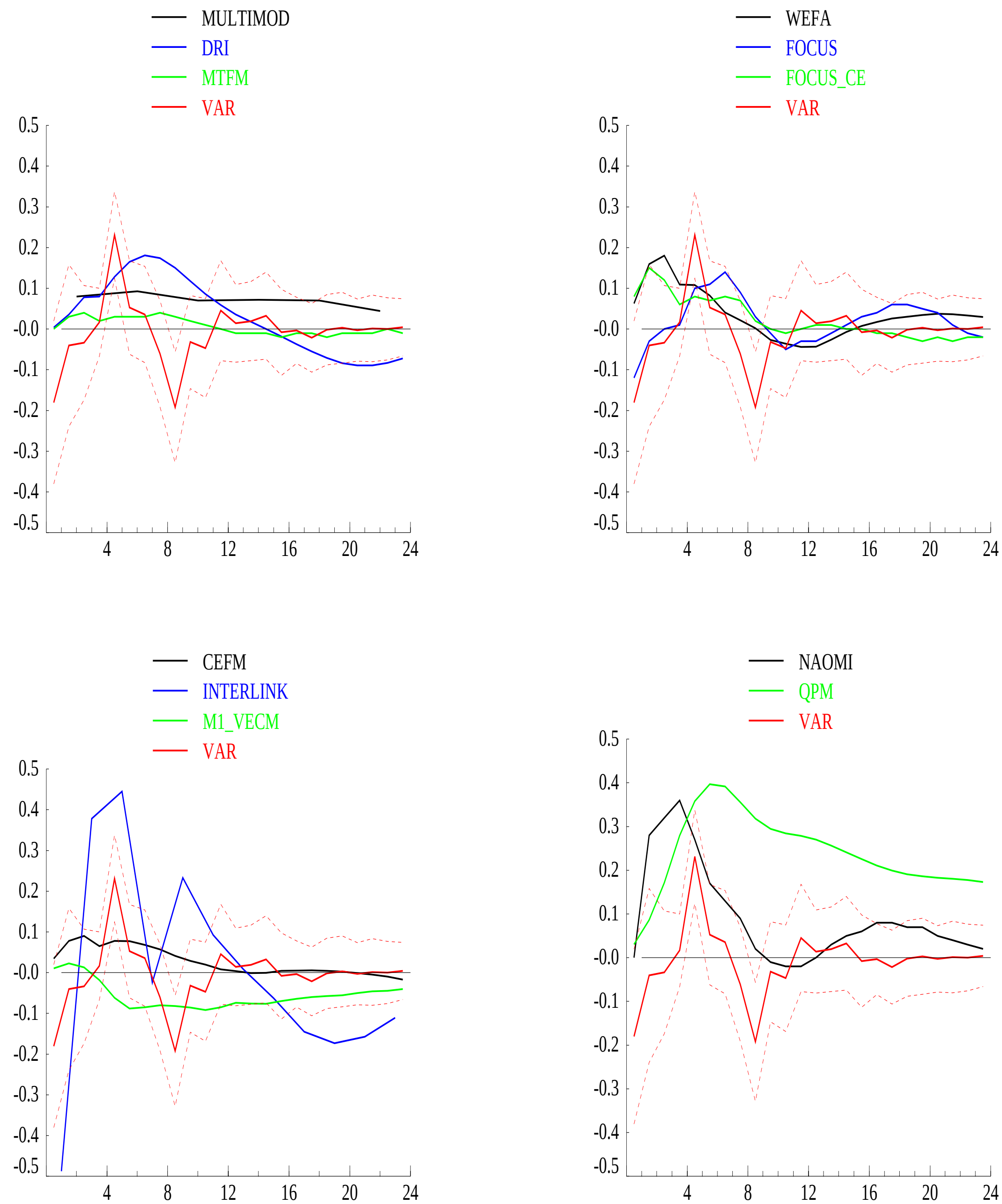
External Shock

Figure C.2a: **Real GDP**, Per cent, Shock minus Control



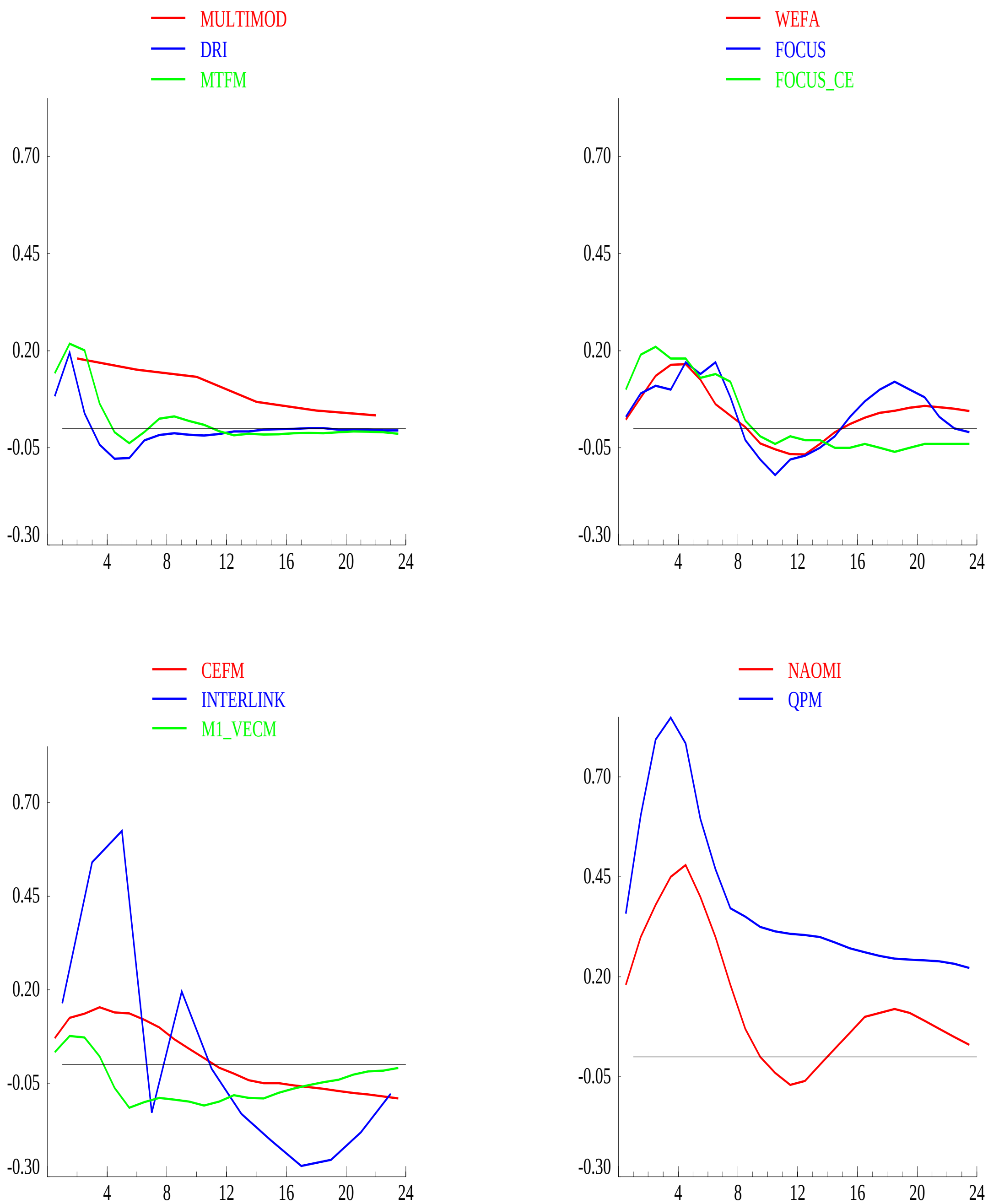
External Shock

Figure C.2b: **Inflation**, Percentage point, Shock minus Control



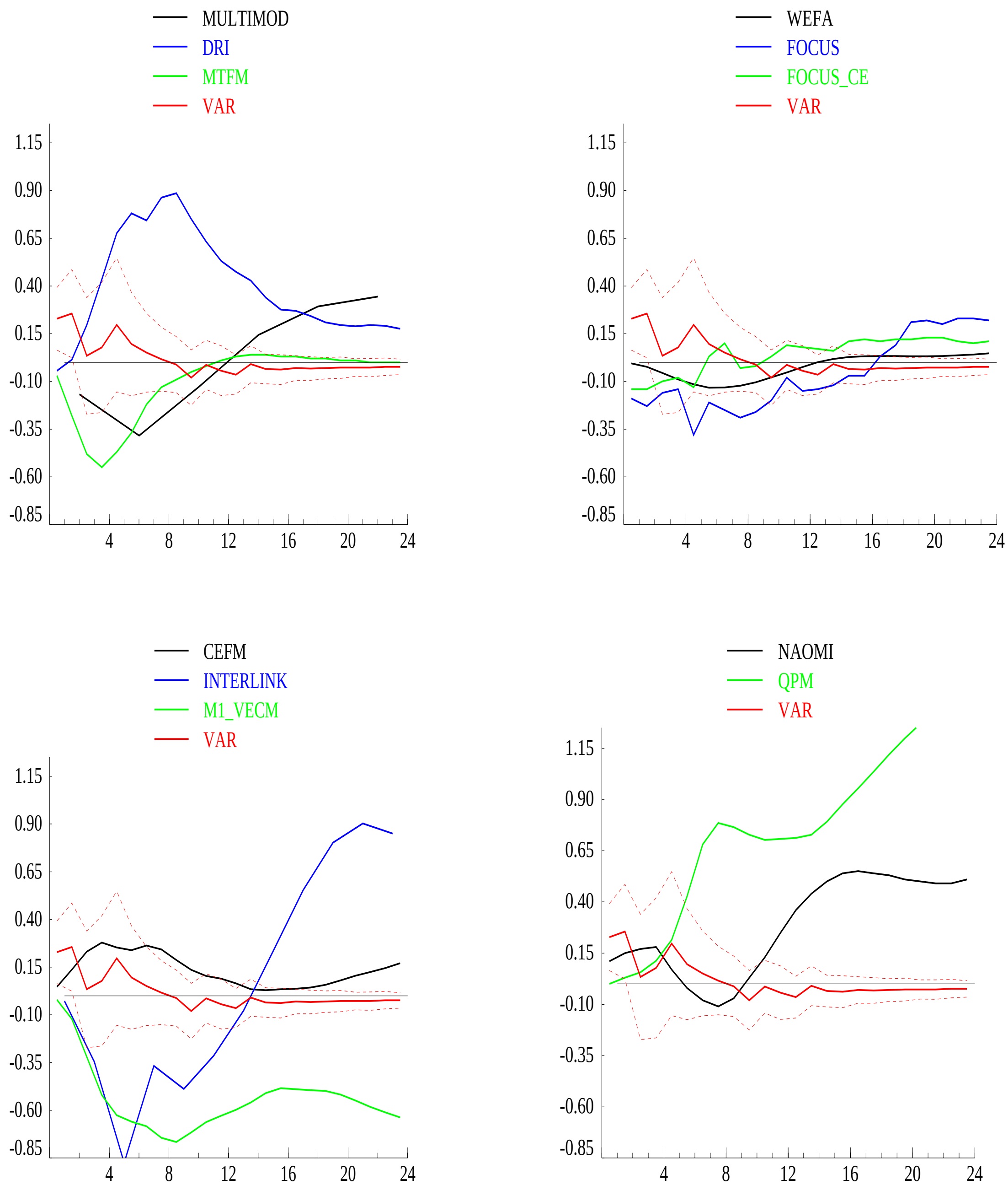
External Shock

Figure C.2c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



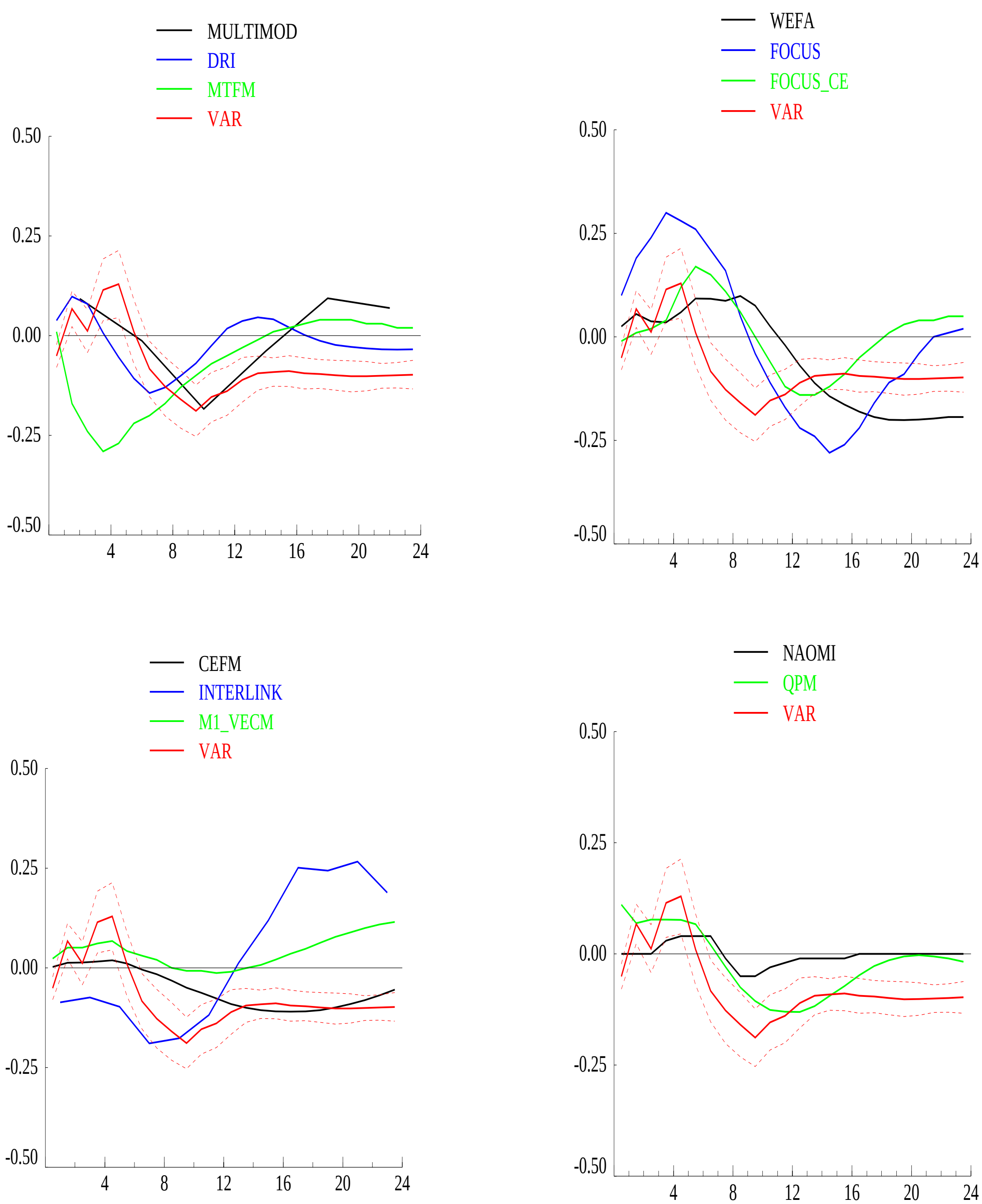
External Shock

Figure C.2d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



