ToTEM: The Bank of Canada's New Projection and Policy-Analysis Model

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- *When the Quarterly Projection Model (QPM) was first used in 1993 as the Bank's main projection and policy-analysis tool, it was considered state of the art among central bank models.*
- *Since QPM's introduction, refinements in modelling techniques, combined with enormous increases in computing power, have led to the development of a new generation of macroeconomic models, commonly referred to as dynamic stochastic general-equilibrium models. The Bank of Canada's new projection and policy-analysis model, the Terms-of-Trade Economic Model, or ToTEM, is such a model.*
- *ToTEM contains four distinct finished-product sectors as well as a commodity-producing sector. The move to a multiple-goods structure means that ToTEM can inform the judgment of Bank staff on a much wider variety of shocks, including relative price shocks.*
- *ToTEM's parameters have been chosen to reflect more recent data in which the volatility and persistence of inflation have declined significantly. One implication of this change is that, in response to typical shocks, inflation returns to the 2 per cent target somewhat faster in ToTEM than in QPM, about six quarters, on average.*

In December 2005, the Terms-of-Trade Economic Model, or ToTEM, replaced the Quarterly Projection Model (QPM) as the Bank of Canada's principal projection and policy-analysis model for the Canadian economy.[1] When it was introduced in September 1993, the aspirations for QPM were decidedly ambitious.[2] It was intended to serve both as the main tool for producing the staff economic projection, which is a key input into the monetary policy decision process (see Macklem 2002), and as a research tool for analyzing significant changes in economic structure or macroeconomic policies that require a deeper understanding of the longer-term equilibrating forces at work in the economy. And by any metric, QPM was highly successful. It helped the staff to interpret the shocks that have hit the Canadian economy since its implementation and to understand many of the key Canadian macroeconomic issues of the 1990s.[3] QPM also had a major impact on the modelling efforts of other inflation-targeting central banks throughout the world.[4]

ToTEM continues the key design philosophy and view of the economy underlying QPM but benefits from the

1. Earlier, two parallel or "shadow" projections were conducted with the model, in conjunction with QPM. For a complete description of ToTEM, see Murchison and Rennison (2006).

2. For a description of the steady-state version of QPM, SSQPM, see Black et al. (1994). For the dynamic model, see Coletti et al. (1996).

3. For a discussion of the important role played by economic models at the Bank of Canada, see Coletti and Murchison (2002) and Duguay and Longworth (1998).

4. In particular, the Reserve Bank of New Zealand and the Swedish Riksbank employ variations of the QPM. More recently the QPM has significantly influenced modelling efforts at the Bank of Japan. Reference to QPM's influence on other central bank models is also made in the 15 July edition of *The Economist* (see Special Report on Economic Models: "Big Questions and Big Numbers").

leaps in technological progress in economics and computing power of the past decade to enhance the fundamental strengths of the earlier model. ToTEM has a stronger theoretical foundation and better explains the dynamics of the Canadian economy.

ToTEM continues the key design philosophy and view of the economy underlying QPM but benefits from the leaps in technological progress in economics and computing power of the past decade to enhance the fundamental strengths of the earlier model.

The purpose of this article is to explain the motivation behind the development of ToTEM, to provide an overview of the model and its calibration, and to describe some simple simulations that illustrate a few of its key properties. A concluding section provides some indication of how the model is expected to evolve.

The Motivation for Developing ToTEM

Since QPM was first used by Bank of Canada staff in 1993, significant advances have been made in the field of applied macroeconomic modelling. Foremost is a more structural approach to modelling economic dynamics that views the economy as a set of rational agents, with each trying to explicitly maximize its well-being, subject to a set of constraints. The model's behaviour, both in and out of steady state, can thus be traced to a set of fundamental assumptions about the structure of the economy.[5] This increased reliance on economic theory in the dynamic model, in turn, results in model simulations that are easier to understand and to explain.

In addition, improved techniques for introducing multiple products into models and greater computing power have facilitated the use of richer, more realistic models that require fewer simplifying assumptions. These advances allow new models like ToTEM to maintain a more detailed structure than was possible with QPM. In particular, ToTEM is better able to capture international linkages in Canada. The core structure of QPM was designed around a one-good model; as a result, QPM had difficulty capturing, for instance, the relationship between commodity prices, the real exchange rate, and real gross domestic product (GDP). Staff therefore had to frequently introduce judgment, based on atheoretical add-on equations or other models (such as Macklem 1993) when analyzing terms-of-trade shocks (e.g., changes in commodity prices).

It is now possible to build models that accommodate multiple goods and optimizing agents where rational expectations are assumed throughout. Such models can be used to examine a broad range of questions of interest to a central bank, e.g., the determinants of exchange rate fluctuations, the implications of relative price movements (including commodity prices), and the aggregate implications of sector-specific shocks. With respect to the latter, it is reasonable to think that the impact of a movement in aggregate demand on core consumer price index (CPI) inflation[6] will differ, depending on whether it is the result of an increase in consumption or in investment demand.[7] Furthermore, in a multiple-goods structure with optimizing agents, a richer set of questions can be considered; e.g., from a welfare perspective, should a central bank target a price index that includes both domestically produced and imported goods, or should it focus solely on the former?

As well, by adopting a model whose core is that of an open economy dynamic stochastic general-equilibrium (DSGE) model, recent PhD graduates hired by the Bank will already be familiar with the basic structure of ToTEM, and therefore, less training will be required. In addition, the underlying optimizing-agent structure used in the model is very flexible. Additional features developed in the academic literature or at other central banks can be introduced (or turned off) in ToTEM in a much more straightforward manner than was the case with QPM. Finally, the use of linearization and new solution techniques allow the staff to simulate ToTEM in a fraction of the time required with QPM.

5. This approach was employed, for the most part, for the steady-state version of the model (SSQPM), but not for the dynamic model. The term steady state refers to the long-run equilibrium predicted by the model, after the effects of all shocks have fully dissipated.

6. The core measure of inflation excludes eight of the most volatile components of the CPI and adjusts the remaining components to remove the effect of changes in indirect taxes. The eight components removed are fruit, vegetables, gasoline, fuel oil, natural gas, intercity transportation, tobacco, and mortgage-interest costs.

