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Making It Real: Bringing Research Models into Central Bank Projections

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Abstract

This paper aims to bridge the gap between models in research and models used to support policy decisions in central banks. Models used in central bank projection environments overlap with research models and benefit from lessons learned in research, but they differ from research models in important ways. For example, to deal with real-world macroeconomic projection issues, central bank models may have a broader scope. To inform policy decision-making, models generally need both a theoretical basis and an ability to "fit" the data. For repeated projection exercises, forecasters need models that can be adapted to deal with data flows, including historical revisions. And, to provide valuable advice, forecasters must incorporate judgement into their projections to address issues outside the scope of the model. If all these challenges are met, then central bank models and projections will also inform the economic narrative that helps the public understand the policy decisions. In this context, this paper is organized around four main themes: 1) model requirements for central bank purposes; 2) overview of the Bank of Canada's main policy models—ToTEM and LENS; 3) challenges in meeting those modelling requirements; and 4) practical approaches to addressing some challenges under time constraints. The paper concludes with a description of how lessons learned from research and practice set the stage for the Bank's future modelling agenda, as discussed in Coletti (2023).

Topics: Economic models; Monetary policy
JEL codes: C32, C51, E37, E47, E52

Résumé

L'objet de notre étude est de combler le vide entre les modèles utilisés en recherche pure et les modèles servant à étayer la prise de décision des banquiers centraux. Les modèles employés dans les environnements de projection des banques centrales ont beaucoup de points communs avec les modèles utilisés dans le cadre de la recherche pure et bénéficient des apports de cette dernière. Ils s'en différencient cependant sous plusieurs plans qui méritent d'être soulignés. Ainsi, pour s'attaquer aux problèmes que posent les projections macroéconomiques dans le monde réel, les modèles des banques centrales peuvent avoir une portée plus grande. Pour aider à la prise de décision, les modèles doivent à la fois disposer d'un fondement théorique et permettre une bonne adéquation avec les données. Les exercices de projection périodiques nécessitent, eux, des modèles qui s'adaptent aux flux de données, notamment aux révisions des données. Enfin, pour apporter des conseils crédibles, les prévisionnistes doivent intégrer une part de jugement dans leurs projections, et ce, afin d'aborder des questions qui dépassent les limites de leur modèle. Une fois tous ces défis relevés, les modèles et projections des banques centrales pourront alors nourrir le récit qui aidera le public à comprendre les décisions des autorités monétaires. Au regard de cet objectif, l'étude s'articule autour de quatre grands thèmes : 1) les critères à remplir par les modèles pour rencontrer les besoins des banques centrales; 2) le survol des principaux modèles économiques de la Banque du Canada : TOTEM et LENS; 3) les difficultés à surmonter pour satisfaire les critères de la modélisation; 4) les méthodes pratiques utiles pour résoudre certaines difficultés quand les délais sont serrés. L'étude se conclut sur une description de ce que les leçons apprises de la recherche et de l'expérience pourraient apporter au programme de conception des futurs modèles, comme analysé par Coletti (2023).

Sujets : Modèles économiques; Politique monétaire
Codes JEL : C32, C51, E37, E47, E52

Introduction

Macroeconomic projections and risk analysis play an important role in guiding monetary policy decisions. Models are integral to this process. They provide consistency in capturing interlinkages and feedback effects between various factors. They also provide rigour that can be used to explore alternative futures. Because the future is uncertain, such investigation is always an important part of the monetary policy decision-making process.

At a high level, economic projections informing monetary policy discussions will include a profile for inflation and economic activity—typically output growth and a measure of economic slack—as well as a monetary policy path that brings inflation back to target. But the projection exercise is much more complex than coming up with a profile for these variables. Beyond reliable forecasting performance, central bank projections require sufficient structure, internal consistency, and detail around the key drivers of output and inflation and the transmission of monetary policy. These factors are important for policy discussions and decisions. They also contribute to providing a compelling narrative around the economic outlook. This is where macroeconomic models come into play.

Macroeconomic models used by central banks draw heavily on economic research conducted by researchers in academic institutions and central banks. However, to be used for policy purposes, models need more depth and versatility than is typical in models used purely for research. Nevertheless, even with the additional detail that is typically built into central bank models, it is still the case that all models are simplifications of the real world. This means that at times there may be developments that are important for the economic outlook but outside the scope of any one model or even the collection of models available to a central bank. More generally, intuition based on theory needs to be balanced against the complications of the real world and what data are indicating.

This is part of the reason why monetary policy decisions are an exercise in risk management. It is also why economic projections can be seen as both an art and a science. The science reflects that models are based on theory and research. Intuition and trust in those models are based on the models' ability to analyze and forecast real-world economic outcomes. The art reflects the need to consider economic developments outside the scope of the models.

An important complication that must be dealt with in using models for projections and policy analysis is that policy decisions are being made in a continuously evolving economic context, while the models themselves generally reflect features that have been important in the past and are calibrated or estimated using historical data. Moreover, the real-time flow of data includes not only new observations but also often revisions to historical data. Models must be flexible to accommodate this evolution.

Using more than one type of macroeconomic model helps with risk management. In thinking of the value of different types of macroeconomic models, it is useful to keep in mind two main objectives that underlie central bank projections and risk analysis: the ability to generate reliable forecasts for policy-makers to use in their decision-making process and sufficient structure to identify the key economic forces driving the outlook. Time-series models are typically well suited for the former, whereas structural models will perform better under the latter. In this context, central banks look to combine signals from both types of models or to leverage models that strike a balance between these two objectives.[1]

This paper discusses how the Bank of Canada brings research models and lessons learned from those models into the central bank projection environment. Four main themes are reviewed: 1) main model requirements for central bank purposes; 2) overview of the Bank of Canada's main policy models—ToTEM and LENS; 3) challenges faced in addressing key model requirements; and 4) examples of approaches followed by the Bank during the COVID-19 pandemic to address some of these challenges on a time-constrained basis. The paper concludes by discussing how lessons learned from experience and research are important for longer-term changes to models and their use. An overview is provided of some of the model development priorities at the Bank outlined in Coletti (2023).