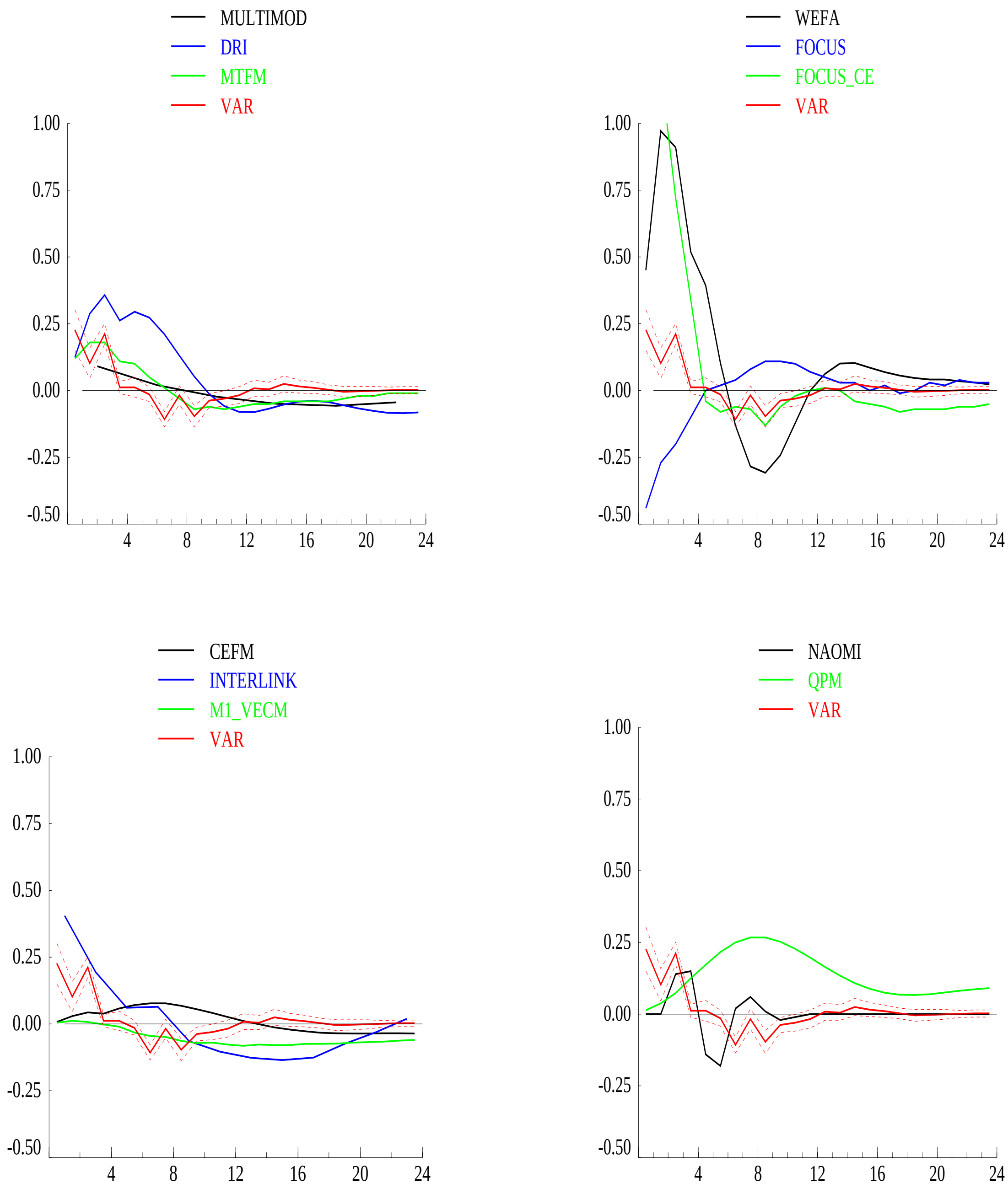
Commodity Price Shock

Figure C.3a: **Real GDP**, Per cent, Shock minus Control



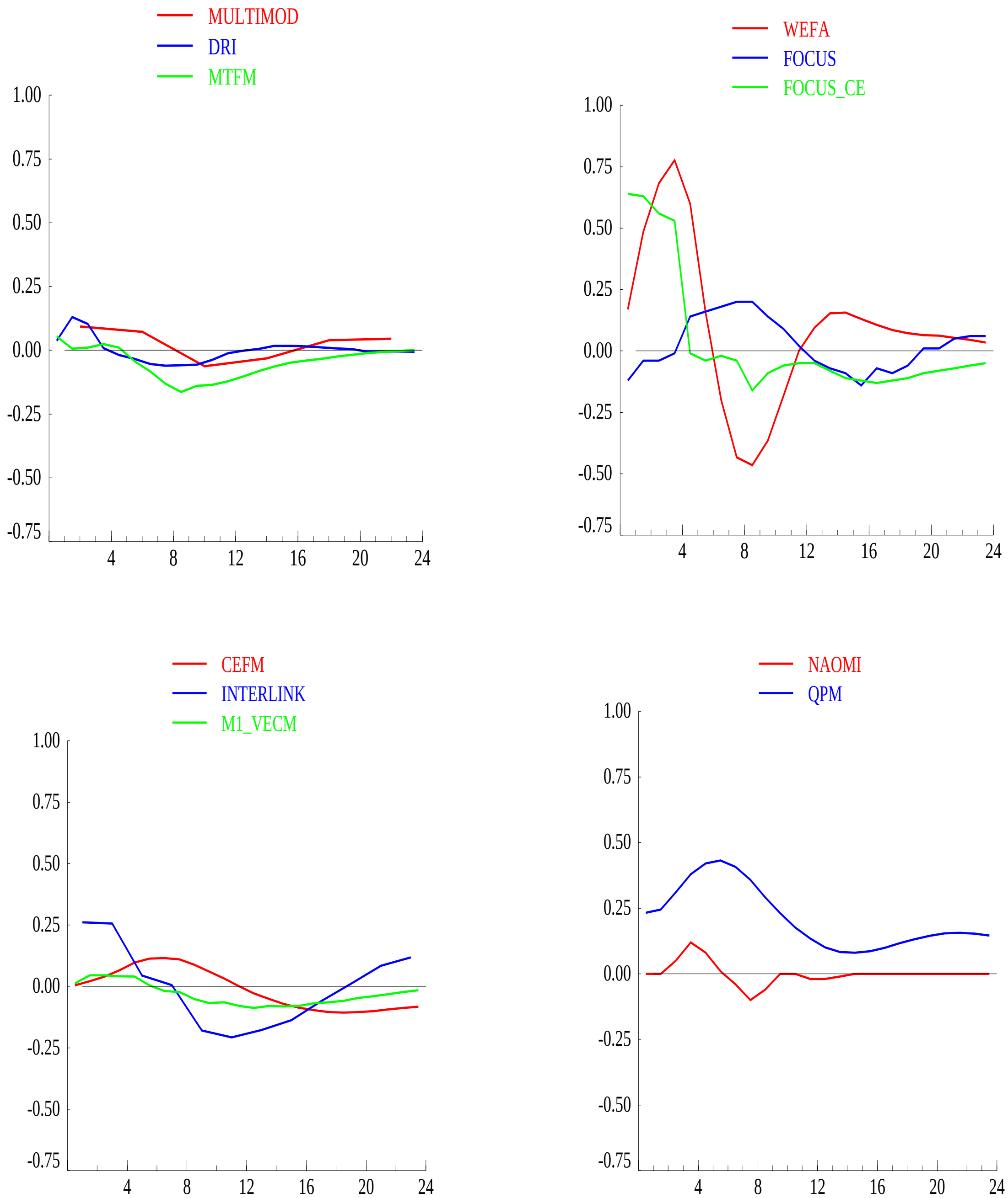
Commodity Price Shock

Figure C.3b: **Inflation**, Percentage point, Shock minus Control



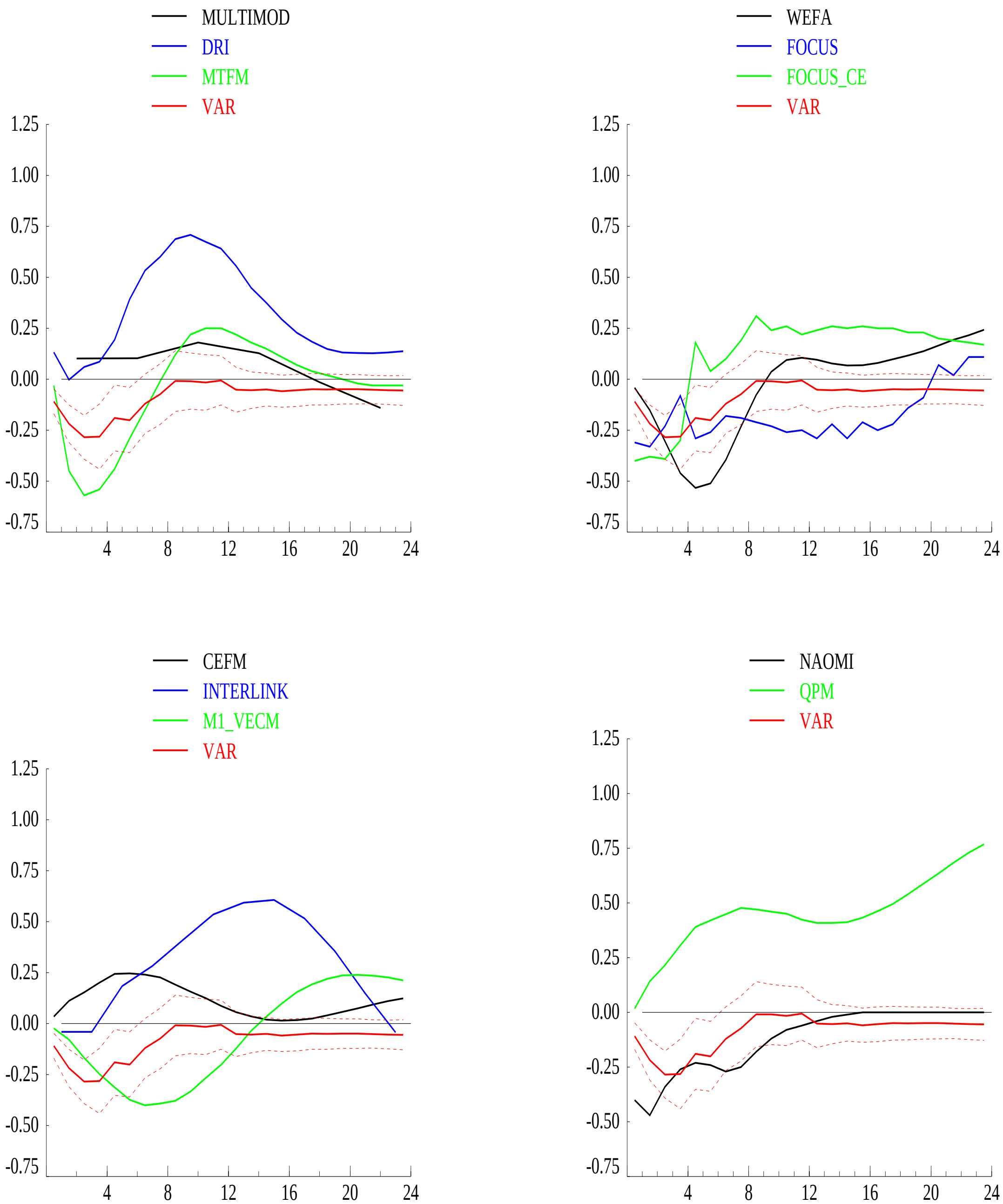
Commodity Price Shock

Figure C.3c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



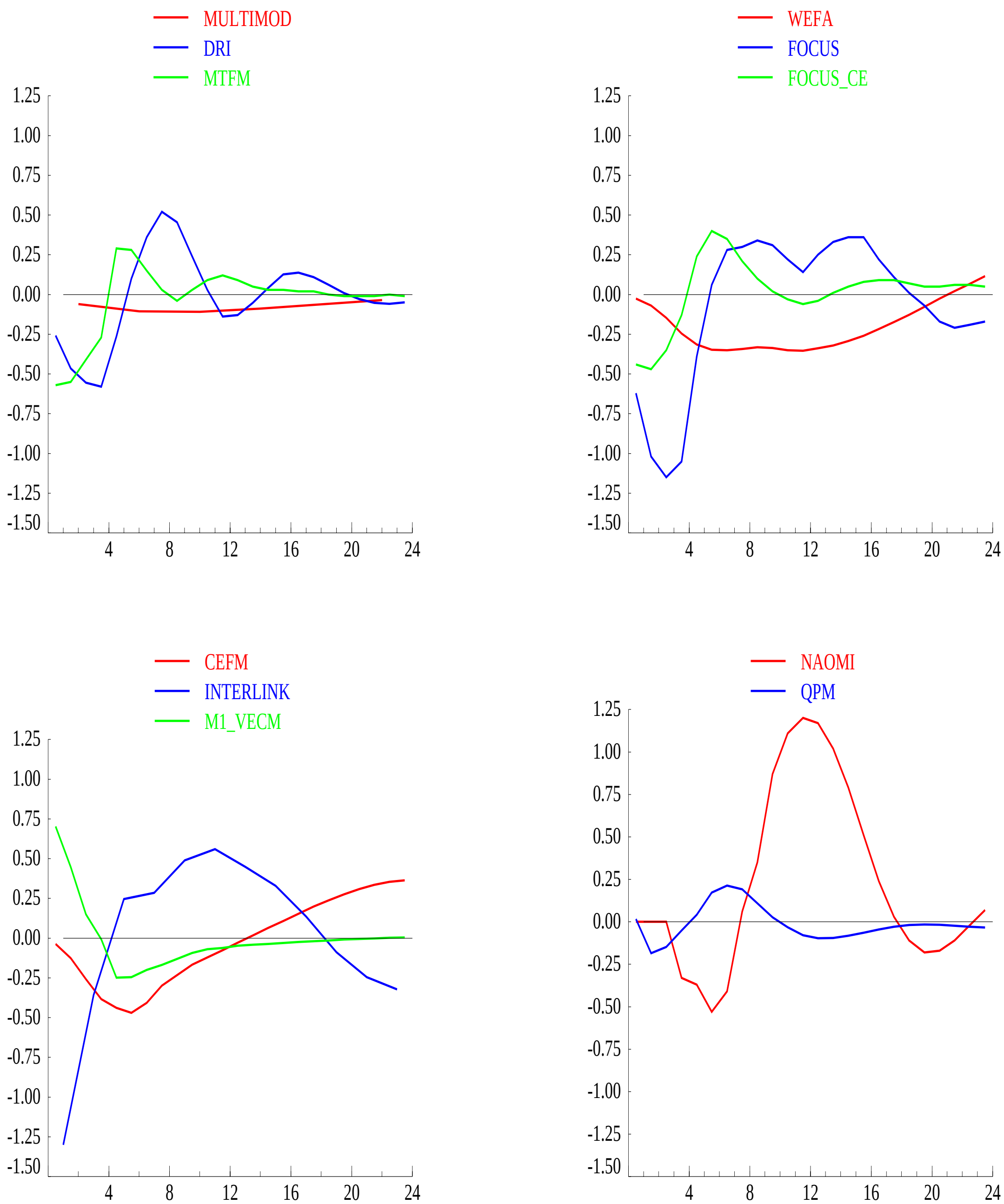
Commodity Price Shock