7. In a one-good framework, a one per cent increase in aggregate demand will have a similar initial impact on prices whether it is the result of an increase in investment or in consumption demand.

To summarize, the objectives in developing ToTEM were threefold. First, the model needed to be more deeply grounded in economic theory than QPM, in order to provide, in particular, more coherent explanations of the model's business cycle dynamics. Second, the model would be better able to analyze the array of shocks that regularly hit the Canadian economy, especially terms-of-trade shocks, without introducing significant judgment when producing the quarterly projection. Finally, the model would be easier to work with, maintain, and change in line with advances in macroeconomic modelling. Having said this, the goal of ToTEM is not so much to implement a fundamentally new view of how the economy works as to provide a richer representation of the current view.

An Overview of ToTEM

ToTEM is an open economy DSGE model with four distinct finished-product sectors as well as a commodity-producing sector.[8] The behaviour of all key variables in ToTEM can be traced to a set of fundamental assumptions about the underlying structure of the Canadian economy, which greatly improves the model's ability to tell coherent, internally consistent stories about how the Canadian economy is—or will be—evolving. The multiple-products approach also allows ToTEM to inform the staff's judgment on a much wider variety of shocks, including relative price shocks, which was quite difficult with one-good models like QPM that included no role for relative prices.

The behaviour of all key variables in ToTEM can be traced to a set of fundamental assumptions about the underlying structure of the Canadian economy.

In ToTEM, there are four sets of agents: households, firms, the central bank, and a representative fiscal authority, or government. The first three are modelled as explicitly maximizing an objective, subject to a set of well-defined constraints. For example, firms in the model wish to maximize their profits, but are faced with constraints such as their production technology and the frequency with which they can change their prices. Consumers wish to maximize their well-being or "utility," subject to a budget constraint that limits the rate at which they can accumulate debt. Finally, the central bank in ToTEM wishes to maximize the well-being of consumers by minimizing deviations of inflation from the target and output from potential, as well as the variability of interest rates, while recognizing that the structure of the economy constrains its simultaneous achievement of these joint objectives (Cayen, Corbett, and Perrier, forthcoming).

Fiscal policy is modelled somewhat more traditionally in ToTEM. The government levies direct and indirect taxes and then spends or transfers to consumers the proceeds of these taxes according to a set of rules that are consistent with achieving a pre-specified ratio of debt to GDP over the medium term. The short-run responses of the rules are calibrated to mimic the historical behaviour of fiscal policy in Canada.

Turning to the details and starting with the role played by consumers (or households), ToTEM assumes the existence of two types of consumers, who differ only in their access to asset and credit markets. The first type, labelled "lifetime-income" consumers, face a lifetime budget constraint but can freely borrow or save so as to reallocate consumption across time. These agents base their consumption decisions on their total expected lifetime income and will choose a very smooth consumption path through time when the real interest rate is constant. Higher (lower) real interest rates will cause lifetime consumers to temporarily increase (reduce) their savings, in order to fully exploit the interest rate change. These agents are also assumed to own the domestic companies and are therefore the recipients of any profits.

"Current-income" consumers, in contrast, face a period-by-period budget constraint that equates their current consumption with their disposable income, including government transfers. In addition to not being able to save or dissave, current-income consumers do not own shares in companies and therefore do not receive dividends. The presence of current-income consumers in ToTEM reflects the simple fact that not all households in the economy enjoy unlimited access to credit markets, as is typically assumed in DSGE models. In terms of model behaviour, the main implication of introducing current-income consumers is that changes to taxes and government transfers have larger consumption effects.

8. For an intuitive discussion of dynamic general-equilibrium (DGE) models, see Moran (2000).

Both types of household sell labour to domestic producers and receive the same hourly wage, which they negotiate with the firm. Here it is important to note that workers are assumed to possess skills that are partially specific to the individual, thereby implying imperfect substitutability across workers. This assumption about the structure of labour markets is important because it means that workers have some market power in determining their wage. We also assume that workers and firms renegotiate the nominal wage about once every six quarters, on average, rather than every period. Furthermore, contract renewals are staggered over time, so a constant proportion are renewed each period. The introduction of "sticky" nominal wages will play a crucial role in creating business cycles in ToTEM while at the same time allowing monetary policy to influence real variables, such as GDP, in the short run (monetary non-neutrality).

In determining households' desired real wage, the assumption that both consumption and leisure are valued by households implies that they will consider *both* their current consumption level and the number of hours they are working when negotiating their wage. All else being equal, higher consumption or higher labour input will cause households to demand a higher real wage. The former effect occurs because a high consumption level makes leisure relatively more valuable. Thus, the only way to persuade the household to continue working the same number of hours is to offer a higher real wage.

Turning to the set of firms in the model, ToTEM contains producers of four distinct types of finished products: consumption goods and services, investment goods, government goods, and export goods. Each type of firm combines capital services, labour, commodities, and imports to produce a finished good. In the current version of ToTEM, only the relative import concentration distinguishes these goods; future versions, however, will allow for differences in the relative intensities of all factor inputs. The production technology for finished goods is characterized by constant elasticity of substitution. Increased capital utilization is possible, but at a cost. In other words, if a firm chooses to use its capital more intensively (by, say, adding an extra shift), the capital stock will effectively age faster, which in turn will reduce its productivity.

In addition to choosing the optimal mix of inputs, firms set a price for their product with an eye to maximizing their expected profits. Under the assumption that the elasticity of demand for any particular firm's product is constant, profit maximization corresponds to choosing a price that is a constant markup over marginal cost.[9] However, as with nominal wages, we assume that prices are costly for the firm to adjust, and therefore it will do so infrequently, and in a staggered fashion.[10] It will therefore not be possible for the firm to maintain a constant markup, except in steady state. Rather, knowing that any price it chooses will likely be in effect for several periods, the firm will set its nominal price so as to maintain a particular average markup over the duration of the period. Subsequent shocks will then cause variations in the firm's relative price, leading to variations in its sales, with low-price firms capturing greater market share.