1. Model requirements for central bank purposes

Central banks have several requirements that macroeconomic models must meet to be helpful in constructing economic projections, conducting risk analysis and informing monetary policy decisions.

A key requirement is that they be able to examine a wide range of policy-related questions, including monetary policy issues and the interpretation and implications of a wide range of shocks. In this context, practitioners will look for a good balance between structure and breadth of the models. This contrasts with models built for research purposes, where greater focus tends to be put on answering a specific question or providing a simple example putting a new empirical approach to use.

An overriding theme is that the models that central banks use for projections must be more versatile than the typical model that is published in an academic journal. However, it is important to emphasize that the policy models central banks use have roots in economic models developed by researchers, including both theoretical and empirical contributions to the literature. Meanwhile, it is generally the case that models used purely for research, that are part of articles aimed for publication in academic journals, need to be streamlined. Clarity around the various factors driving the issue being explored is key. This is true whether the

[1] Models are also used by a central bank to investigate questions related to the central bank's mandate (in addition to informing the decisions to achieve that mandate). In this context, the Lucas critique becomes relevant. Reduced-form time-series models are not well suited for examining the trade-offs associated with different monetary policy frameworks—including changes to mandates or to policy reaction functions.

research draws on structural behavioural assumptions or reduced-form time-series data properties.

Model developers within central banks take advantage of the lessons learned from research and adopt features from a multitude of research models. In so doing, they embed in their models the features and relationships that are seen as important for understanding the macroeconomy and how it evolves, while also capturing key data regularities. The goal is to achieve the right balance of theory and empirical fit.

In this context, monetary policy models have several basic requirements.

1.1 Economic structure

First, like all models, those used by central banks must be suited for purpose. For an inflation-targeting central bank, this means having a well-developed inflation-determination process and a rich structure for monetary policy transmission. Monetary policy needs to be forward looking since policy actions have lagged impacts. It is critical that real economic activity, inflation and monetary policy are all appropriately interdependent in the model and that these interrelationships are explicit.[2]

Sufficient financial market detail is needed to adequately depict monetary policy transmission. This includes capturing the impact of monetary policy changes on the financial market variables (such as medium- to long-term interest rates and asset valuations) that feed directly into decision-making by households and firms. In addition, because Canada is a small open economy, models need to account for movements in exchange rates. International trade is important as a share of domestic production, and the Canadian dollar price of imports feeds directly into domestic inflation.

Forward-looking expectations are a critical part of monetary policy transmission. Market expectations for the future path of the policy interest rate are a primary driver of the medium- to long-term interest rates faced by households and firms looking to borrow. More generally, economic agents look to the future in making their own decisions. For instance, households take their future earnings into account when making consumption decisions. This is particularly true when they are making large purchases such as housing, appliances or vacations. Likewise, when businesses make investment decisions, they need to think about what future demand for their products and services will be. And, when they make their pricing decisions, they need to think about how they expect costs to evolve.

Sufficient disaggregation of aggregate demand components is also critical for understanding how monetary policy actions will impact future economic activity and inflation. Changes in the policy interest rate affect some sectors sooner than others. For example, spending on housing is usually affected first, with consumer expenditures on durable goods next in line,

[2] For instance, the historical time-series properties of gross domestic product implicitly capture historical policy decisions. However, having an autoregressive specification that is good at forecasting does not provide information on what policy would be doing to achieve that forecast.

followed by spending on other goods and services. In addition to the timing of the impact, the size of the impact also differs across components of aggregate demand. Clearly, some demand components—like government expenditures and exports—are either minimally or indirectly affected by domestic monetary policy decisions. Nevertheless, developments in these components affect demand and therefore are relevant for setting policy.

Disaggregation can also be important for understanding inflation developments, as became clear during the pandemic. Strength in the housing sector led to rising inflation in shelter prices. International developments such as strong global demand, rising commodity prices and supply chain disruptions drove increases in goods prices. Subsequently, strong domestic demand, partly related to the timing of the removal of health-related restrictions, contributed to a pickup in non-shelter service price inflation.

Sufficient disaggregation also helps with communications. Public communications explaining decisions should refer to economic developments and projections. Thus, the projections must be of standard economic variables that are familiar to the public. In this sense, for example, a stand-alone forecast of an output gap would not be understood as well as one that is published alongside forecasts of real gross domestic product (GDP) growth and potential output growth. A breakdown of the GDP components is also more relatable because it provides detail on components of spending that the public is likely familiar with.

1.2 Modelling levels of variables

Second, the ability to predict the levels of key variables is important in central bank projection models. Models that aim only to forecast deviations from unmodelled trends are of limited value on their own to policy-makers. Most macroeconomic variables grow over time (for instance, as population or labour productivity increases in the case of real activity, or as prices increase in the case of nominal variables). While deviations from trend may, at times, be the more relevant concept in setting monetary policy, the data (as in the examples above), drift up over time, but the underlying "trends" are not observable. This means that to bring the data into a model of detrended variables, the trends also need to be modelled.

1.3 Flexibility

Third, the central bank projection environment requires models to be flexible enough to address new questions as they arise. This can happen frequently. Sometimes new developments can be incorporated into a projection using informed judgement. At other times, changes to the models may be needed. This contrasts with models built purely for research purposes, for which the implications of incoming data flows are generally not a consideration. Given tight timelines around the monetary policy process, it is important that model changes can be implemented flexibly. Several examples come to mind ranging from the re-estimation of model parameters required after historical data revisions to the addition of a new channel of impact for an important economic development (e.g., the modelling of household debt and its implications for consumption).

Also important is the ability to change assumptions regarding how expectations are formed to reflect, for example, varying degrees of "naiveness," learning behaviour or model-consistent expectations. This can implicate two different sources of persistence in inflation expectations. One is the extent to which the inflation target is an effective long-run anchor, a key issue for an inflation-targeting central bank. The second is the extent to which the persistence of deviations of expected inflation from the perceived inflation target may change. These types of changes are more difficult to implement in purely structural models, especially under system estimation.

2. Overview of ToTEM and LENS

The requirements reviewed in the first section are not new as of the COVID-19 pandemic. In some form or another, they were top of mind during the past development of the Bank of Canada's main macroeconomic models of the Canadian economy that are currently used for projections and risk analysis.