Figure C.3d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



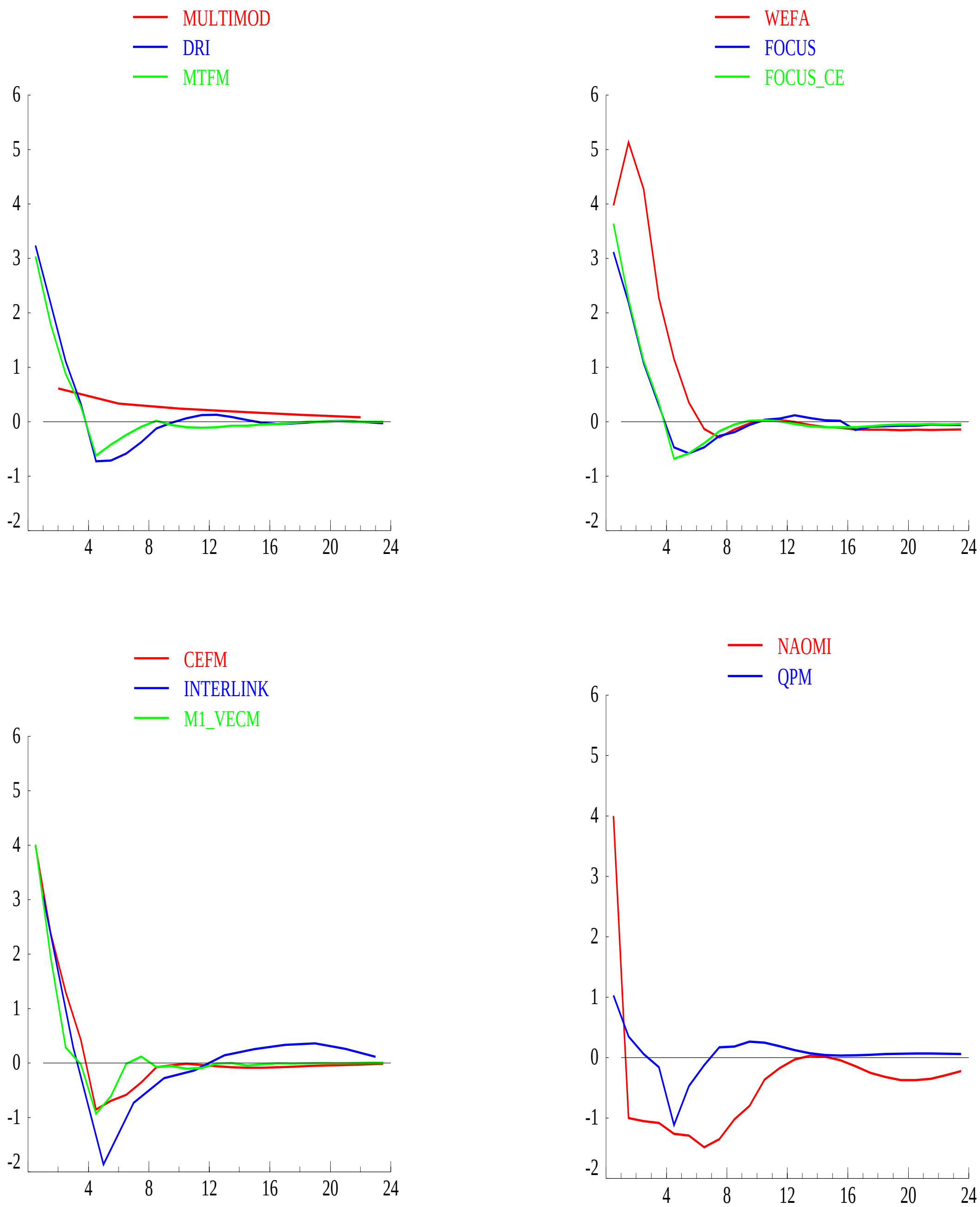
Price-Level Shock

Figure C.4a: **Real GDP**, Per cent, Shock minus Control



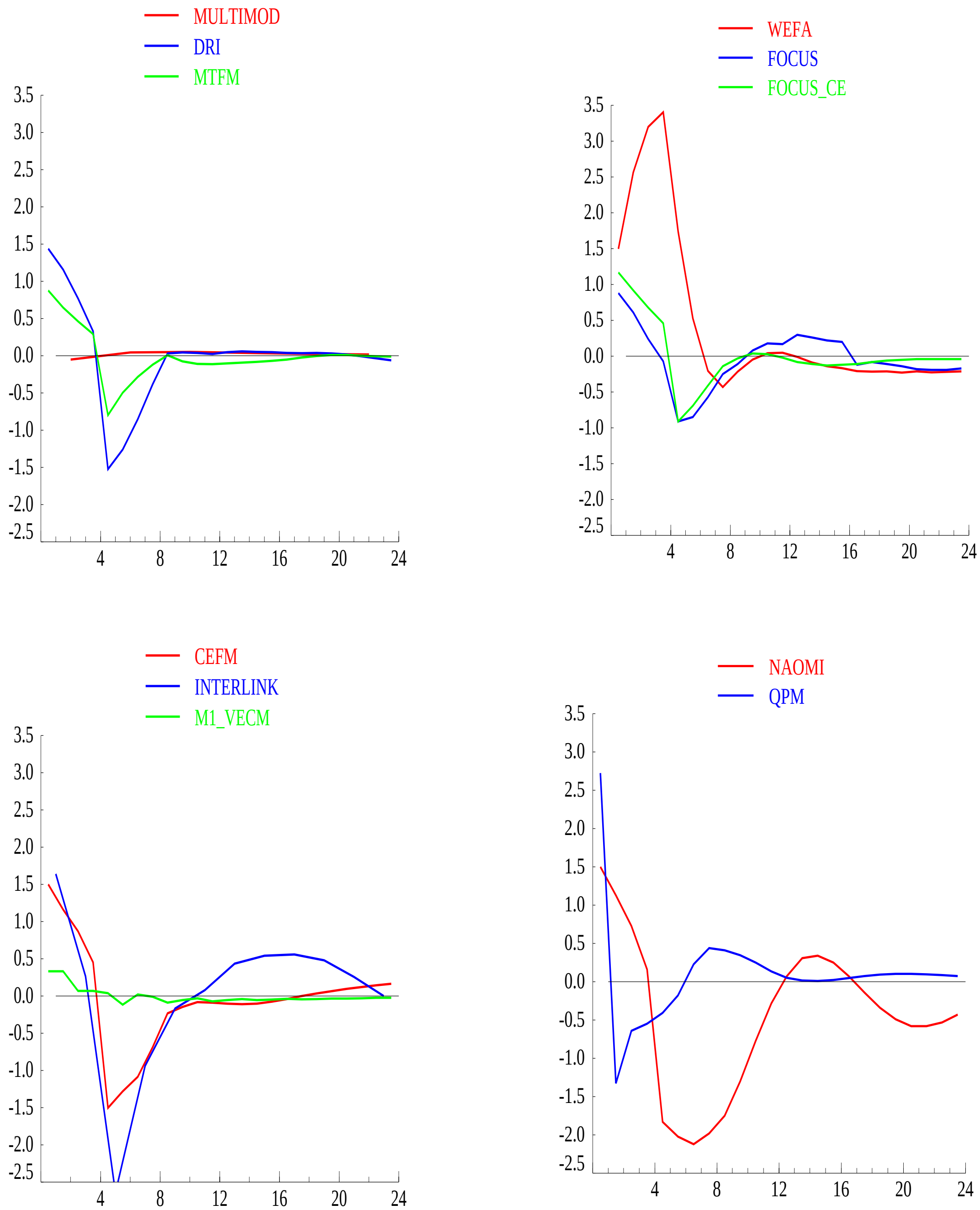
Price-Level Shock

Figure C.4b: **Inflation**, Percentage point, Shock minus Control



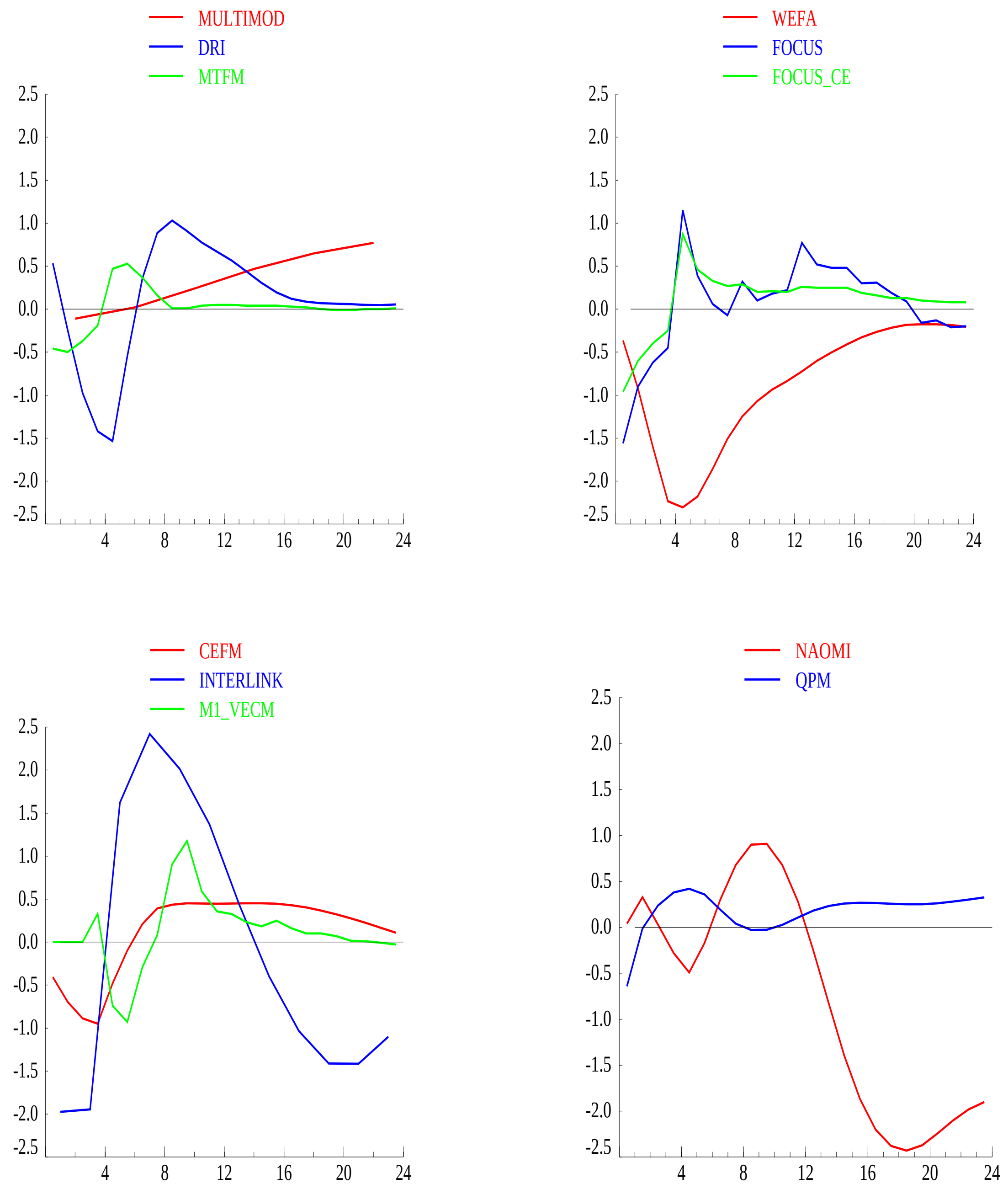
Price-Level Shock

Figure C.4c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



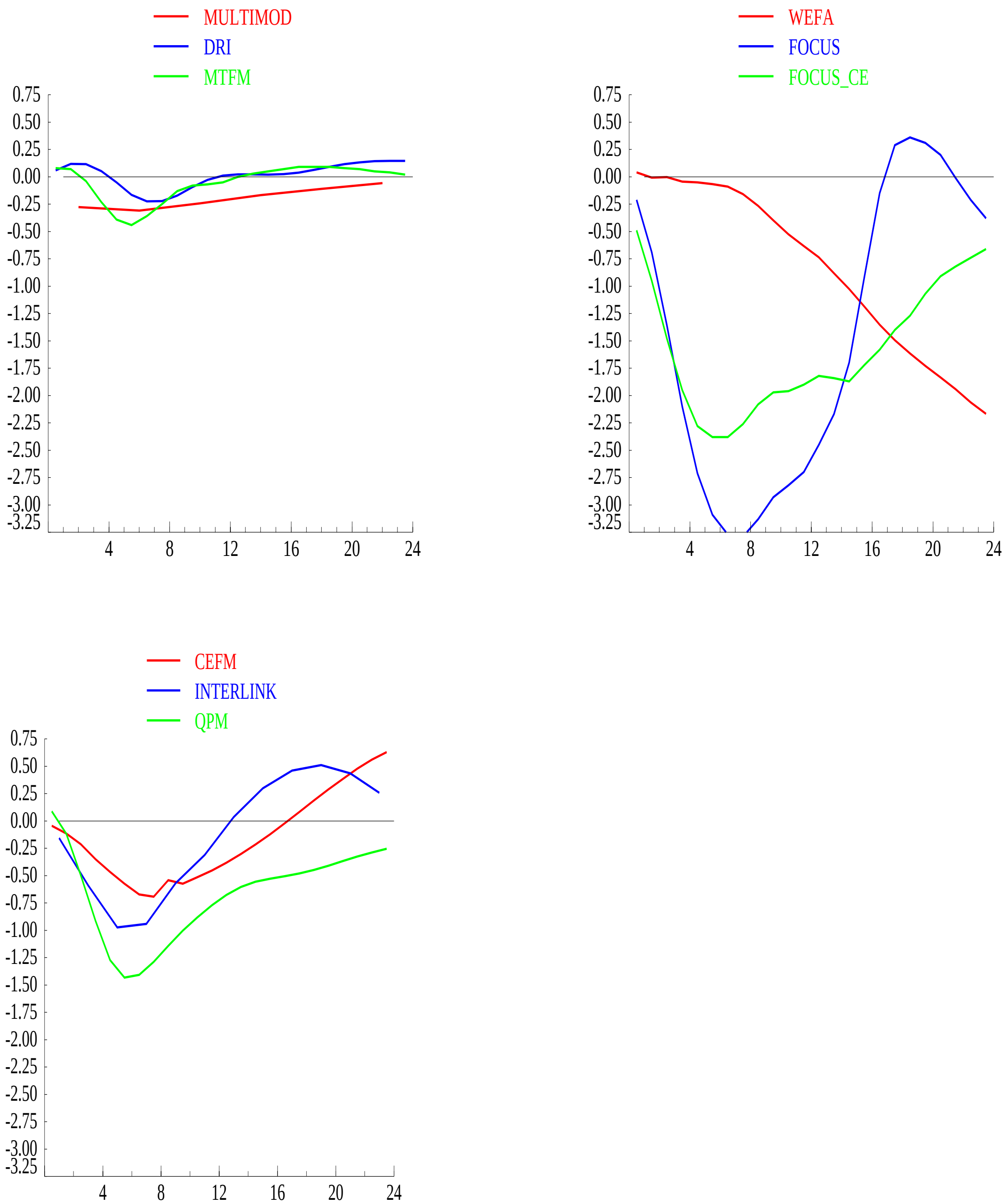