Imports are treated as inputs to production, rather than as separate final goods. An importing firm buys goods from the foreign economy according to the law of one price and sells them to producers of finished goods at a price that is also adjusted only periodically. Thus, movements in exchange rates or foreign prices are not fully reflected immediately in the price paid by domestic producers. Furthermore, since the prices of both imported inputs and finished products are sticky, the model includes an element of vertical or supply-chain price staggering, which is crucial in allowing the model to generate realistic exchange rate pass-through to the CPI.

ToTEM also contains a separate commodity-producing sector. This is important for Canada, not only because the production of raw commodities accounts for roughly 13 per cent of GDP in Canada, but also because the finished-products and raw-materials sectors are characterized by different technologies and competitive structure. Much of the production of raw materials is highly price inelastic in the short run. At the same time, it is difficult to differentiate a commodity produced in Canada from one produced abroad. Finally, for most commodities, Canada can be viewed as a price-taker: it is too small a supplier to have any influence on world commodity prices. To properly understand the effects of commodity-price shocks, it is therefore necessary for a model to contain an explicit distinction between the commodity-producing and manufacturing sectors, as well as their respective

9. As in the labour market, the goods market is assumed to be characterized by imperfect competition, which implies that firms have some power to choose a price different than that of their competitors and still remain in business. Marginal cost refers to the cost to the firm of producing one additional unit of output.

10. The frequency of price readjustment has been calibrated in ToTEM to about twice per year, broadly consistent with the survey evidence presented in Amirault, Kwan, and Wilkinson (2006).

markets. In ToTEM, commodities are either exported, consumed directly by households, or used in the production of finished products.

Given their importance to the conduct of monetary policy, it is worth highlighting two particular aspects of ToTEM: the inflation process and the monetary policy transmission mechanism. These two aspects also illustrate some interesting conceptual differences between ToTEM and QPM.

The inflation process

ToTEM and QPM differ somewhat in terms of a theory of price determination. The underlying "story" for why, for example, inflation tends to rise when demand exceeds long-run supply, differs across the two models. In ToTEM, price increases are driven by marginal cost increases; in QPM, the output gap is the critical determinant of inflation in the short run. These conceptual differences do not, however, imply important differences in the behaviour of inflation across the two models since, for the most part, movements in costs tend to coincide with movements in the output gap. Rather, quantitative differences in the behaviour of inflation across the two models reflect the historical sample used to calibrate ToTEM (see "Model Calibration," below) not differences in assumed market structure.

In ToTEM, price increases are driven by marginal cost increases; in QPM, the output gap is the critical determinant of inflation in the short run.

As is now the convention in the literature on DSGE models, firms in ToTEM seek to maximize profits in an environment where the elasticity of demand for their goods is assumed to be constant and prices are sticky. A natural implication of these assumptions is that inflation is driven exclusively by current and expected future movements in marginal cost. Marginal cost, in turn, is increasing in firm-level output and, therefore, the firm-level short-run supply curve is upward sloping. For instance, higher production will tend to be associated with higher capital investment and more intensive utilization of existing capital. Both factors reduce productivity at the firm level, given that the installation of new capital causes production disruptions and that higher rates of utilization cause the existing capital stock to depreciate faster.

The monetary policy transmission mechanism

In Canada's current policy framework, the instrument of monetary policy is the target overnight interest rate.[11] In ToTEM, the Bank of Canada influences the nominal rate for 90-day commercial paper through its influence on the overnight rate. The level of the nominal short-term rate does not, however, directly affect real spending. Instead, consumption and investment decisions are based on the entire expected future path of short-term real interest rates; i.e., the demand side of the economy can be viewed as being influenced by a long-term real interest rate. Furthermore, changes in nominal short-term interest rates only influence this long-term real rate because prices and wages are not fully flexible in the short run. Similarly, monetary policy only affects the trade balance to the extent that nominal interest rate changes affect the real exchange rate, which, again, hinges on the assumption of nominal rigidity. In a world with fully flexible prices and wages, monetary policy would influence prices, but not real activity. In a world with considerable nominal rigidity, monetary policy influences inflation primarily through its influence on real activity.

In QPM, the adjusted yield spread,[12] by assumption, fulfilled dual roles as the instrument of monetary policy and as the relevant variable in households' consumption and savings decisions. In other words, there was a direct link between the actions of the central bank and consumption, and thus no way to explore the link between the influence of monetary policy and the degree of nominal rigidity.[13]

Model Calibration

As with any economic model, ToTEM contains several parameters for which economic theory does not assign specific values; rather, it provides only a sensible range of values. Typically, parameters are chosen so that

11. The overnight rate is the interest rate at which major financial institutions borrow and lend one-day (or "overnight") funds among themselves; the Bank sets a target level for that rate.

12. The adjusted yield spread is defined as the difference between the 90-day commercial paper rate and a 10-year government bond yield, adjusted for a measure of the term premium.

13. At the time, the use of the yield spread was justified on the grounds that it reflected the stance of policy better than short-term rates did and provided "a parsimonious way to capture the effects of the full term structure on aggregate spending" (Coletti et al. 1996).

the model's behaviour mimics as closely as possible the behaviour of the economy over some historical sample period. Specifically, the values for many of ToTEM's parameters were chosen such that the model's steady state exactly replicates key means in the data for the period 1980 to 2004. The values of the remaining parameters were chosen from estimates available in the existing literature or based on the model's ability to reproduce key properties of historical business cycles. Particular attention has been given to the model's ability to replicate certain temporal cross-correlations that appear to be robust in the historical data, and also to the model's theoretical impulse-response functions.

The time-series properties of certain key macro variables, most notably inflation, have changed markedly since the beginning of the 1990s (see Longworth 2002 for an extensive review). While exact dates are somewhat uncertain, both the volatility and persistence of inflation have declined markedly in the 1990s and 2000s relative to previous decades. In addition, the slope of the empirical Phillips curve has decreased, as has the extent to which exchange rate movements get passed through to the CPI. In other words, inflation is now less sensitive to excess demand and supply pressures as well as to movements in relative prices such as the exchange rate.