There is a long tradition of using models for projection and policy analysis in central banks going back to the 1970s. This includes the Bank of Canada, where different generations of models have been developed and used over the years.[3] Currently, Bank staff use two main models on an ongoing basis: ToTEM and LENS.

ToTEM was introduced in 2006 and has undergone two major updates, in 2011 and 2017. The initial version of ToTEM is described in Murchison and Rennison (2006). The first major update, which introduced multiple interest rates and added a more general structure for wage- and price-setting behaviour, is described in Dorich et al. (2013). The latest version, described in Corrigan et al. (2021), introduced household debt, a more detailed modelling of the housing market, and improved measures of the determinants of non-commodity exports. LENS was introduced in 2014 (Gervais and Gosselin 2014) and has been updated on an ongoing basis. The model specifications for both ToTEM and LENS draw heavily on research. While the two models are similar in size, they differ in a few important ways.

ToTEM is an open-economy, multi-sector dynamic stochastic general equilibrium (DSGE) model with utility-maximizing households and profit-maximizing firms. Its structure is based on the pioneering work of Woodford (2003), who brought nominal frictions into real business cycle models, thereby providing a structural framework for monetary policy analysis. The ToTEM specification drew on the household utility representation of King, Plosser and Rebelo (1988), the Calvo (1983) approach to sticky prices, and assumed firm-specific capital as in Altig et al. (2011) and Woodford (2005). Relative to these closed-economy research models, ToTEM was expanded to include a multi-goods framework with international trade in finished products and commodities.

[3] See Poloz (2017) and Coletti (2023) for a discussion of the different generations of models used at the Bank.

The strength of ToTEM is its theoretical structure and ability to explain implications of shocks affecting the economy. Given its structure, ToTEM is well suited to conduct simulations of alternative monetary policy frameworks without being subject to the Lucas critique.[4] In ToTEM, persistence in macroeconomic variables comes from assumed frictions that constrain rapid changes in many variables (frictions to price adjustment are standard in DSGE models for monetary policy) and assumed persistence in structural shocks. The model is log-linearized around assumed deterministic trends so that in practice the structure generates covariation over time in detrended variables.

LENS was developed as a semi-structural model that, as in the DSGE approach, has equations based on optimal decision-making with adjustment costs and forward-looking expectations. The "semi-structural" label reflects that the model does not provide a mapping between equation residuals and structural shocks. The methodology was first used in the Federal Reserve's FRB/US model (Brayton and Tinsley 1996).[5] It draws on the pioneering work of Tinsley (2002) that generalized the typical quadratic assumptions on frictions to be higher order and showed how decision equations could be mapped into error-correction equations with cross-coefficient restrictions. In this way, the resultant model specifications did not require that data be detrended. Moreover, compared with DSGE models, because the optimization theory is applied more flexibly, equations better capture patterns in historical data without the need for ad hoc assumptions about the persistence of structural shocks. The persistence in macroeconomic variables comes from expectations of future changes in conditioning variables and a flexible specification for the frictions that constrain rapid changes in the decision variable. Another advantage of this approach to modelling is that it facilitates more elaborate or detailed economic structure and is flexible enough to be adapted quickly to a changing economic environment.

Given these features, ToTEM is used mainly for policy and risk analysis, whereas LENS is used mainly for constructing the base-case projection. Bank staff leverage the strengths of each model for different purposes: a structural model to understand how assumed behaviour leads to key relationships among macro variables and a time-series model to understand the data, their individual persistence and their joint evolution over time. Using both models to inform policy discussions enhances risk management.

[4] ToTEM has played an integral role in evaluations of alternative monetary policy frameworks as part of the repeated five-year review of the agreement between the Bank of Canada and the Government of Canada on Canada's monetary policy framework. As background to the 2021 renewal of the agreement, alternatives to the 2% inflation-targeting framework were assessed based on a broad range of qualitative and quantitative criteria. For details on this "horse race," see Dorich, Mendes and Zhang (2021).

[5] Additional details on FRB/US, including downloadable FRB/US equations, documentation, data, simulation programs and specialized model solution code, are available on the Federal Reserve's website.

3. Challenges

Even with models designed to meet the requirements reviewed in the first section, challenges remain. This section summarizes a number of real-world issues faced by economists constructing projections. These relate to:

- the treatment of expectations
- the modelling of the supply side of the economy
- the emergence of important developments that fall outside of modelled features of the economy
- the necessary reliance on trending data
- the likely non-linearities and asymmetries in the real world

3.1 Treatment of expectations

As discussed in the previous section, projection models need to embed some form of forward-looking behaviour, at least for a subset of economic agents. However, there is considerable debate about how to best model expectations.

In applications of models for research, expectations are commonly assumed to be consistent with full knowledge of the dynamics of the model. They are referred to as model-consistent expectations (MCE). In an MCE solution, expectations are required to be the same as the solved future value of the corresponding variable. While this approach can simplify solving the model and may be appropriate to address specific research or policy questions, it may not always be realistic in a forecasting environment.

One alternative is to assume that agents form their expectations under limited knowledge of the joint dynamics of the variables at play. For instance, expectations can be based on projections from estimated small-scale auxiliary vector autoregression (VAR) models that capture average historical empirical relationships.[6] The Bank has a modified version of LENS where agents' expectations follow VAR-based forecasts. In this version, VAR-based expectations imply a larger impact of monetary policy shocks on GDP due to the greater sensitivity of long-term interest rates and the exchange rate to changes in the short-term rate. The economic outlook suggested by this version of the model tends to be different, as agents do not perfectly foresee future policy rate movements. Staff have used this version of

[6] Sims (1980) brought attention to VARs as tools that could be of use to macroeconomists, and a large literature followed examining the forecast performance of VARs. In fact, to a large extent, VARs became the base case against which the forecast performance of other models was judged. The FRB/US model was developed to run under alternative assumptions about how expectations are formed. VAR expectations was one of the possibilities. For additional details, see Brayton et al. (1997). Data properties derived from VAR models also served as reference for calibration of early versions of DSGE models.

the model to assess risks around the base-case assumption of model-consistent expectations.[7]

Adaptive learning is another way to depart from rational expectations and improve the realism of the forecasting process. One example is endogenous gain learning, in which agents use a simple autoregressive process to forecast inflation. In this framework, the gain varies endogenously depending on the resulting forecasting performance. Bank staff have used this type of specification to assess de-anchoring risks—that is, the possibility that long-run inflation expectations move away from the target if inflation is persistently high.[8, 9] However, it may be advantageous to think about dividing inflation expectations into two components: views on the long-run anchor (the inflation target) and views on the expected deviation of inflation from that anchor. In this context, evidence of a shift in the long-run anchor away from the inflation target is of particular concern because it may signal a loss of credibility in the central bank's ability to achieve its mandate.

