USE OF MACROECONOMIC MODELS AT THE CENTRAL BANK OF CHILE

2020

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Chile

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PREFACE

The way that the Board of the Central Bank of Chile (CBC) interprets the objective outlined in its Organic Constitutional Law (LOC) regarding the currency's stability translates, in operating terms, into maintaining forecasted annual inflation at 3% over a policy horizon of around two years. Within the framework of the CBC's commitment to increasing transparency, this book provides a broad description of the different economic models that assist the Board in this task and their role in the decision-making process and as tools for analysis and forecasting.

At the CBC, economic models are used as organizers of the analytical framework with which inflationary behavior and monetary policy (MP) transmission mechanisms are studied, to forecast inflation and other variables of interest, and to evaluate how the economy would respond to different events and interest rate trajectories. In an ever-changing economy, no model can fully encompass all the relevant factors for determining monetary policy. In that sense, the Board's vision on the economy rests on examining various models, applying judgment as needed, based both on the circumstances of the moment, and on an assessment of each of the models' limitations.

The models described in this document, which is an update of the book "Modelos macroeconómicos y proyecciones del Banco Central de Chile" published in 2003, are under constant study and refinement, and evolve as techniques for dealing with macroeconomic policy issues progress. The Board of the CBC will determine the future guidelines of the modeling agenda as new challenges arise.

The contents of this book were prepared by the Economic Modeling Department, under the Economic Research Management of the Central Bank of Chile. In addition to the Department's staff, many economists from other areas of the Bank took part in its production including, but not limited to: Elías Albagli, Agustín Arias, Francisco Arroyo, Gent Bajraj, Felipe Beltrán, Lissette Briones, Francisco Bullano, Gonzalo Calvo, Guillermo Carlomagno, Gabriel Correa, Marcus Cobb, Andrés Fernández, Jorge Fornero, Miguel Fuentes, Benjamín García, Mariana García, Diego Gianelli, Mario González, Sebastián Guarda, Juan Guerra, Matías Muñoz, Tomás Opazo, Manuel Paillacar, Camilo Pérez, Víctor Riquelme, Diego Rodríguez, Andrés Sansone, Matías Solorza, Johanna Torres, Rocío Valdés, Juan Marcos Wlasiuk and Roberto Zúñiga. Creating this document would not have been possible without the leadership and vision of past managers of monetary policy, macroeconomic analysis, international analysis, research, and other incumbent and former officials who promoted the development of an important part of the model structure described in this book, including Pablo García, Luis Oscar Herrera, Alberto Naudon, Sergio Lehmann, Klaus Schmidt-Hebbel, Claudio Soto, Juan Pablo Medina, Javier García-Cicco and Markus Kirchner. Finally, we would like to thank all the members of the Board for their strong and enthusiastic motivation and leadership in supporting this initiative since its inception.

1. INTRODUCTION

"[Models] are a real and essential element in the preparation of well-coordinated policies.
But they cannot do this job all by themselves.
Models constitute a framework or a skeleton and the flesh and blood will have to be added by a lot of common sense and knowledge of details."

Jan Tinbergen,
Nobel Prize in Economics reception speech, 1969

As established by the Constitutional Organic Law (LOC) of the Central Bank of Chile (CBC), the purpose of the monetary authority is to "ensure the stability of the currency and the normal functioning of internal and external payments." Currency stability translates into maintaining inflation low, stable, and predictable over time. Ensuring the normal functioning of payments involves safeguarding credit intermediation, the supply of payment services, and the financial markets' risk allocation. The Bank's publications "Financial Policy of the Central Bank of Chile" and "Monetary Policy of the Central Bank of Chile in the Framework of Inflation-Targeting" describe the characteristics and implementation of the policies that the Central Bank of Chile uses to meet these objectives.

The CBC conducts its monetary policy under an inflation targeting scheme complemented by a floating exchange rate regime. This scheme includes the commitment to use the instruments granted by law to maintain the forecasted annual inflation rate at 3% over a two-year horizon. This commitment guides economic agents' expectations and transforms the inflation target into the economy's nominal anchor.

The CBC's monetary policy framework requires a high degree of transparency and communication. The CBC devotes efforts to this area through preparing and publishing the Monetary Policy Report (MP Report) and the Statement and Minutes of the Monetary Policy Meetings (MP meetings), among other elements. Good communication and a high degree of transparency ensure that the different players better understand the Bank's decisions. This, in turn, contributes to these being more effective in achieving the proposed objectives, enhancing the credibility of the CBC's inflation target.