These changes in the properties of inflation are reflected in the behaviour of ToTEM. With respect to inflation persistence, for example, it takes seven quarters, on average, for inflation to return to the target following a shock in ToTEM when faced with the typical macroeconomic shocks observed over the 1980 to 2004 period, compared with about 10 quarters in QPM.[14] Moreover, when the shocks are drawn from the less-volatile 1991 to 2005 period, the average time declines to six quarters (Cayen, Corbett, and Perrier, forthcoming).[15]

An important consequence of a reduction in the persistence of structural inflation is that monetary policy need not look as far into the future when setting policy since, all else being equal, the maximum impact on inflation of monetary policy actions arrives sooner. This implication is also reflected in the calibration of ToTEM's optimized monetary policy rule: when specified in terms of year-over-year inflation, the policy feedback horizon is one year, which is again, about half of the six to eight quarters assumed in QPM.

Exchange rate pass-through, defined as the per cent change in the core consumer price level at a particular time horizon stemming from an initial one per cent exchange rate movement of average persistence, is markedly lower in ToTEM than in QPM after two years and beyond. At a one-year horizon, both QPM and ToTEM predict pass-through of about 0.05 per cent. After two years, however, QPM predicts that this number should rise to 0.18 per cent, about double that predicted by ToTEM, and the difference continues to grow with the time horizon.

A qualitatively similar result obtains for differences in the influence of excess demand (or supply) on inflation across the two models. In general, a shock to domestic demand causes inflation to rise by less, and the peak response occurs sooner and diminishes faster in ToTEM than in QPM.

Model Properties: A Few Illustrative Shocks

In this section, the implications of three exogenous shocks are analyzed using ToTEM to demonstrate the model's most important properties. The shocks selected are: (1) a temporary shock to households' desired level of consumption, (2) a temporary country risk premium or exchange rate shock, and (3) a temporary shock to the world price of commodities. Collectively, these shocks illustrate the main channels or propagation mechanisms in the model. In addition, they represent shocks frequently faced by the staff during the quarterly projection exercise. For the sake of brevity, we provide a description of the aggregate implications only for the consumption and exchange rate shocks, while providing somewhat more detail at the sectoral level for the commodity-price shock.

Consumption shock

This first shock shows the effects in ToTEM of an exogenously driven increase in domestic demand, in this case a temporary reduction in households' desired savings that causes consumption to increase by about 1.25 per cent at the end of the first year of the shock.

14. For a recent discussion of the appropriate inflation-target horizon in Canada, see Coletti, Selody, and Wilkins (2006).

15. It is important to note here that in measuring the time it takes for inflation to return to target over the 1991 to 2005 sample, we use an absolute criterion (inflation within 0.05 percentage points of the target, or between 1.95 and 2.05 per cent). As a result, the reduction in the time taken for inflation to return to the target, as defined here, reflects the reduction in the volatility, as well as the persistence, of inflation noted in the text above.

The responses of the key macroeconomic variables of interest are presented in Chart 1.[16] Two high-level features of the results are worth noting at the outset. First, there are no steady-state real effects on either stocks or flows from the shock because it is assumed to be temporary. Second, inflation responds very little to the shock and quickly returns to the baseline path.

Turning to some of the details of the simulation results and beginning with the composition of domestic demand, we first note that ToTEM's multiple-products structure affects the results. Real interest rates rise immediately following the increase in consumption, leading to a real appreciation of the currency and a decline in the relative price of investment, given that investment goods have a high import concentration in Canada. The relative price of investment declines sufficiently to generate a small increase in demand for capital goods. A peak increase of just over 0.1 per cent occurs in the middle of the second year of the simulation.[17]

The initial impact of the temporary consumption shock is an increase in real GDP of almost 0.5 per cent by the end of the first year, after which output gradually returns to control. The combination of stronger demand for consumption goods, which requires imports as factor inputs, and a 0.6 per cent real appreciation of the currency generates a 0.7 per cent increase in import demand, while exports fall by about 0.5 per cent. Thus, while GDP increases following a shock to domestic demand, the trade balance also worsens, suggesting that some of the extra consumption is borrowed from abroad.

It is also instructive to examine the supply response in the model in more detail. In ToTEM, firms meet an unexpected increase in demand for consumption goods in the short run through an increase in the use of variable inputs: labour, capital services, commodities, and imports. While the firm chooses the input combination so as to minimize its costs, no combination exists that will allow it to increase production without increasing its marginal cost, even if the prices of factor inputs remain unchanged. As a result of higher costs, all firms supplying more output would like to charge a higher price in order to maintain their profit margins. Only a subset, however, can change their price when the shock hits, so in aggregate, prices will rise by less than marginal cost and the average markup in the consumption-goods sector declines.

ToTEM predicts that a 0.4 per cent increase in real marginal cost will cause year-over-year core CPI inflation to rise 0.17 percentage points above target at the end of year one. So how does monetary policy ensure a quick return of inflation to the target in ToTEM? First, note that the increase in expected inflation causes a modest tightening (12 basis points at its peak) by the monetary authority. The tightening phase lasts about 2.5 years, however, and in ToTEM, the duration of the interest rate increase is as important as the size. Thus, monetary policy commits to a sustained, albeit modest, period of tighter policy that causes the expected future real interest rate to rise. Higher real interest rates reduce consumers' incentive to indulge in present consumption and firms' incentive to invest. At the same time, higher rates cause a real appreciation of the currency that facilitates a substitution away from domestic factor inputs towards imported inputs. The exchange rate appreciation also increases the price of Canadian exports abroad, thereby reducing export activity and further reducing excess demand pressures. All of these effects combine to help restore aggregate demand at its long-run, sustainable level, while at the same time returning inflation to its targeted level.

In ToTEM, the duration of the interest rate increase is as important as the size.