3.2 Modelling the supply side of the economy

Models used to inform monetary policy decisions have typically put more emphasis into understanding the cyclical behaviour and interest-rate sensitivity of the demand side of the economy rather than the supply side. The supply side is often aligned with potential output, capturing estimates of long-run, or sustainable, non-inflationary economic activity. In economic projections, monetary policy acts to speed the return of the economy to its economic potential. In this way, as the forecast horizon expands, the projection of the level of GDP converges to potential output, and the projection of GDP growth converges to potential output growth.[10]

Potential output is seen as evolving more gradually than demand. The capital stock is large relative to investment, so fluctuations in investment imply only slow changes in the underlying capital stock. Labour supply moves with the labour force, in turn reflecting population growth and labour force participation (including what demographics might have to say about the evolution of the labour force). Such factors tend to move slowly and be

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[7] In practice, the flexibility of LENS means that it is possible to use varying degrees of sophistication when modelling expectations formation. For instance, simulations could be based on a variant of LENS in which financial market participants are assumed to have a sophisticated understanding of policy and the dynamics of the economy implied by MCE, while households instead are assumed to base their expectations on the limited information embedded in the VAR models.

[8] Another type of learning mechanism is where agents use random-walk beliefs to form their expectations. This can lead to extrapolative behaviour and create boom-bust cycles.

[9] Kozicki and Tinsley (2001) find that US long-horizon expectations are well modelled using an adaptive learning model in which the perceived inflation target is a geometrically declining weighted moving average of past observations on inflation. Learning about the perceived inflation target based on policy rate surprises is another way to assess de-anchoring risks (Kozicki and Tinsley 2005). Both these articles assume that there is no time variation in the parameters that capture the persistence of inflation from the perceived inflation target.

[10] See the April 2023 *Monetary Policy Report* and Champagne et al. (2023) for details on the methodology and latest assessment.

predictable. Emphasis on potential output also tends to exclude cyclical factors—such as utilization rates.

While this way of thinking works well in normal times, it did not work during the COVID-19 pandemic. Impediments to the use of existing capital were huge (consider, for example, government-mandated shutdowns—capital existed but was not being used). As well, supply chains were disrupted, which had clear impacts on total factor productivity. As a result, it was necessary to distinguish between supply and potential output.

Another supply-side issue is whether potential output should be endogenous or exogenous to the model. Traditionally, demographic drivers of labour supply are viewed as largely exogenously driven and predictable. Adding such detail to the projection model could unnecessarily complicate the specification. However, investment, for example, is typically an endogenous variable and important for capital and labour productivity. This example provides one motivation for having an endogenous trend for labour productivity.

3.3 Developments that fall outside of modelled features of the economy

The challenges associated with the real-time flow of data are an aspect of economic projections within a central bank that differentiate it from most academic research in economics. When conducting research, a researcher usually has data, time to conduct analysis and consider results, and also time to refine models. But, at the Bank of Canada, staff make new projections every three months under a pre-established timeline. Each time a new projection is made, there are new data points. And sometimes entire histories of data series have been revised by the data publisher since the previous projection cycle. This may mean that interpretations of what was happening in the past can change. As well, when data revisions are large enough, models may need to be re-estimated before they can be used with the most recent data to conduct a projection.

At times, developments are important for the economic outlook but outside the scope of the models. Bank staff deal with this through judgmental adjustments to the economic projections. In particular, they identify the variables that are most likely to be influenced by these unmodelled developments. Then they use a wide variety of sources of economic information to estimate the implication of what is missing from the model. From a methodological point of view, such economic analysis is used to force future equation residuals to deviate from what past behaviour would suggest in order to approximate the impact of what is missing from the model.

3.4 Trending data

One of the major challenges in developing a model for use in economic projections is the need to deal with trending data. While some transformations to trending data make it closer to stationary (for instance, looking at GDP growth rather than GDP levels), such transformations often remove information that can be important in making monetary policy decisions. As a result, both trends and cycles need to be modelled. This may be done jointly or separately. As discussed earlier, the Bank's models take different approaches. Both approaches have challenges.

LENS models the *levels of trending* data—it implicitly captures evolution in the trends and in the cycle. While it can be thought of as modelling both trends and cycles, it does not explicitly identify these two components. It captures the long-run co-movement of trending data, but gaps between decision variables and conditioning variables should not be interpreted as "cycles" in the sense of "deviations from trend." This means, for example, that the model on its own does not provide a clean estimate of the output gap.

ToTEM is a log-linearized model and aims to explain co-movement of *detrended* data.[11] Since the detrending is done outside the model, to be used for projections, ToTEM has to be used in conjunction with a model of the trends.[12] Since ToTEM is a model of stationary deviations, forecasts of deviations shrink at longer projection horizons, and economic projections become increasingly dominated by the trend projections.

Thus, both LENS and ToTEM use externally provided estimates of potential output. Notwithstanding the additional need during the pandemic to distinguish between the long-run concept of potential output and the shorter-run concept of supply, even estimating the level of potential output is challenging. A large literature points to sizable revisions to estimates of potential output over history.[13]

Uncertainty associated with estimates of potential output are a particular challenge for monetary policy models. Forecasts of potential output anchor projections of GDP. And, in LENS, historical and forecasted levels of the output gap have been a driver of inflation projections. In addition, a standard way of representing monetary policy decisions in models is through a reaction function in which the policy interest rate is adjusted, possibly gradually, to movements of the output gap and inflation. Thus, uncertainty in estimates of potential output maps into uncertainty in estimates and forecasts of the output gap, inflation, GDP growth and the policy rate.