This volume is part of this process of improving transparency. It is an update of the book published in 2003[1]/ and aims to provide information on the current state of the CBC's forecasting tools and the models' role in the Board's decision-making process[2]/. This book is a joint effort from different areas of the Bank's Monetary Policy Division, coordinated by the Economic Modeling Department.

First and foremost, the role models play at the CBC is that of organizers of the analytical framework used to study the mechanisms of monetary policy transmission[3]/. Indeed, it does not suffice to

[1]/ "Modelos Macroeconómicos y Proyecciones del Banco Central de Chile", 2003.
[2]/ This book is accompanied by an online repository containing various documents describing its contents in more depth, plus the computer-based codes of the main general equilibrium models.
[3]/ Monetary policy transmission mechanisms are defined as the channels through which the different sectors of the economy are affected by changes in interest rates owing to the decisions of the Central Bank.

casuistically observe the economy's current state to understand the forces at play in determining inflation. Instead, a careful and systematic approach is needed, which can be structured appropriately with the help of models. Such models facilitate the understanding of the current state of the economy, allowing to infer the state of those variables that are not directly observable in the data.

Second, the models support the Board's decisions by formulating quantitative forecasts for the relevant economic variables. The monetary policy instruments in an inflation-targeting regime operate with a lag and, therefore, must consider the expected economic situation when the actions in question take effect. The forecasts are the fundamental tool for describing that future scenario. As stated by Svensson (1997), the lag with which monetary policy operates means that, in practice, inflation-targeting regimes should rather be understood as "expected inflation targeting."

Third, having models that describe monetary policy's transmission mechanisms allows understanding and quantifying the most likely response of the economy, especially inflation, to the various innovations or news and evaluating the response to monetary policy actions.

In the CBC, a set of frequently used models and a series of auxiliary or satellite models complement each other. The main models seek to accurately capture the transmission mechanisms considered relevant most of the time and are used most frequently and intensively. Meanwhile, auxiliary models act as a complement to the results of the main models. They also facilitate the analysis of phenomena that occur less frequently and are not captured in these other models.

The economic models described in this book also differ in the emphasis given, on the one hand, to including constraints derived from economic theory, and on the other, to the statistical analysis of historical correlations between variables. The first type of models, called structural models, are helpful for understanding the reasons behind expected behaviors and, as explained in box 1.1, for conducting counterfactual exercises and analyzing alternative scenarios. The second type of model, referred to as econometric models in this book, emphasizes forecast accuracy. As a result, they can generate, simply and efficiently, an accurate assessment for the short-term most likely behavior of the variables of interest, where structural models typically have less predictive power. The decision of which model to use in each case is made considering the different approaches' strengths and weaknesses. Models with statistical emphasis are usually utilized for short-term forecasts. In contrast, models with greater economic theory emphasis are generally used for medium-term forecasts and counterfactual exercises.

Finally, it should be noted that model development is a continuous process that advances in several dimensions, incorporating new information sources and empirical and theoretical developments. The CBC's experience of recent years has been precisely this, gradually improving and refining their models. Thus, this book reflects the current state of these models, and future versions should be expected with variants and extensions that will improve its present contents.

1.1 Macroeconomic models and monetary policy decisions

The basis for any monetary policy decision-making process is the careful analysis, based on the accumulated experience, of the economy's current end expected state. However, looking at the data alone does not permit a straightforward interpretation of past lessons. Economic models help clarify and organize this process by painting a structured picture of the economy and assisting in informed decision-making. Based on a systematic assessment of past economic behavior, macroeconomic models can provide a quantitative forecast for the most likely evolution of the economy[4]/. Furthermore, the use of models provides information on the possible implications of future policy decisions.

Models as organizers of the analysis

The use of models allows for an orderly discussion and analysis of monetary policy. Models help anchor the discussion on the future evolution of the economy based on its past behavior's statistical analysis. Furthermore, economic models allow grouping into the same conceptual framework the various determinants of inflation and quantify the magnitudes and timings of monetary policy's different transmission channels. This can be achieved thanks to the models' coherent internal structure, with economic theory playing a fundamental role. In this context, the models need to include feedback channels that reflect the fact that agents consider what others are doing when making their own decisions.