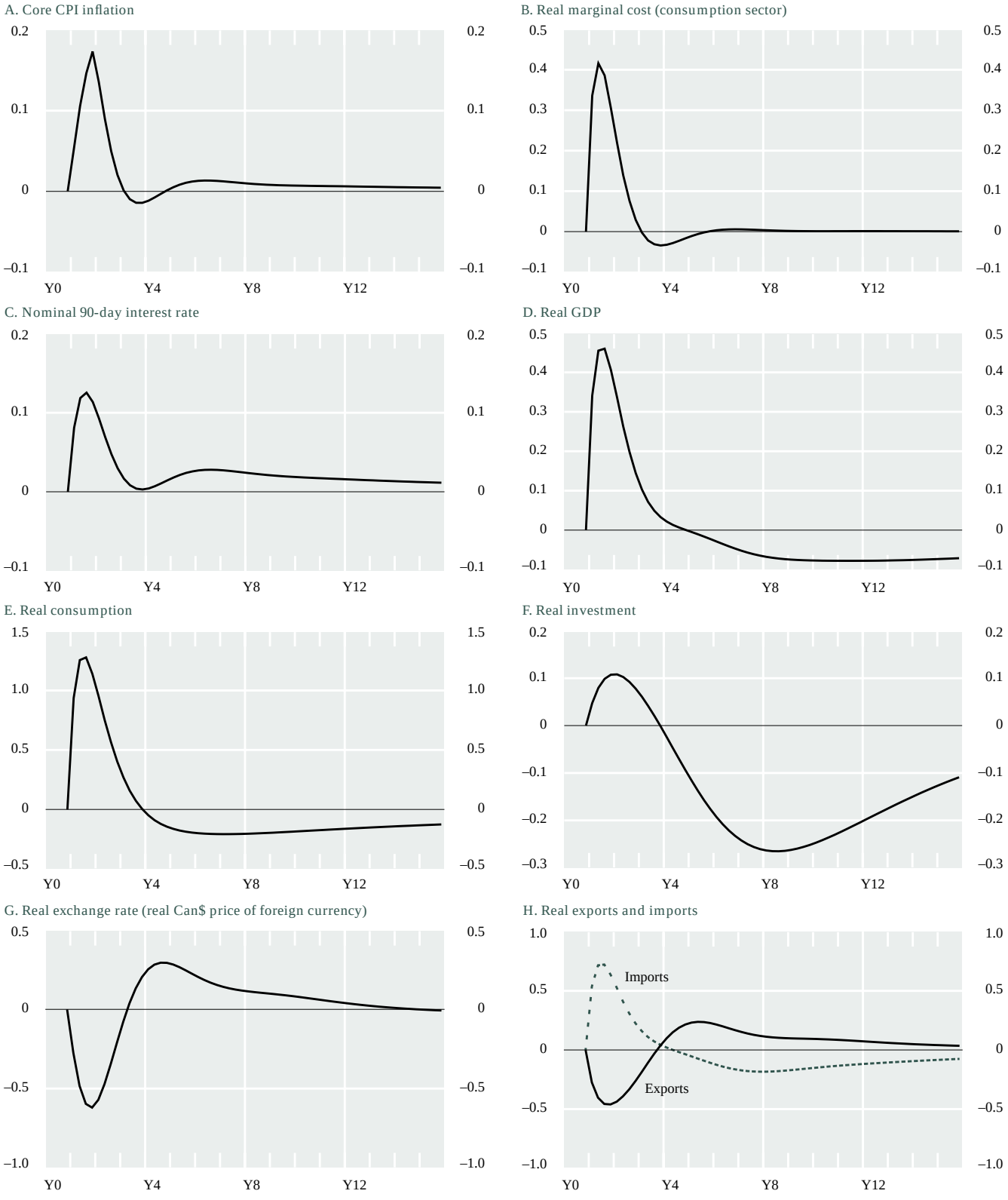
As with any model that accounts for stocks, in ToTEM, there is a price to be paid by consumers for their temporary spending binge. In this case, the increase in consumption is partially financed through a deterioration of the net foreign asset (NFA) position. However, because of the assumption that the desired NFA level remains unchanged in the shock, a period of dissavings must be matched by a period of increased savings which, in ToTEM, is reflected by a sustained period of consumption that is slightly below steady state (starting in year four).

16. The charts show the per cent deviations (relative to a baseline simulation with no shock) for all variables except interest rates and inflation rates, which are expressed in percentage points. Owing to the fact that simulations are done with a linearized version of ToTEM, the starting point (or baseline) does not affect the simulation results. Furthermore, the response of the model is linear in the magnitude of the shock.

17. This contrasts with the typical result found with one-good DSGE models, i.e., that consumption and investment move in opposite directions.

Chart 1

Consumption Shock



Exchange rate shock

This second shock shows the effects in ToTEM of an exogenous shock to the country-specific risk premium, which has the effect of depreciating the currency by about 6 per cent by the end of the first year. In Bank of Canada parlance, this may be regarded as a Type Two exchange rate movement, in that it does not reflect the endogenous adjustment of the exchange rate to another shock or economic development that has direct implications itself for the demand for Canadian goods and services, but considers the exchange rate depreciation itself the shock.[18]

The responses of the key macroeconomic variables of interest are presented in Chart 2. The solid lines capture the response of the baseline calibration of ToTEM, which assumes a net steady-state markup of prices over marginal cost of 5 per cent. The broken lines illustrate the model's response to the same shock, assuming a markup of 2 per cent, which corresponds to a higher level of competition in the goods market (goods become more substitutable). For the moment, we will focus on the behaviour of the baseline model calibration.

Again, some high-level results are worth noting at the outset. As with the temporary consumption shock, there are no steady-state real effects on either stocks or flows from the shock because it is temporary. However, the effects of this shock on inflation are somewhat longer-lived than in the first shock, given that, in ToTEM, a depreciation of the exchange rate feeds into import prices and marginal cost only gradually, whereas a shock to demand affects marginal cost immediately.

Specifically, a depreciation of the exchange rate in ToTEM causes an increase in the Canadian-dollar price of imported intermediate goods, investment goods, and commodities—all inputs to the production of finished products. A depreciation of the exchange rate therefore triggers an inward shift of the supply curve in the goods market.