Revisions to estimates of potential output and other trends create additional challenges when structural models are used in the projection process. When estimates of trends over history are revised, estimates of historical structural shocks will also be revised. This could change the

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[11] Cayen, Gosselin and Kozicki (2009) propose an approach to estimate model-consistent trends, given a model of detrended data as a starting point and assuming the trends were orthogonal to the detrended data. Canova (2014) builds on this work and provides a methodology for estimating both a structural model and a flexible non-structural link between the model and the raw data.

[12] The trends model used with ToTEM is based on a combination of filters and cointegration relationships.

[13] See, for instance, Orphanides and Van Norden (2002), Barnett, Kozicki and Petrinec (2009) and Champagne, Poulin-Bellisle and Sekkel (2016).

interpretation of what structural shocks were behind historical fluctuations of economic variables.

3.5 Nonlinearities and asymmetries

Another important challenge in bringing models to real-world use is that models are necessarily simplifications of reality, and to keep them workable, specifications are usually linear. This is partially due to practical issues. Though they are simplifications, they are still remarkably complex in detail compared with most research models. Linearity facilitates the projection process. But linearity also assumes away issues that are more likely to be important when the economy is operating away from its potential.

- For instance, research has found support for non-linear Phillips curves. In particular, analysis suggests that the slope may be steeper when the economy is in excess demand—implying that inflation is more responsive to excess demand than to excess supply. This may reflect that cost shocks are passed through more completely.[14]
- The Beveridge curve for Canada also provides an example of a potential driver of a non-linearity in the economy relative to what our main policy models would suggest.[15] When job vacancies as a share of unemployment are elevated, slower growth and an easing of excess demand may occur without a typical rise in the unemployment rate. This can happen if the slowing of economic activity occurs through a reduction in vacancies rather than through a decrease in employment.

A related challenge to the constraints of linearity is the ability of macroeconomic models to address asymmetric risks. Financial vulnerabilities—such as those associated with elevated debt levels—can lead to large downward skews to projected distributions of economic activity. Such skews may be less visible in mean, median or modal projections yet can be very relevant as part of risk analysis. Tools such as "growth at risk" calculations can help provide estimates of how alternative policy decisions may influence future distributions of risks.[16]

4. Approaches to addressing challenges: The pandemic experience

Constructing economic projections became more challenging during the COVID-19 pandemic. Faced with time and technology constraints, economists generating economic

[14] See Harding, Lindé and Trabandt (2022).

[15] See Lam (2022) and Macklem (2022).

[16] Adrian, Boyarchenko and Giannone (2016) is an influential paper looking at the asymmetric relationship between financial conditions and risks to GDP growth. Duprey and Ueberfeldt (2018) show how to decompose the outlook for the distribution of future GDP growth into macroeconomic and financial stability risks. Duprey and Ueberfeldt (2020) illustrate the trade-off that policy-makers face between GDP tail risk and short-term smaller deviations from expected GDP.

projections had to use practical approaches to address many of these challenges. These approaches helped to shed light on issues that either were outside the scope of the main policy models or implied different parameterizations of the model than had been appropriate before the pandemic. Over the long term, developing new models is possible. However, even with this flexibility, there are limits to what can be done.

4.1 Unmodelled aspects of the economy

Models are always susceptible to misspecification. Whenever simplifications of the real world are made in a model's specification, there is a risk that excluded factors could one day become important. During the pandemic, one example was that supply deviated from potential output, as mentioned above.

For monetary policy purposes, it had not been necessary to account for temporary but persistent and broad-based disruptions to supply in the almost 30 years of inflation targeting before the COVID19 pandemic. But, during the pandemic, these disruptions inhibited or slowed production and added to costs. In fact, supply-side issues became more important than demand-side factors in projections of inflation (see **Box 1**). While the gap between actual GDP and estimated potential output had traditionally been consistently useful for explaining movements in core inflation before COVID-19, this regularity broke down during the pandemic. Two factors caused this breakdown:

- First, because of shutdowns and other disruptions to the supply process, estimates of potential output no longer provided a good proxy for supply.
- Second, variations in costs driven by factors largely disconnected from demand became more relevant in driving inflation than estimates of excess demand were.

Box 1

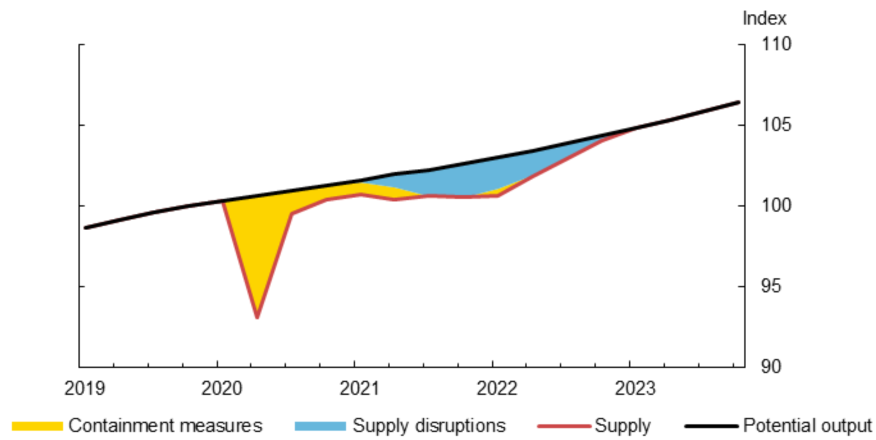
Impediments to utilization: Accounting for containment measures and supply disruptions

In its October 2020 *Monetary Policy Report*, the Bank of Canada distinguished between potential output and supply for the first time. This was done because linking domestic inflationary pressures to the difference between demand and supply in the Canadian economy revealed the importance of explicitly acknowledging factors that were limiting supply relative to potential output.

Chart 1-A, taken from the January 2022 *Monetary Policy Report*, shows that early in the pandemic, containment measures that shut down some businesses were responsible for driving a wedge between what the economy was producing and what the economy could produce if all capacity were fully utilized. Later in the pandemic, containment measures became less important, while other supply disruptions (such as delivery challenges and elevated worker absences related to illness) increased in importance. Given such supply-side issues, the measures of the gap between actual GDP and supply indicated a less negative or more positive output gap and greater inflationary pressures than would the traditional gap between actual GDP and potential output.