It is important to note that while models can provide timely forecasts about the most likely evolution of various economic variables, these will always be subject to a considerable degree of uncertainty. A critical analysis of the results and an informed use of judgment are fundamental in the discussion leading up to policy decisions.

Models and economic forecasts

Because changes in the monetary policy interest rate affect the economy with a lag, policy decisions cannot be based only on contemporary events. Instead, it is necessary to determine whether the current policy orientation is compatible with an inflationary trajectory that allows the fulfillment of the objective of price stability within the monetary policy horizon. In that sense, the inflation forecast acquires a predominant role, as they become monetary policy's explicit operating objective.

Inflation and economic growth forecasts are done frequently, in an iterative and interactive process, with Monetary Policy Meetings and Reports as the main milestones. This process configures a central forecast scenario for inflation and other relevant variables. Additionally, the use of models allows for the analysis of alternative scenarios, thus generating a balance of risks and sensitivities that are useful as inputs for monetary policy communication.

Policy evaluation and exercises

A model that adequately captures the transmission mechanisms of monetary policy not only serves the purpose of forecasting but can also be applied in artificial settings to analyze different policy exercises and simulations. This computer-based laboratory is helpful to isolate and quantify policy effects, which in the data become entangled with multiple other disturbances to the economy or

[4]/ Careful analysis of past forecasts and how they compare with the actual performance of the economy also provides valuable information for evaluating, reformulating, and updating the models.

under conditions other than the current circumstances.

On the one hand, models allow to tackle issues related to the short- and long-term effect of changes --either transitory or permanent-- in variables unrelated to monetary policy, such as the global scenario or fiscal policy. These exercises are essential for monetary policy because of their implications on the path of inflation and because they allow recommending monetary policy responses when facing a variety of possible scenarios.

On the other hand, macroeconomic models allow the Bank to evaluate the impact of monetary policy changes in terms of the magnitudes and lags with which they affect inflation and growth. If this is coupled with a clear policy objective, the use of models allows assessing which is the most appropriate way of implementing monetary policy.

Box 1.1: **The Lucas critique and the use of economic models.**

Among other things, models facilitate the assessment of how alternative policies would affect the economy. This kind of analysis is often the subject of interest of policy makers and academics. For example, what impact would a particular change in the monetary or fiscal policy regime have on the economy?

In a famous contribution, Lucas (1976) emphasized that it is crucial to consider the expectations of households, businesses, and other relevant agents for this type of analysis. These players are likely to change their expectations in the face of a policy change, and these expectations will inform their decisions. By influencing the agents' decisions, expectations become a critical determinant of the aggregate effect of the policy change. The so-called Lucas critique claims that assessing an alternative policy without considering its impact on the agents' expectations will result in erroneous conclusions.

As an example, consider the relationship between the interest rate and the level of economic activity. A historical analysis will suggest an inverse relationship between these two variables over time, which reflects that, in general, an expansionary monetary policy stance (i.e., low interest rates) results in increased economic activity. If a central bank were to consider changing its monetary policy regime persistently to exploit that inverse relationship and boost economic activity through sustained monetary expansion, its analysis would be susceptible to the Lucas critique. Why? Because such an analysis would be based on a historical relationship that would fail to consider how people's and firms' expectations would adjust to the new policy. Most likely, in the face of a new, more expansionary policy, individuals would adjust their expectations so that they would only expect higher inflation and no expansion of economic activity would materialize. The historical relationship between the interest rate and the level of economic activity would not survive the policy change. We have, then, that an analysis will be susceptible to the Lucas critique if it is based on a model that only considers the historical correlations, or "reduced-form relationships". On the other hand, the analysis will be robust to the Lucas critique if it is based on a model that explicitly incorporates how the alternative policy affects the agents' expectations.

To provide a policy analysis that is robust to the Lucas critique, the values of the model's parameters should not change in the face of policy changes. Such parameters, known as "deep" or "structural", reflect the preferences and objectives of individuals and firms that inform their decisions with expectations about their environment, including the prevailing policy regime. In contrast, an analysis susceptible to the Lucas critique is based on historical reduced-form relationships that are likely to change when the policy regime is altered, thus yielding erroneous results.