Exporters of manufactured goods are affected by both the supply and demand dimensions of the shock. The price of their inputs increases, but demand for the output also increases. On net, the depreciation causes manufactured and commodity exports to rise by a combined 2 per cent, while consumption declines by as much as 0.35 per cent.

Unlike in QPM, imports also increase in ToTEM (by about 0.5 per cent) immediately following a depreciation of the exchange rate. This difference emerges because, in ToTEM, the negative substitution effect (due to higher prices paid for imported intermediate inputs) is weaker than the income effect (higher demand for all inputs as aggregate demand increases). On net, real GDP increases by almost 0.4 per cent towards the end of the second year of the simulation, and returns to its control level after about four years.

Higher prices for import, investment, and commodity inputs to production eventually cause core CPI inflation to rise (peaking at 0.3 percentage points in year two of the shock) as producers of consumer products partially pass on their cost increases in the form of higher retail prices, which triggers the monetary authority to tighten policy by almost 50 basis points in the second year.

The experimental modification of the assumed degree of competition in the finished-products sector is interesting in that it demonstrates the breadth of analysis that can be carried out with more structural models such as ToTEM, whose parameters all have explicit economic interpretations.

All else being equal, when markets are very competitive, demand, and therefore marginal cost, will be very sensitive to a firm's relative price in ToTEM. This means that high competition should cause less relative-price variation and therefore, at the aggregate level, inflation should be less sensitive to movements in economy-wide real marginal cost. The same nominal exchange rate shock now causes core CPI inflation to peak at about 0.17 percentage points above control, about half of its baseline-calibration response (broken line, Chart 2A). As a result of the weaker inflation response, monetary policy is not required to tighten by as much and, thus, output peaks at just over 0.8 per cent above control, more than double its baseline response.

Commodity-price shock

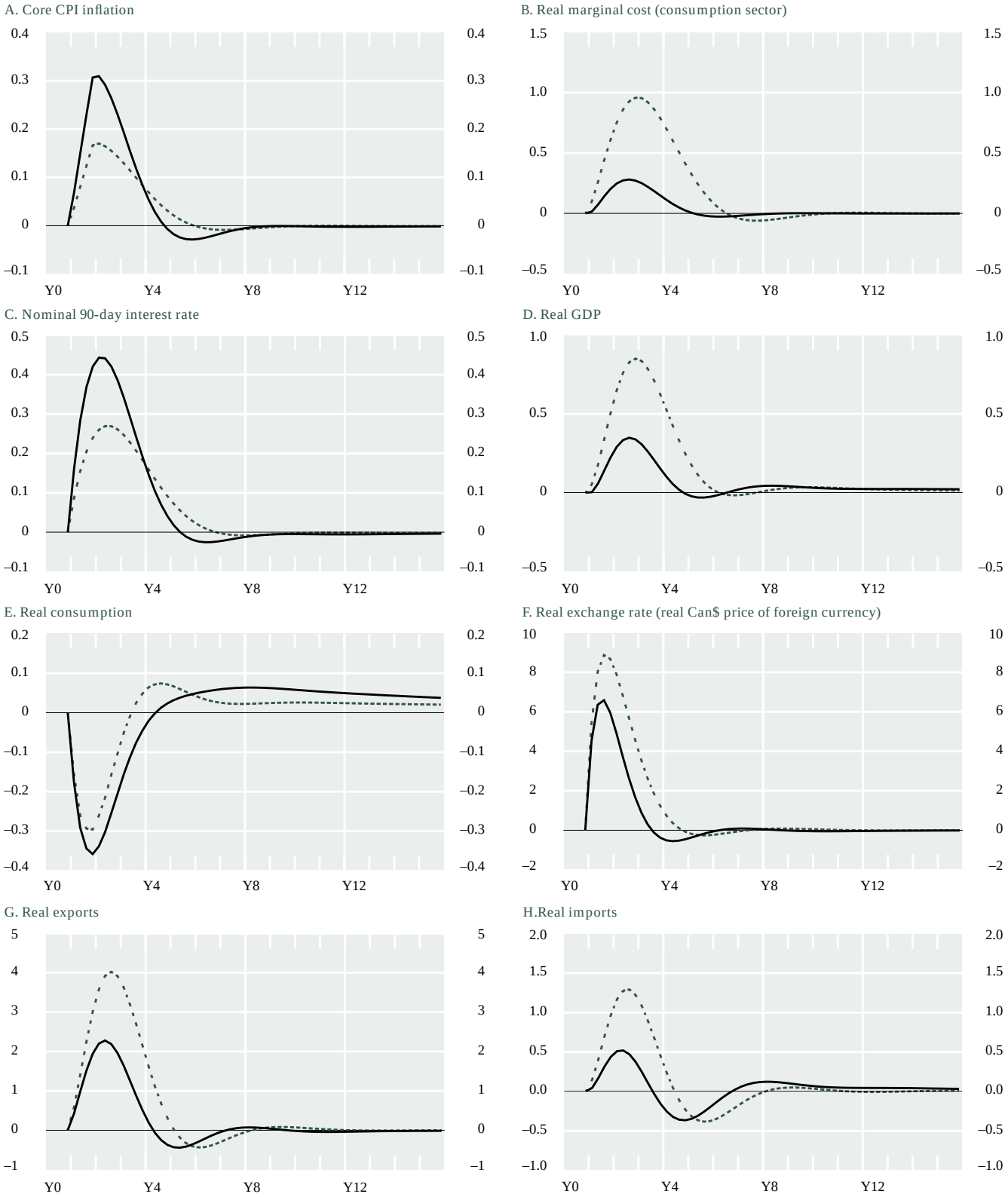
The third shock shows the effects in ToTEM of a temporary 10 per cent increase in the world price of commodities stemming from a supply disruption that arises in other commodity-producing countries but leaves Canada's commodity supply unchanged. It is assumed that the shock affects the price of all commodities—energy and non-energy—the same. We also assume that this negative supply shock temporarily lowers rest-of-world GDP, which reduces the demand for Canadian manufactured exports.