Chart 1-A: Supply disruptions are expected to dissipate gradually over 2022

Index: 2019Q4 = 100, quarterly data



Note: "Supply disruptions" includes the short-term effects on supply of supply chain disruptions and labour market mismatch. The area labelled "Containment measures" in 2022Q1 also includes the effects on supply of worker absences due to the rise in COVID-19 cases.

Sources: Bank of Canada calculations, estimates and projections

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Many other details of model specifications needed to be re-examined during the pandemic. For instance, separating goods and services when projecting consumption, exports and imports became important. And, critically for central banks, traditional specifications of equations for inflation ceased to explain the dynamics of inflation.

4.2 Use of alternative scenarios to evaluate risks

For central bankers, it is important to seek out diverse views and understand differing interpretations of the same data. This helps provide the clearest picture of what is happening in the economy and contributes to better-informed monetary policy decisions. Part of the projection process is identifying key sources of risk and examining both the probabilities that they will be realized and the potential economic consequences if they are. Macroeconomic models are valuable tools to do this.

Risk scenarios can be constructed using the same model as the base-case projection but under different assumptions. Risk scenarios can also be constructed using different models. Both types of scenarios help address the challenge of possibly having different interpretations of data and different views of what that data could mean for the economic outlook and inflation.

One important component of models of inflation is expected inflation. Bank staff have examined what happens when the specification for expected inflation is changed. This type of exercise is critical because in their baseline versions both LENS and ToTEM assume model-consistent expectations and perfect credibility of the inflation target. The takeaway from this work is that if learning makes inflation expectations more sluggish and leads to persistent deviations from rational expectations, then in order to stabilize expectations, monetary policy may need to be more aggressive in response to a deviation of inflation from target (see **Box 2**).

Box 2

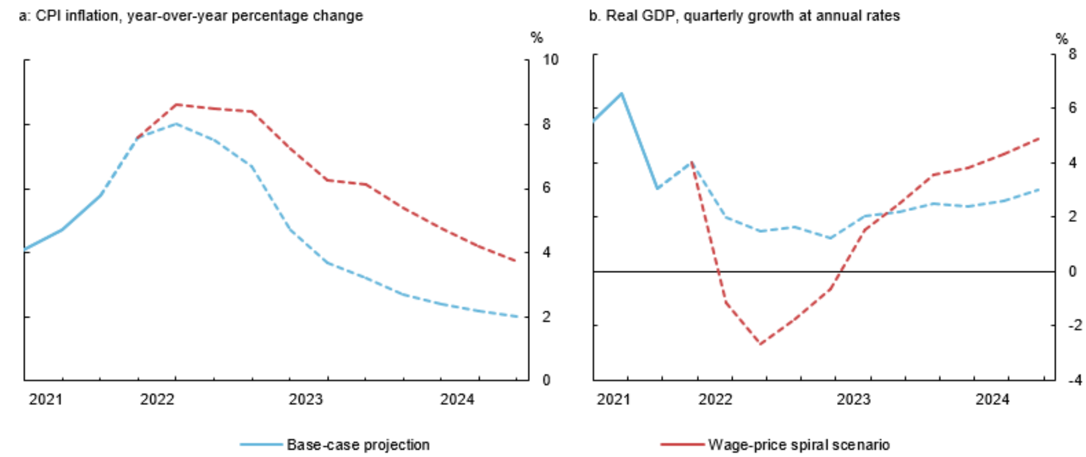
Scenario with a wage-price spiral

Both ToTEM and LENS model specifications assume that inflation expectations are well anchored on the 2% inflation target. The baseline economic projections in the Bank of Canada's *Monetary Policy Report* also generally assume well-anchored inflation expectations. However, in July 2022, with inflation high and broadening, higher inflation expectations, a tight labour market and strong wage growth, it became important to consider a risk scenario in which inflation expectations became unanchored. This risk analysis was not part of the base-case economic projection. It was published in the Risk section of the July 2022 *Monetary Policy Report*.

Bank staff used judgement in ToTEM to develop an alternative scenario to illustrate such a risk. The risk scenario was designed also to include a wage-price spiral. In the scenario, the spiral prompts inflation expectations, wages and prices to ratchet upward. With de-anchored expectations, inflation stays higher than it would otherwise have been, even with easing demand and flat or declining commodity prices (**Chart 2-A**). To break the vicious cycle, monetary policy works to re-anchor long-term inflation expectations to the 2% target. This is done by setting monetary policy much tighter than in the base case and creating additional excess supply.

Chart 2-A: In the wage-price spiral scenario, inflation is higher and growth is slower

Quarterly data



Sources: Bank of Canada and Bank of Canada calculations and projections

In addition to examining the sensitivity of the inflation outlook to models of expectations, the Bank has conducted extensive analysis to understand the underlying drivers of inflation dynamics since the onset of the pandemic. Before the pandemic, Phillips curve specifications had done a reasonable job of explaining in-sample variability in core inflation measures in Canada, even as their predictive ability declined significantly in other countries. However, during the pandemic, as previously discussed, unmodelled cost pressures became more relevant than excess demand in driving inflation. This proved to be a particular challenge for models such as LENS, in which the output gap is the main determinant of inflation.

The Bank responded by considering the implications of multiple models of the drivers of inflation, including specifications emphasizing demand-driven forces; supply-related cost drivers; and bottom-up constructions based on a decomposition of inflation into non-energy goods, energy, non-shelter services, and services components (**Box 3**). Looking across scenarios based on such different model specifications helps reduce the risk associated with potential model misspecification. Some of these specifications ended up being reflected in the base-case projection.