Price-Level Shock

Figure C.4d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



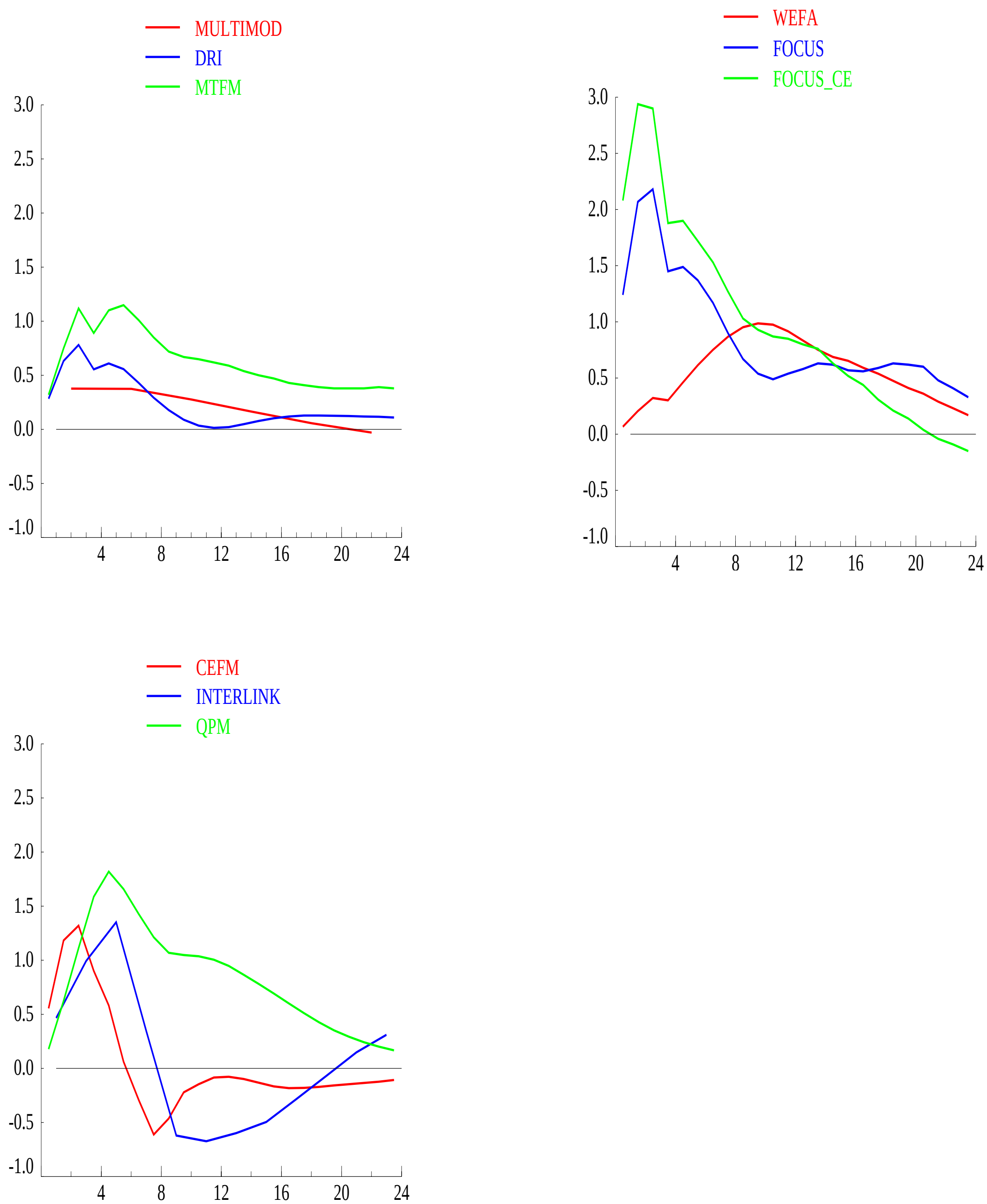
Wage Growth Shock

Figure C.5a: **Real GDP**, Per cent, Shock minus Control



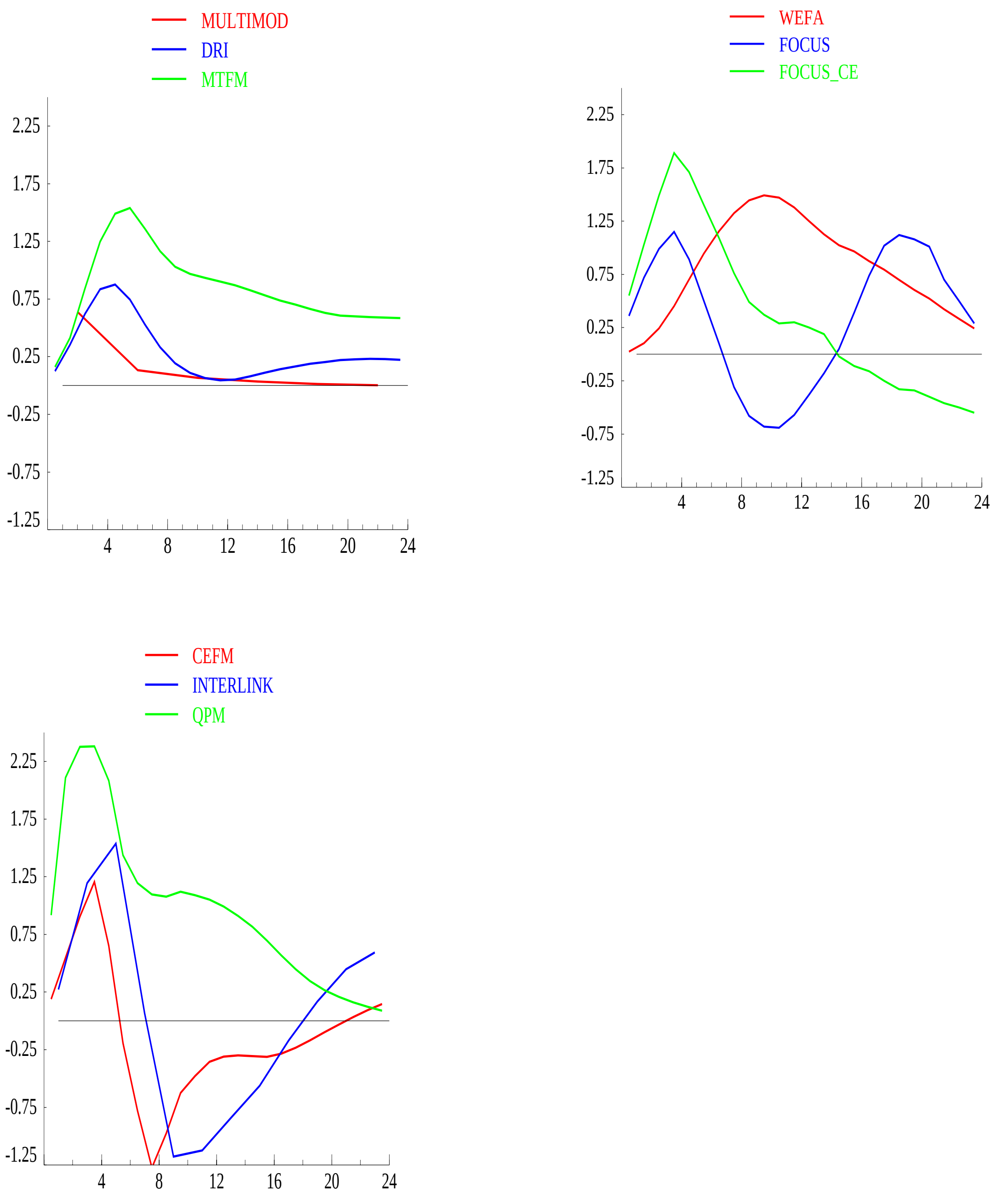
Wage Growth Shock

Figure C.5b: **Inflation**, Percentage point, Shock minus Control



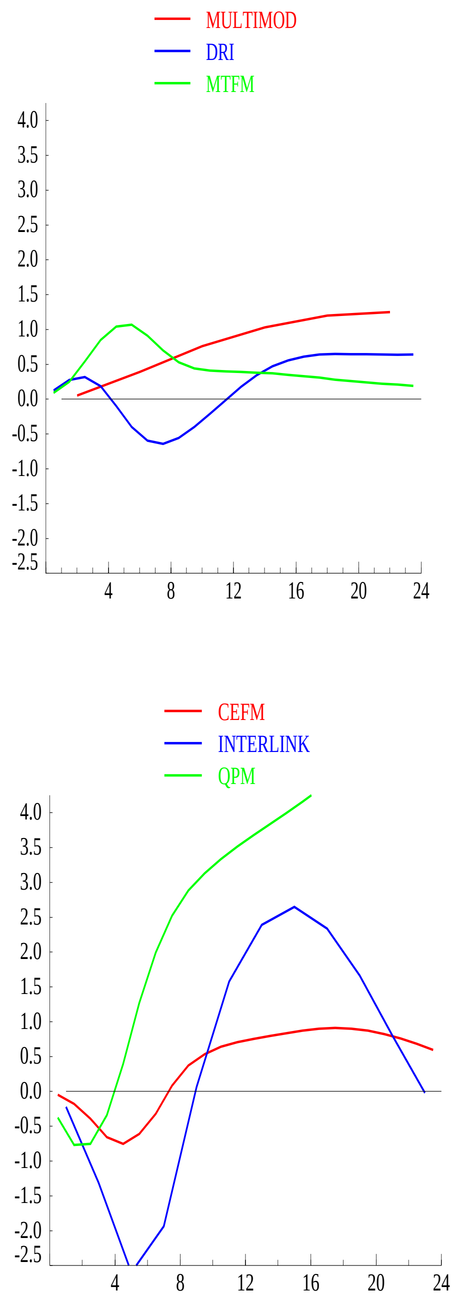
Wage Growth Shock

Figure C.5c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