18. See Ragan (2005) for a discussion of Type One versus Type Two exchange rate movements.

Chart 2

Exchange Rate Shock

baseline calibration (5% steady-state markup)
high-competition scenario (2 % steady-state markup)



Perhaps the most striking feature of the results is just how important commodity prices are for the Canadian economy and how long lasting the effects of even a temporary change in commodity prices (roughly three years) can be (Chart 3). One of the most noteworthy effects of the increase in commodity prices is the sustained increase in consumption (about 0.4 per cent for the first five years), which lasts about 20 years. This effect captures the response of households to the increase in their wealth, which is evidenced by an immediate increase in their net foreign asset (NFA) holdings. Furthermore, since we assume an unchanged desired NFA position, even stronger consumption is required to gradually restore the former NFA level.

Also noteworthy is the 2.5 per cent appreciation of the real exchange rate that builds over the first year and then persists for several years to come.[19] This real appreciation is generated endogenously by the model in order to encourage higher imports, which are needed first to stabilize the NFA position and ultimately to restore it to its pre-shock level. The appreciation eventually leads to a fall in the price of import-intensive investment, thereby boosting investment spending by as much as 0.7 per cent in year five.

On the trade side, commodity exports essentially form the residual between commodity production and demand for commodities in Canada. For a temporary shock such as this, the positive supply response by commodity producers is quite small.[20] Owing to the price increase, however, there is some substitution away from commodities by firms and consumers, and so commodity exports rise about 1.4 per cent. Manufactured exports, in contrast, fall by 1.2 per cent at the end of year two in response to the appreciation of the exchange rate and the reduction in demand in the rest of the world. Finally, imports flourish (0.5 per cent in year five), owing to both an immediate and strong income effect and a strong substitution effect that builds gradually as lower import prices at the border are passed through to manufacturing firms.

In the labour market, higher overall demand in the economy causes firms to increase their demand for labour input, measured in ToTEM as hours worked. This increase in hours, combined with stronger consumption spending, leads households to raise their desired real wage. However, since only a small subset of households can actually renegotiate their wage at the outset of the shock (recall that wage contracts are staggered and last about six quarters, on average, in ToTEM), the aggregate real consumer wage initially falls by as much as 0.2 per cent, which, from the representative firm's point of view, helps to stem the rise in real marginal cost.[21] Only after about three years does the real wage rise above control.

Turning to the nominal side of the economy, core CPI inflation initially rises by as much as 0.1 per cent (0.2 per cent for CPI inflation) and then falls below control in year three. The behaviour of inflation can be explained by the impact of commodity and import prices on real marginal cost in the consumption sector. Initially, the large increase in commodity prices, combined with an overall reduction in productivity, causes marginal cost to rise. However, as commodity prices return to control and the appreciation of the exchange rate begins to show up in the price paid by manufacturing firms for imports, real marginal cost falls below control.

Over the medium term, real GDP remains above control while inflation has returned to target. This arises from the increase in capital stock from higher investment activity in preceding years. Thus, a persistent rise in the terms of trade in ToTEM generates a small, but sustained, increase in potential output. Were the commodity-price shock permanent, potential output would rise permanently by about 0.5 per cent.

Conclusion

The decision to develop a new model was intended to return the staff's projection and policy-analysis model to its state-of-the-art status. The goal was to build a model in the spirit of QPM, but one that is more structural, with multiple goods that will handle a wider array of shocks, with less need for judgmental intervention.

While ToTEM is a significant accomplishment, it should be stressed that all economic models are simplified representations of a complex reality. How good a representation they are depends on the state of knowledge and technology in the economics discipline at the time they are built. Indeed, our intended approach is to make continuous improvements to

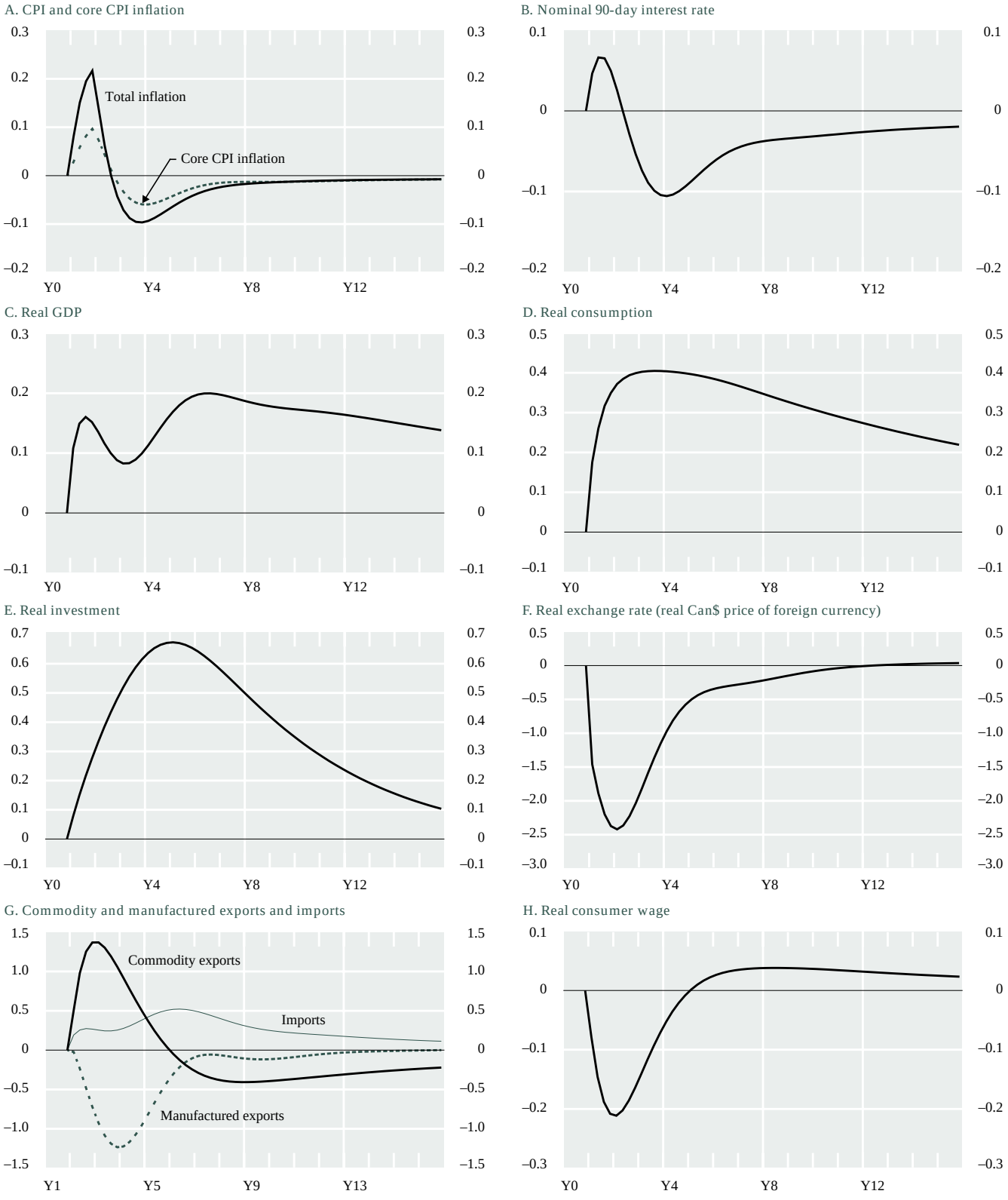
19. If the increase in commodity prices were permanent, the real exchange rate appreciation would be more than twice as large, consistent with the cointegration evidence for Canada (see Amano and van Norden 1995).