Box 3

Non-linear pass-through of cost pressures

Inflation equations in both ToTEM and LENS had very large residuals in 2021 and early 2022 relative to the pre-pandemic model specification for inflation. While these residuals were correlated with indicators of global supply chain pressures, more work was needed to understand the implications for Canadian inflation. Bank of Canada staff leveraged detailed input-output information from Statistics Canada to track the costs involved in bringing goods to Canadian consumers. They found a high correlation between the consumer price index for goods and various costs, including those related to imports, freight, distribution, labour, business services and energy. Following this work, staff built an alternative cost-based specification of the Phillips curve that was better able to explain inflation. This specification was used to assess risks around the base-case inflation forecast.

In addition, changes in firm pricing behaviour were observed generally starting in late 2021:

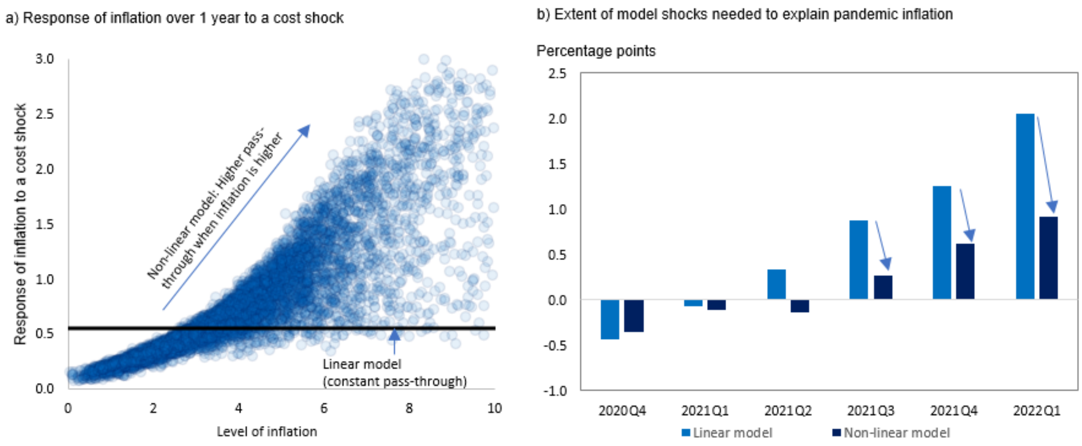
- Pass-through of input costs to output prices increased and occurred more quickly.
- The typical frequency and size of price adjustments increased.

This posed a challenge to the Bank's conventional models, which assume that pricing behaviour does not change over time. Research models were particularly helpful in improving the Bank's understanding of the implications for inflation. Bank staff built an alternative version of ToTEM where pricing behaviour varied depending on the state of the economy. In particular, the model allowed the extent to which a given increase in costs would be reflected in consumer prices to depend on the initial level of inflation.[17]

In this type of non-linear model, the relationship between pass-through and inflation gets steeper the higher the level of inflation (**Chart 3-A**). This type of model fits the period of the 2008–09 global financial crisis better, is better able to explain the surge in inflation during the pandemic and is consistent with firms increasing their frequency of price adjustment when inflation is higher. The Bank has used this modified version of ToTEM to assess risk around the base-case inflation projection.

[17] Survey evidence also supports this theory. For instance, responses to the Bank of Canada's Business Outlook Survey indicate that as demand strengthened near the end of 2021, businesses found it easier to pass along cost increases. References to the need to find efficiency gains to offset such costs and not raise prices by as much became rare. Only as excess demand was easing did firms once again start referring to efforts to increase productivity.

Chart 3-A: Importance of non-linear effects



Source: Bank of Canada simulations

Although LENS and ToTEM have been the main macroeconomic policy models used at the Bank for Canadian economic projections, the Bank also has a behavioural agent-based model that became available for use during the pandemic (Hommes et al. 2022). This model, called CANVAS, simulates individual behaviours of many different agents and takes advantage of information from the Canadian input-output tables to provide an overall picture of the Canadian economy. CANVAS has become another tool to construct alternative scenarios for inflation across sectors. It has been particularly informative in the context of lockdowns and supply chain issues.

During the pandemic, other issues that were outside the basic model specifications arose. One example was the use of unconventional monetary policies, including forward guidance and quantitative easing.[18] And the pandemic itself was outside basic model specifications. But while models can be adjusted to capture many missing features, the onset of the COVID-19 pandemic is better thought of as an example of Knightian uncertainty—an event that may be possible, but whose impacts may be hard to anticipate and where related probabilities cannot be meaningfully estimated in advance.

4.3 Explaining thinking to address Knightian uncertainty

Knightian uncertainty refers to events that could happen, but for which one cannot assign a probability. Alternatively, one could think of Knightian uncertainty as being consistent with a situation when even a reasonable subset of possible outcomes could be contingent on too many as-yet-unresolved conditions to predict.

[18] These policies, which can be thought of as deviations from the historical policy reaction function, were accounted for in economic projections by using judgement. Quantitative easing has been captured, for instance, by using judgement to reduce the size of term premiums in bond yields relative to what they would otherwise have been.

The Bank's risk management approach to monetary policy acknowledges Knightian uncertainty. The Bank recognizes that some outcomes could happen but that when they might materialize cannot be predicted. Even in such situations, decisions need to be made. So, decision-making is conditional on assumptions.[19]

The onset of the pandemic in 2020 is an excellent example of Knightian uncertainty. It provided central bankers with a lot to think through. There had been pandemics in the past, but nothing of the scale of the COVID-19 pandemic had occurred since the global economy had become so integrated and interconnected. This means there was no playbook to consult. In this context, rather than provide an economic projection, the Bank explained its thinking around the channels of impact of the pandemic and related uncertainty (see **Box 4**).