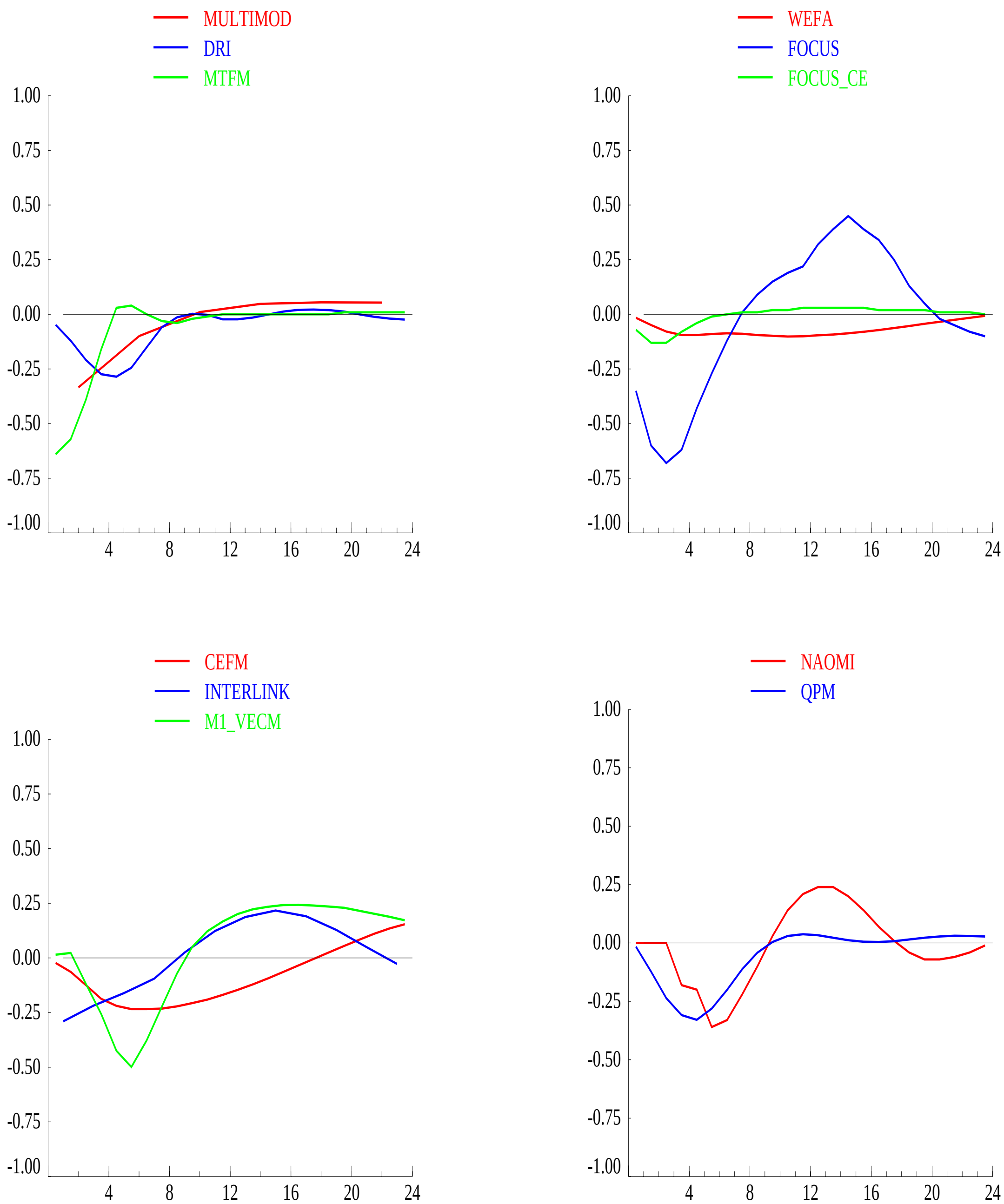
Wage Growth Shock

Figure C.5d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



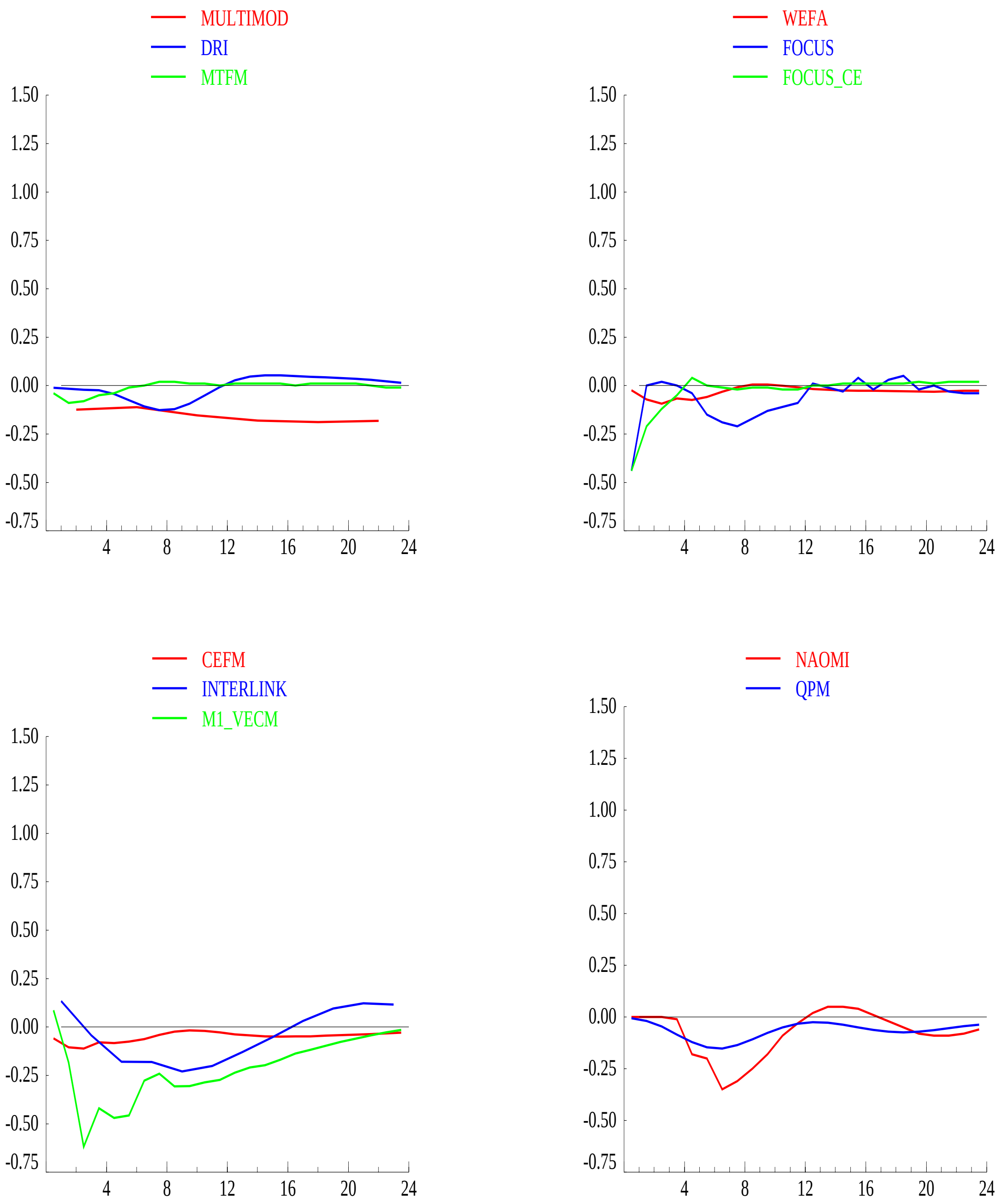
Nominal Short-Term Interest Rate Shock

Figure C.6a: **Real GDP**, Per cent, Shock minus Control



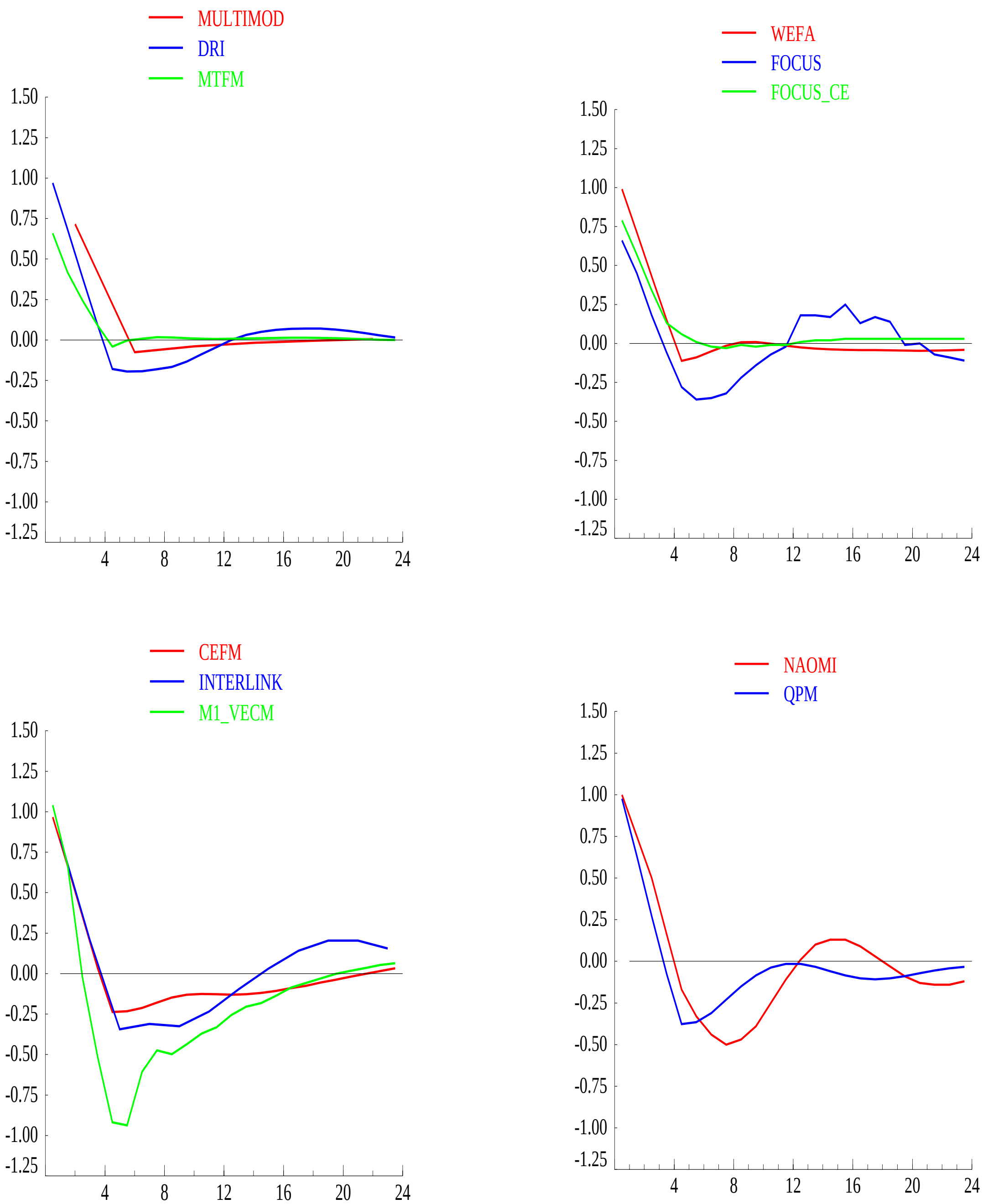
Nominal Short-Term Interest Rate Shock

Figure C.6b: **Inflation**, Percentage point, Shock minus Control



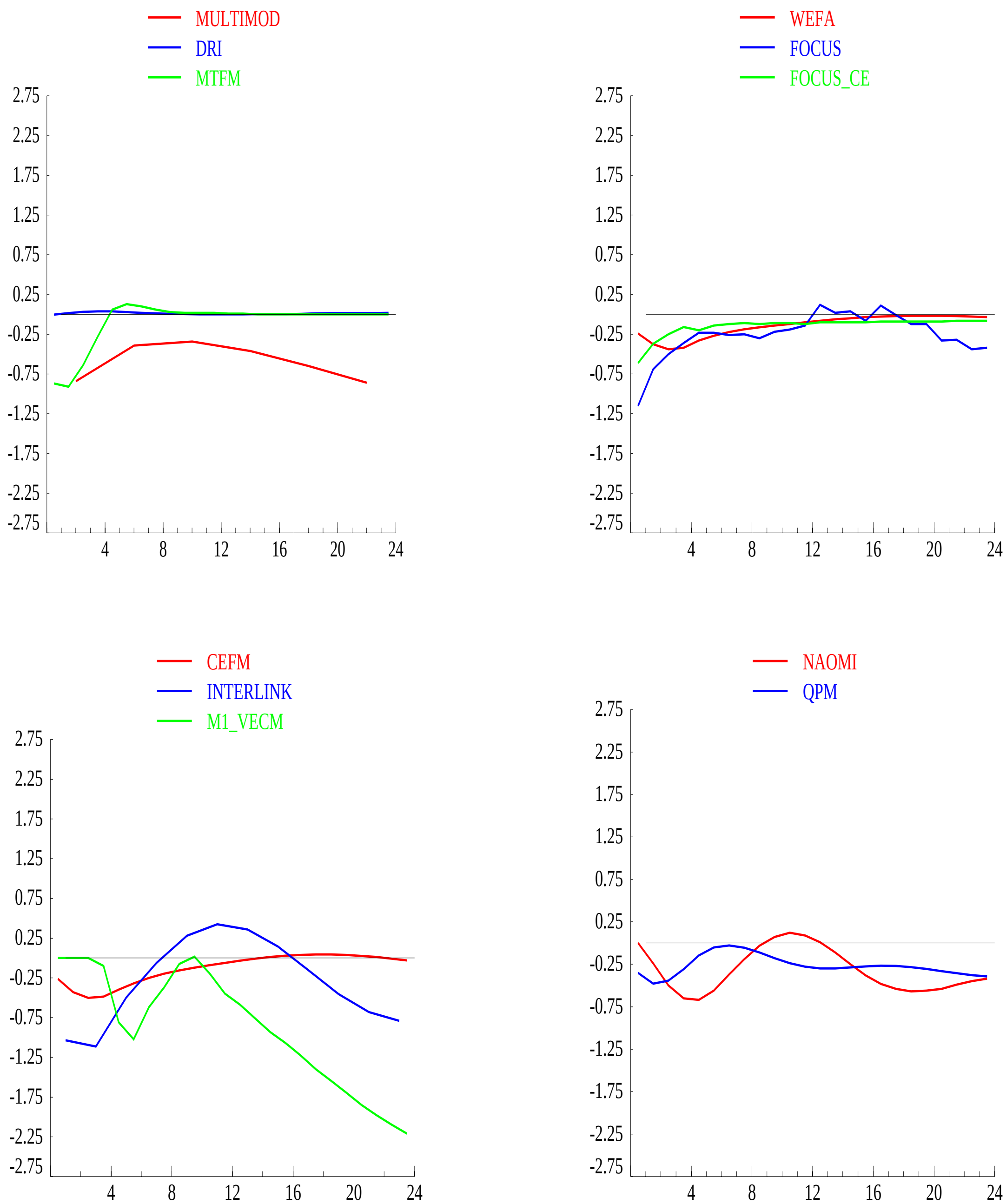
Nominal Short-Term Interest Rate Shock