20. The supply response by commodity producers depends critically on the persistence of the commodity-price increase. A permanent increase would generate a significantly larger positive supply response.

21. In a world with flexible wages, the real wage would immediately rise, putting more upward pressure on real marginal cost and reducing the overall GDP expansion. Thus, in a model like ToTEM, the elasticity of real activity with respect to commodity prices is closely linked to the degree of nominal flexibility in the labour market.

Chart 3

Commodity-Price Shock



ToTEM as new technologies and knowledge become available. In the near term, we intend to concentrate our efforts on improving two aspects of the model: its empirical properties and its supply side, particularly in the commodities sector.

Our intended approach is to make continuous improvements to ToTEM as new technologies and knowledge become available.

With respect to the empirical properties, our plan is to formally estimate the model parameters directly, although it may be necessary for a time to use calibration techniques for some parameters. In general, the benefits of estimation over informal calibration techniques are twofold. First, estimation should help the model make more accurate forecasts. Second, it would yield a measure of the uncertainty associated with the parameter estimates that could be used to assess risks to the projection, to construct confidence intervals, and to aid in the design of more robust monetary policy rules.

With respect to the supply side of the model, each type of firm currently combines capital services, labour, commodities, and imports to produce a finished good. In the current version of ToTEM, only the relative import content distinguishes these goods; future versions, however, will allow for differences in the relative intensities of all factor inputs to reflect that capital goods and commodities are more capital intensive than consumer products and that government spending may be more labour intensive. Work is also planned to better capture adjustment costs in the production process and to make an explicit distinction between energy and non-energy commodities.

Finally, in the medium term, the staff plans to revisit the manner in which expectations are formed in ToTEM. While appropriate in most cases, purely rational expectations can be unrealistic under certain circumstances, particularly when unusual shocks that are not well understood by private agents hit the economy. Future versions of ToTEM will offer greater flexibility in the treatment of expectations. In addition, work is currently underway at the Bank to introduce a financial sector into a small DSGE model (see the article, "Modelling Financial Channels for Monetary Policy Analysis," in this issue). Once completed, the staff plans to examine carefully the potential benefits of introducing such a sector in ToTEM.

Literature Cited

Amano, R. and S. van Norden. 1995. "Terms of Trade and Real Exchange Rates: The Canadian Evidence." *Journal of International Money and Finance* 14 (1): 83–104.

Amirault, D., C. Kwan, and G. Wilkinson. 2006. "Survey of Price-Setting Behaviour of Canadian Companies." Bank of Canada Working Paper No. 2006-35.

Black, R., D. Laxton, D. Rose, and R. Tetlow. 1994. *The Steady-State Model: SSQPM. The Bank of Canada's New Quarterly Projection Model, Part 1*. Technical Report No. 72. Ottawa: Bank of Canada.

Cayen, J.-P., A. Corbett, and P. Perrier. Forthcoming. "An Optimized Monetary Policy Rule for ToTEM." Bank of Canada Working Paper.

Coletti, D., J. Selody, and C. Wilkins. 2006. "Another Look at the Inflation-Target Horizon." *Bank of Canada Review* (Summer): 31–37.

Coletti, D. and S. Murchison. 2002. "Models in Policy-Making." *Bank of Canada Review* (Summer): 19–26.

Coletti, D., B. Hunt, D. Rose, and R. Tetlow. 1996. *The Dynamic Model: QPM, The Bank of Canada's New Quarterly Projection Model, Part 3*. Technical Report No. 75. Ottawa: Bank of Canada.

Duguay P. and D. Longworth. 1998. "Macroeconomic Models and Policy Making at the Bank of Canada." *Economic Modelling* 15: 357–75.

Longworth, D. 2002. "Inflation and the Macroeconomy: Changes from the 1980s to the 1990s." *Bank of Canada Review* (Spring): 3–18.

Macklem, T. 1993. "Terms-of-Trade Disturbances and Fiscal Policy in a Small Open Economy." *Economic Journal* 103: 916–36.

———. 2002. "Information and Analysis for Monetary Policy: Coming to a Decision." *Bank of Canada Review* (Summer): 11–18.

Moran, K. 2000. "Dynamic General-Equilibrium Models and Why the Bank of Canada Is Interested in Them." *Bank of Canada Review* (Winter): 3–12.

Murchison, S. and A. Rennison. 2006. 'ToTEM: The Bank of Canada's New Quarterly Projection Model." Bank of Canada Technical Report No. 97. Ottawa: Bank of Canada.

Ragan, C. 2005. "The Exchange Rate and Canadian Inflation Targeting." *Bank of Canada Review* (Autumn): 41–50.