Box 4

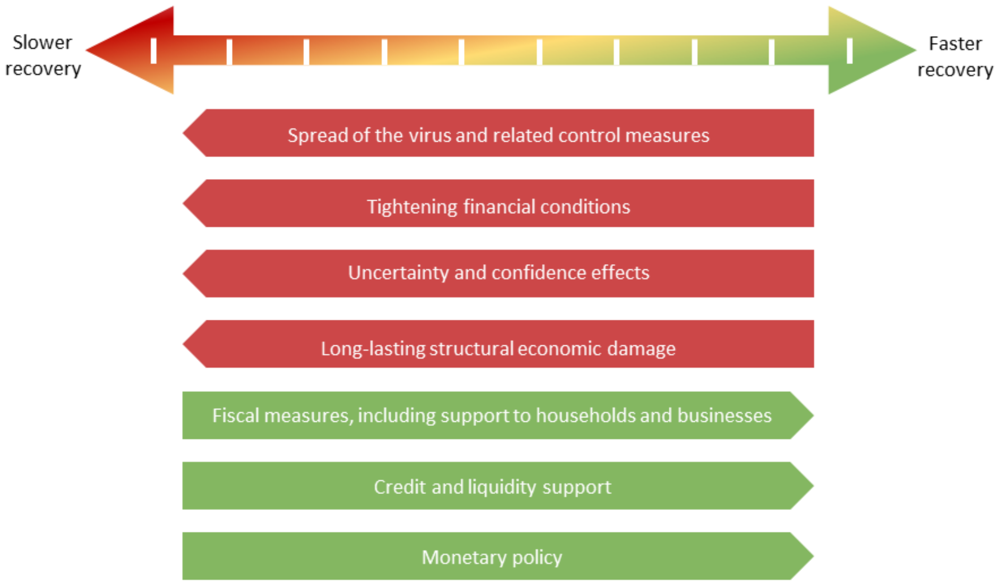
Knightian uncertainty in practice

A key issue that had not been foreseen at the onset of the pandemic was the type of public health measures, and especially lockdown measures, that would be introduced to contain the spread of the virus. At the time of the April 2020 *Monetary Policy Report*, there simply was not enough information to make a reliable economic projection.

But, even with the economy in such unfamiliar territory, central bankers needed to make policy decisions and explain those decisions. There is value in explaining the logic and thinking around issues that are outside the scope of models. Rather than providing a comprehensive but highly uncertain projection of the economy, the Bank focused on explaining how it was thinking the pandemic would affect the economy. This included identifying the channels through which the pandemic was most likely to affect the economy (**Figure 1-A**).

[19] See Kozicki and Vardy (2017).

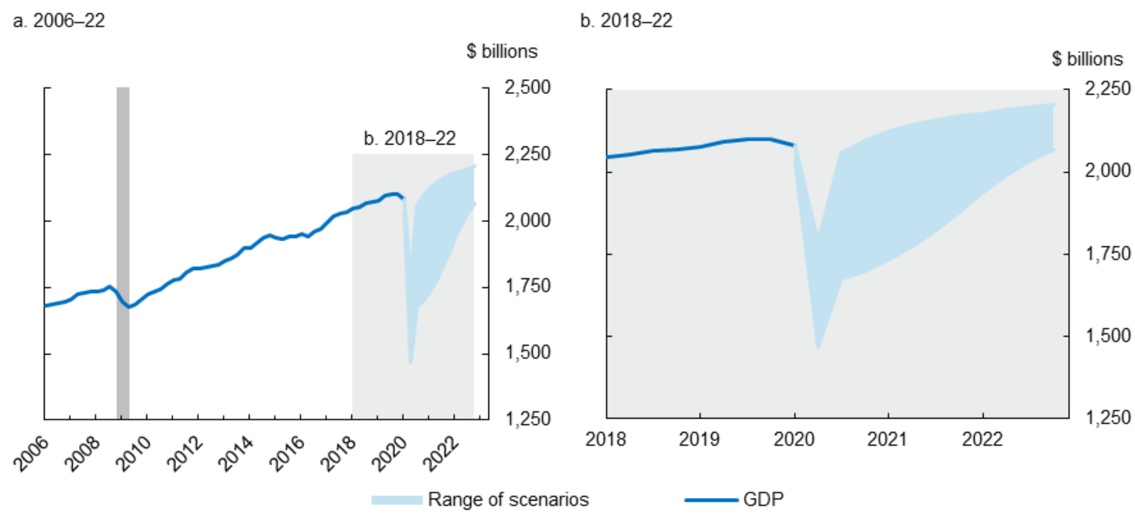
Figure 1-A: Potential impact of COVID-19 pandemic



A range of outcomes was possible, and the Bank sought to communicate that uncertainty as clearly as possible rather than avoid it (**Chart 4-A**). The idea was that providing clarity in the Bank's thinking would contribute to stability.

Chart 4-A: Many paths for the economic recovery are possible

Real gross domestic product (GDP), chained 2012 dollars, quarterly data



Note: The dark grey shaded area refers to the 2008–09 recession.
Sources: Statistics Canada and Bank of Canada calculations and projections

Conclusion

This paper focuses on helping the reader understand the existence and drivers of differences between models and the use of models in purely academic research versus in actual projections and risk analysis. Producing economic projections requires balancing science and art. The science provides the starting-point tools and helps with calibration. The art helps fill in gaps between model assumptions and a constantly evolving real world. In this context, the previous section provided examples of some approaches taken by the Bank of Canada in a time-constrained environment to address challenges associated with the use of models when faced with the unprecedented shocks associated with the COVID-19 pandemic.

Over time, however, research can provide insights and methodological advances that justify a more thorough re-examination of model specifications. Such an exercise should be supplemented with information about the strengths and weaknesses of past model specifications learned through the use of the models in actual projections. Together, new advances from research and lessons learned from practice can contribute to developing a new generation of central-bank models. The new specification can be optimized relative to what has become most important for informing monetary policy decisions.

The Bank recently undertook such an exercise. Coletti (2023) summarizes an assessment of LENS and ToTEM against a broad list of requirements for policy models and proposes a way forward for the next generation of projection and policy models used at the Bank.[20] In particular, Coletti provides a thoughtful summary of research that will influence modelling decisions related to:

- firm price-setting behaviour
- inflation expectations
- the supply side of the economy (labour market and production networks)
- integrating the structural model and idiosyncratic trends
- endogenous heterogeneity
- use of data-rich techniques

In addition to a next generation of model specification, the way forward proposed by Coletti explicitly incorporates an approach to conduct risk management. Use of multiple model variants and specialty models will be part of this—recognizing the clear advantages that multiple models have provided in conducting risk analysis since the onset of COVID-19. Future modelling efforts will be guided by many important research advances and the challenges that have increased in importance during the pandemic.

[20] The requirements listed in Coletti (2023) are consistent with the discussion in the first section of this document but are organized differently.

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