Figure C.6c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



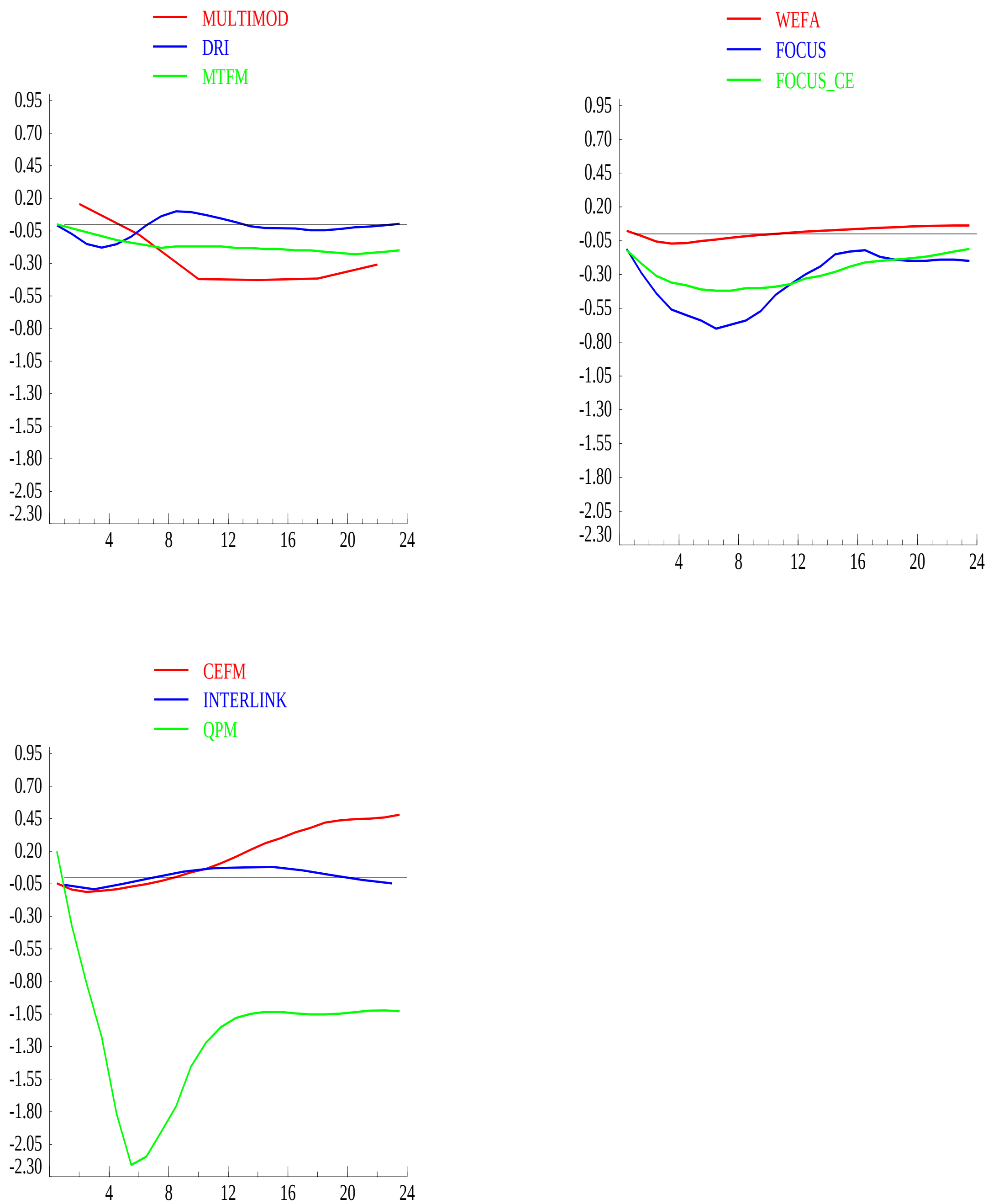
Nominal Short-Term Interest Rate Shock

Figure C.6d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



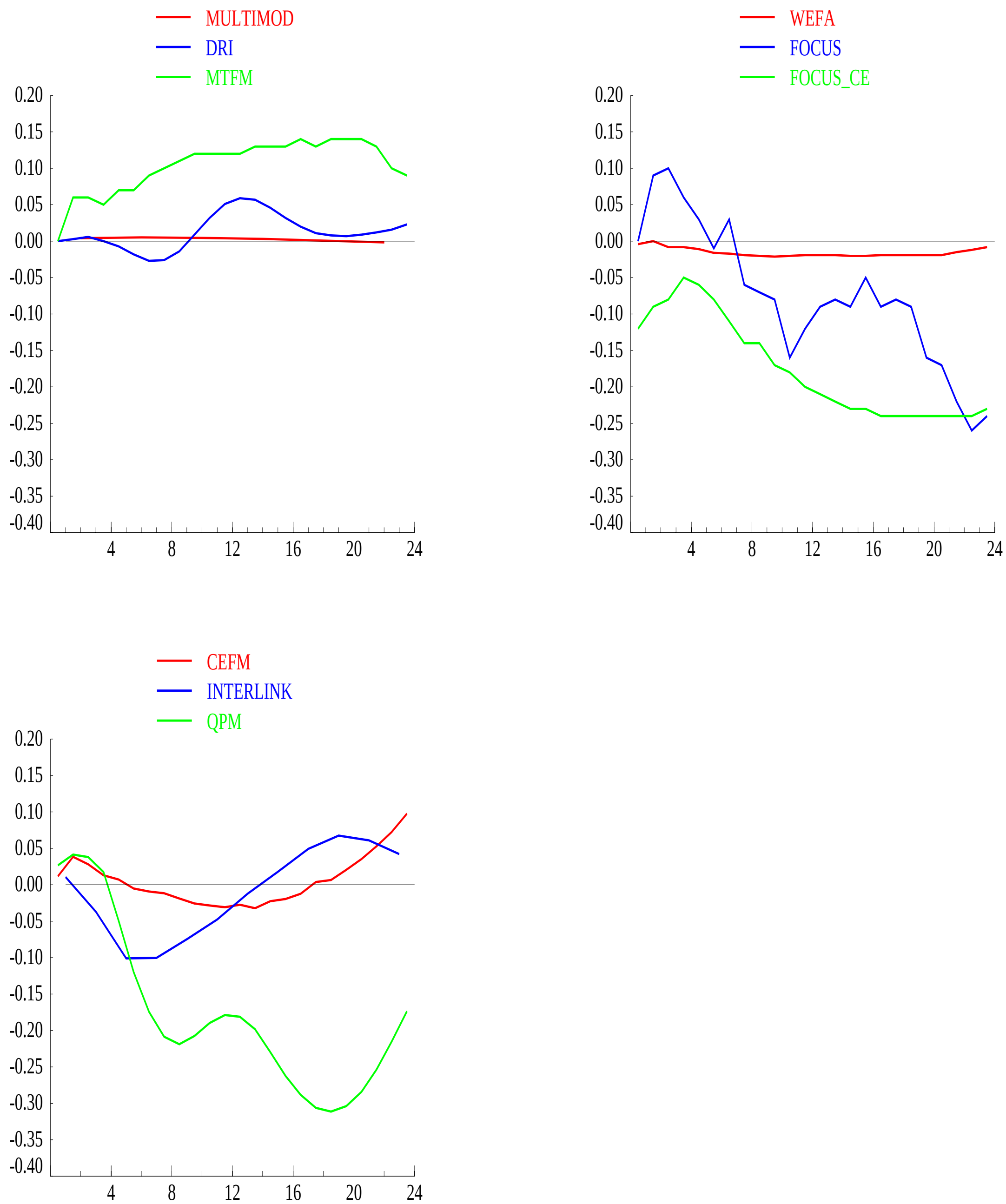
Nominal Long-Term Interest Rate Shock

Figure C.7a: **Real GDP**, Per cent, Shock minus Control



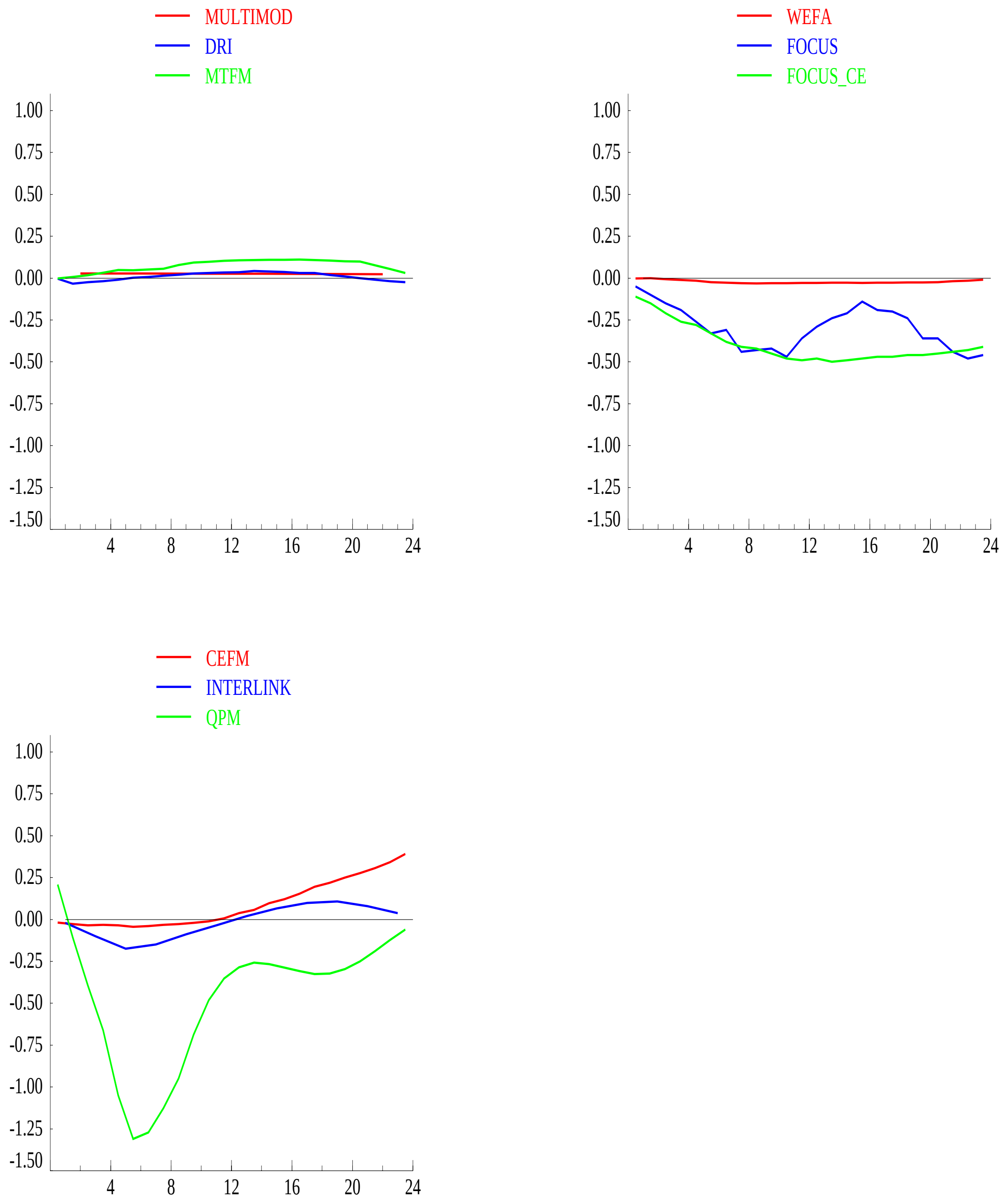
Nominal Long-Term Interest Rate Shock

Figure C.7b: **Inflation**, Percentage point, Shock minus Control



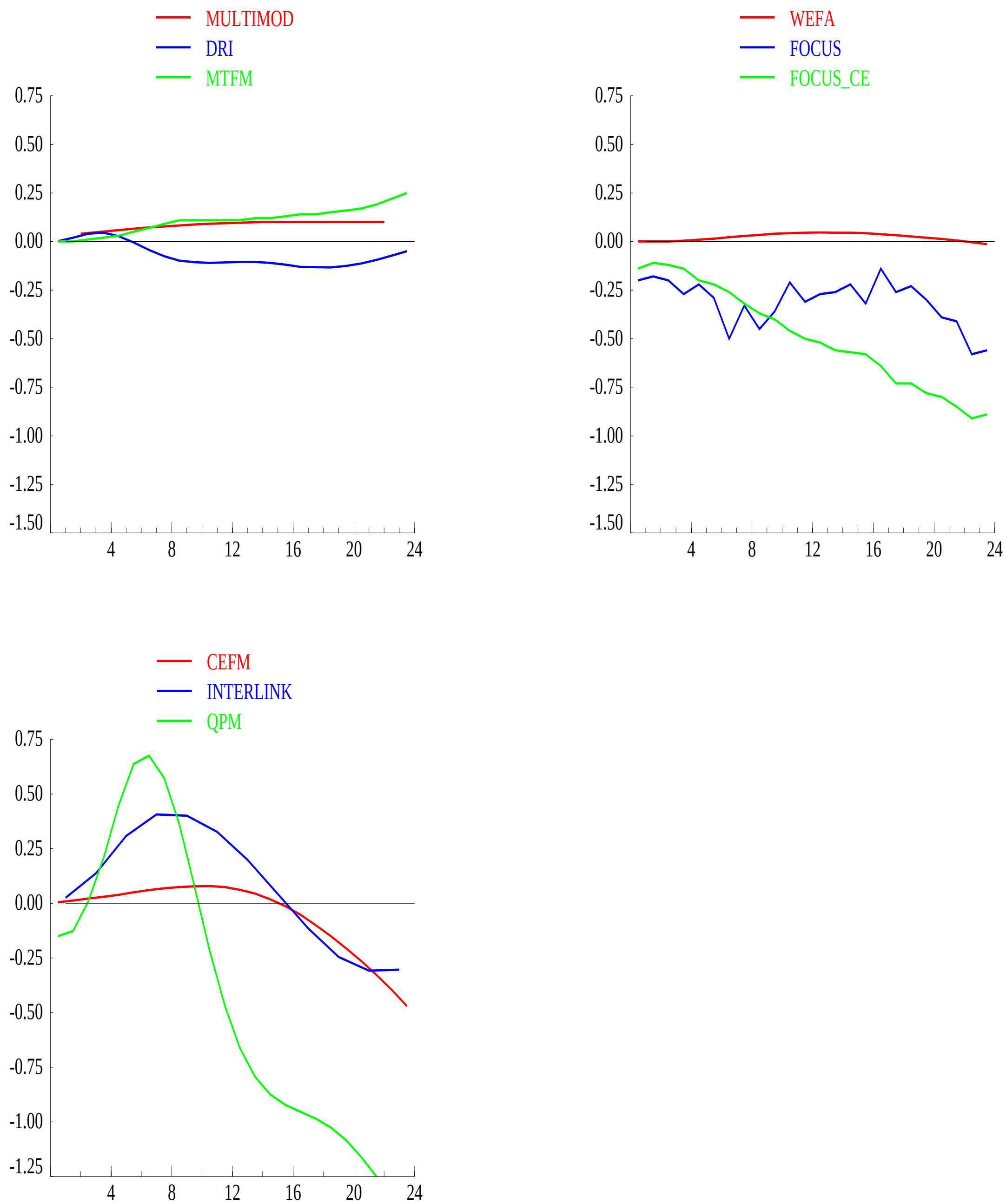
Nominal Long-Term Interest Rate Shock

Figure C.7c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



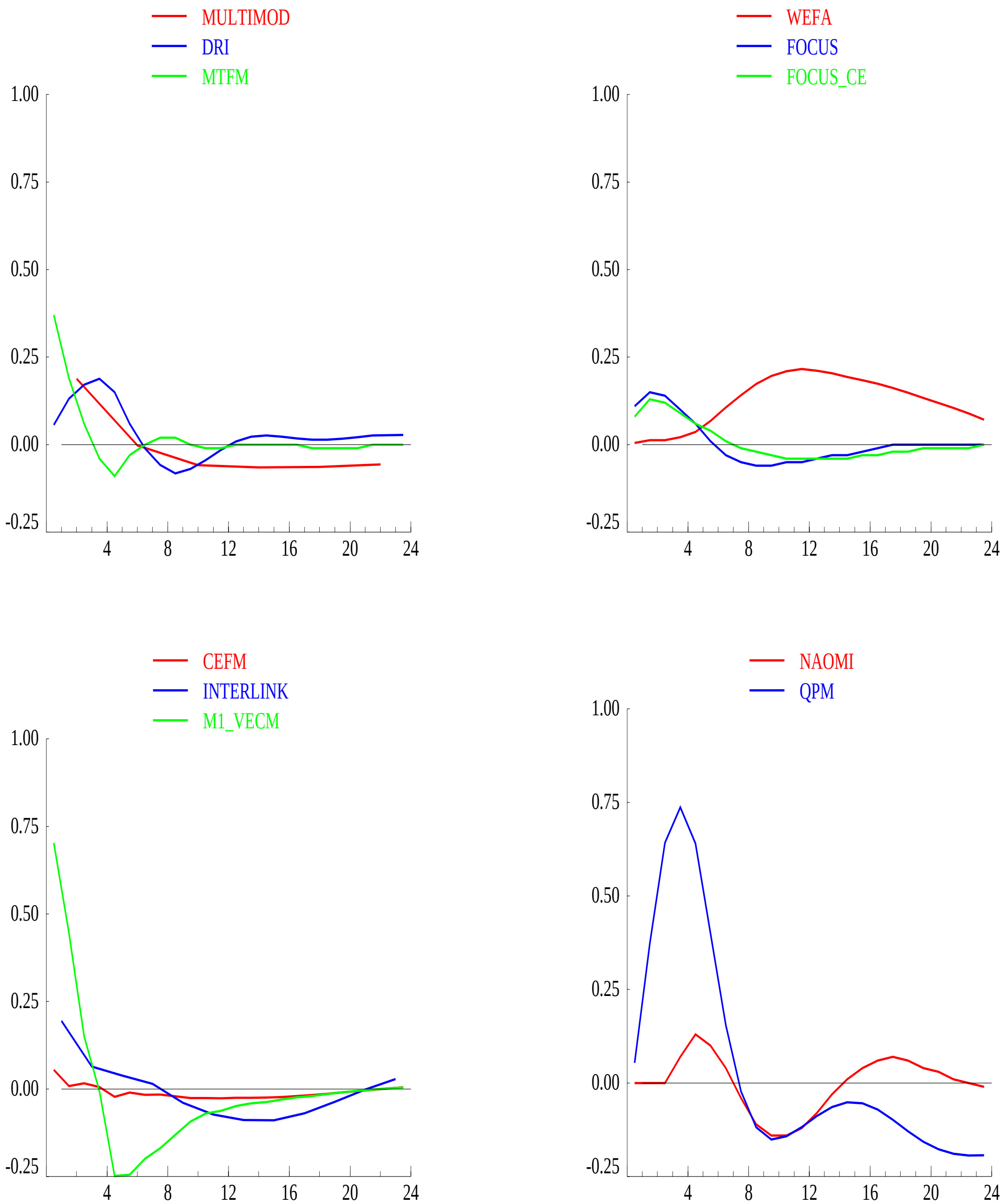
Nominal Long-Term Interest Rate Shock

Figure C.7d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



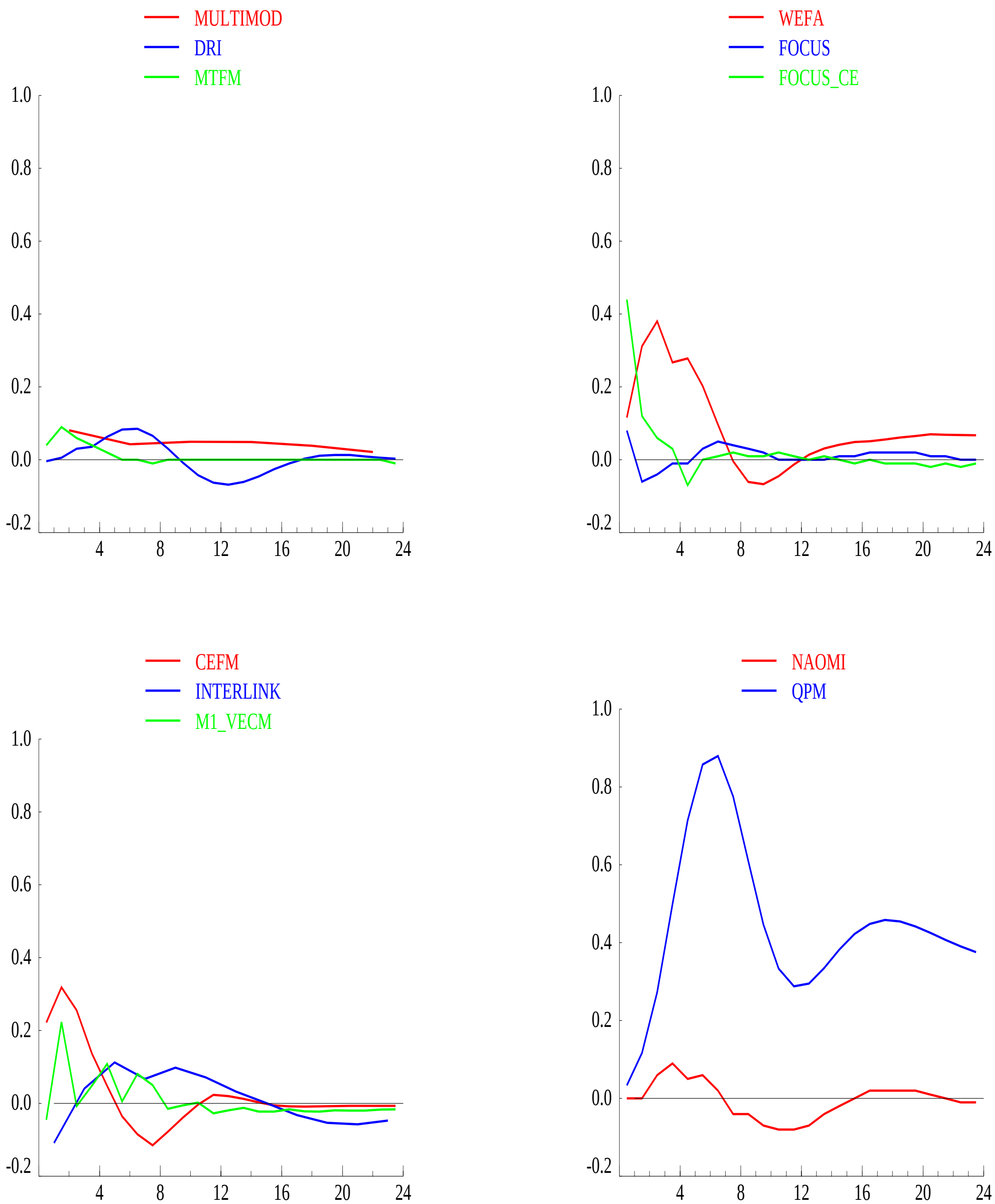
Nominal Exchange Rate Shock

Figure C.8a: **Real GDP**, Per cent, Shock minus Control



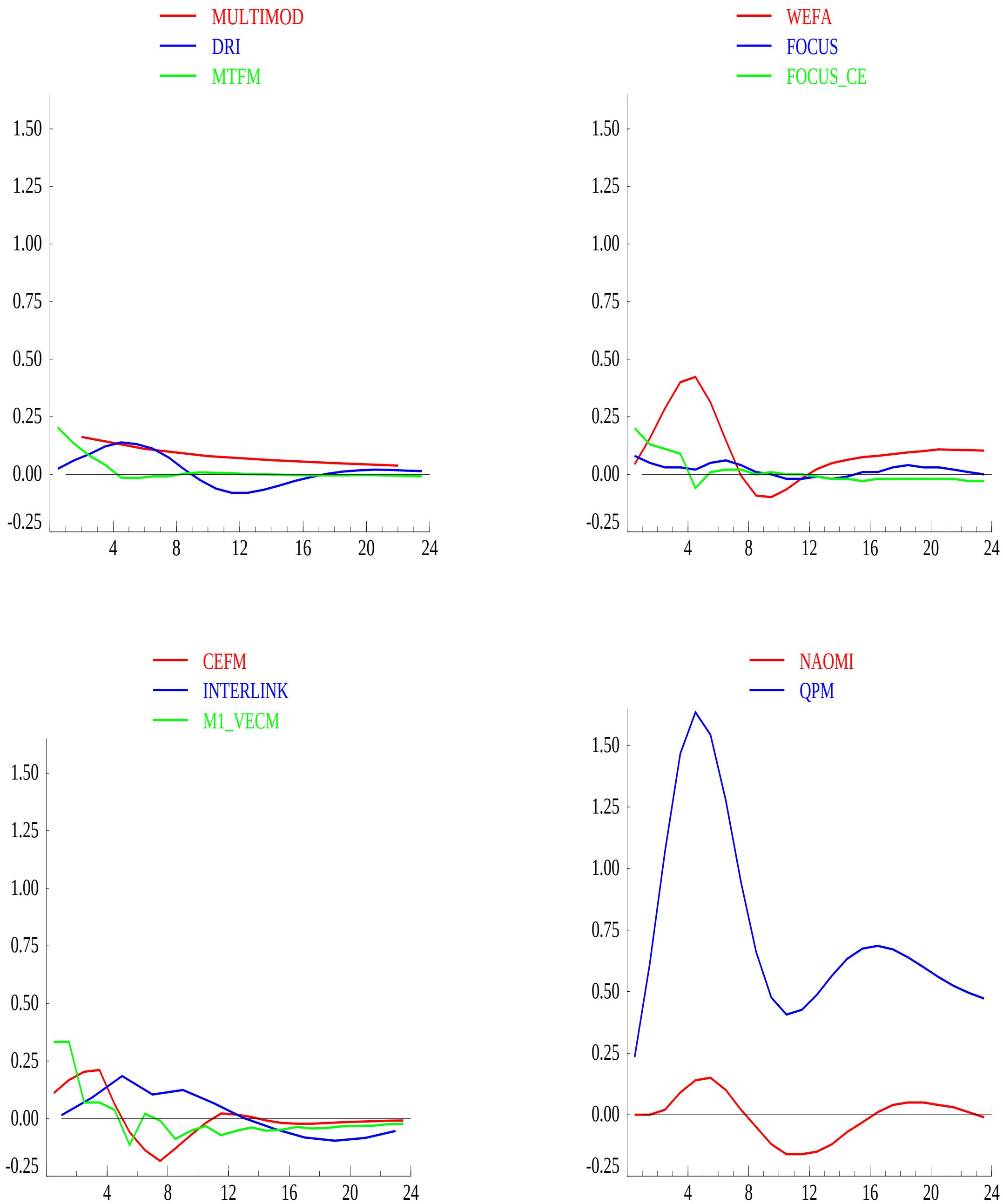
Nominal Exchange Rate Shock

Figure C.8b: **Inflation**, Percentage point, Shock minus Control



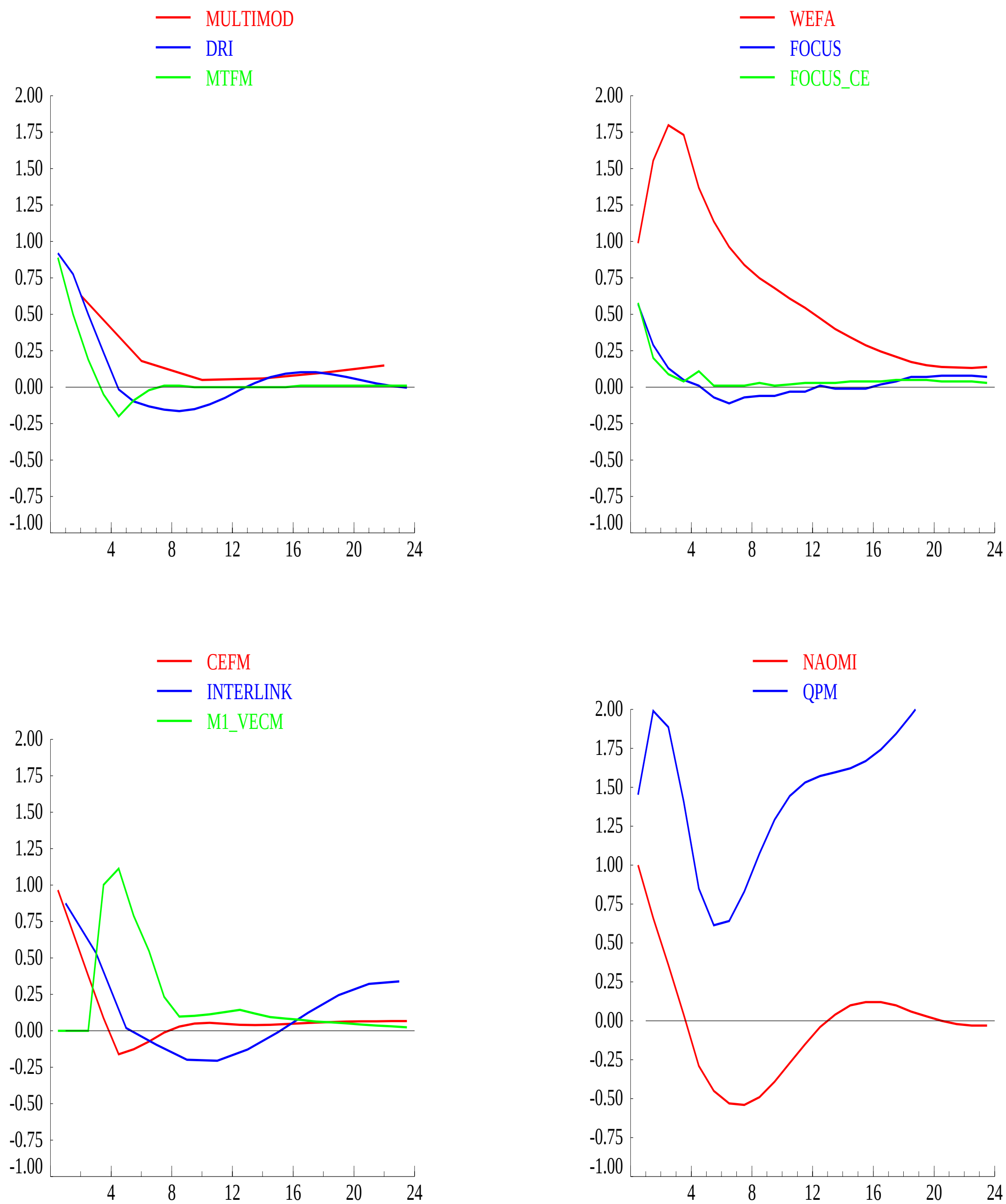
Nominal Exchange Rate Shock

Figure C.8c: **Nominal Short-Term Interest Rate**, Percentage point, Shock minus Control



Nominal Exchange Rate Shock

Figure C.8d: **Nominal Exchange Rate**, Per cent, Shock minus Control
(+) depreciation, (–) appreciation



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