Similar to structural models used at other central banks and international organizations, the XMAS model, described in sub-section 3.3.2, has microeconomic foundations and parameters relating to the preferences and objectives of individuals and firms that make decisions considering their expectations about the future. This makes it largely robust to the Lucas critique. Therefore, it is more suitable to analyze alternative policies than less structured models such as the MSEP described in sub-section 3.3.1. However, to the extent that models like XMAS overlook aspects relevant to specific contexts, they will lose the robustness to the Lucas critique. For example, in these models, individuals and firms form their expectations based on a perfect knowledge of the entire structure of the model and all its parameters. This assumption, known as rational expectations, facilitates solving these models and understanding their sults. However, there may be scenarios where agents form their expectations significantly different from the model's assumptions.

Suppose agents form their expectations based on partial information about the structure of the economy and/or its current state, and this mechanism is relevant for a specific analysis. In that case, models like the XMAS will lose robustness to the Lucas critique. While it is difficult for a model to be entirely robust to the Lucas critique, it is advised that analyses of alternative policies are based on models with microeconomic foundations, such as XMAS. As there is no such thing as a perfect model, the judgment of Board members and CBC economists is essential when interpreting the models' results.

1.1.1 The role of judgment

Beyond their usefulness, one must bear in mind that economic models are abstract simplifications of reality: they require multiple simplifying assumptions and include a limited number of economic agents, relationships, and mechanisms. Furthermore, there is uncertainty about which is the most appropriate model for each case and moment in time, the true value of the parameters of each model, the stability of the relationships among variables, and the unforeseen future occurrences. For these reasons, at all stages of a model's development and use, there must be a constant dialogue with the economic judgment of experts who understand their inherent limitations.

In developing the models, it is necessary to decide which assumptions will be made and what mechanisms will be introduced. It is not always desirable to incorporate as many theoretical constraints, or as few simplifying assumptions as possible, into the structure of a model. Introducing new aspects may not be advised if it makes the model too computationally expensive or less tractable regarding the shocks and policies' transmission mechanisms. In this sense, the trade-off between complexity and parsimony must always be considered. The choice of structure will usually depend on the question to be answered and the information available.

Even with a properly developed model, the influence of judgment must be present at all stages of building the scenarios on which policy decisions are based. In this sense, these judgments will complement the models' forecasts, helping to overcome their limitations by inputting data elements that the models cannot interpret correctly. Appropriate use of judgment ensures that the combination of short-term information, model predictions, and sensitivities about the economy's future course is consistent and reflects the Board's vision.

At the CBC, the short- and medium-term forecasts, in both the national and international areas, contain elements of judgment provided by the technical staff that complement the information provided by the forecasting models. The judgments are generated from the expertise of the staff, from quantitative elements not considered in the forecasting models, and from quantitative and qualitative information obtained through surveys conducted by the Bank itself[5]/ as well as by other local or external institutions. The application of judgment considers the specific characteristics of the various forecast models, their simplifying assumptions, and the degrees of uncertainty associated with their forecasts. Additionally, in reviewing the expected monetary policy scenario, the Board gives feedback regarding the central scenario and the sensitivities of the outlook proposed by the technical staff[6]/. After this feedback process, the Monetary Policy Division proposes monetary policy options to the Board for each Monetary Policy Meeting, where again the judgment of the technical staff becomes relevant. Finally, in the policy decision and its communication to the public, the Board's judgment is again preponderant.

Most recently, the Board has embarked on a gradual process of incorporating elements related to the judgments applied to the forecasts in its public statement. This measure stems from considering the importance of judgement in the forecasts, of transparency in the communication of the rationale behind monetary policy decisions, and in response to the recommendations of the committee of experts that in 2019 evaluated the performance of the CBC in fulfilling the mandates of its Constitutional Organic Law (LOC)[7]/.

[5]/ From 2013 onwards, the BCCh, in the framework of its "Business Perceptions Report", conducts interviews with the administrative and managerial staff of companies in different economic sectors with the aim of obtaining qualitative information to complement the analysis of the economy and the process monetary policy decision making. This report provides a vision from the perspective of the companies that can hardly be obtained from other sources and is an essential component to determine part of the judgment applied to the forecasting process.

[6]/ The forecasting process distinguishes between: a) the central scenario, defined as the most likely expected trajectory for the different economic variables; b) the baseline scenario, which, based on the central scenario, includes a set of sensitivities with a greater probability of occurrence consistent with the reported inflationary and growth ranges; and c) the risk scenarios, i.e. sensitivities with a lower probability of occurrence that summarize the evaluation of the most relevant risks facing the economy.

[7]/ The full report is available at www.bcentral.cl.

1.2 Structure of the document

The structure of this book reflects the expertise accumulated over recent years in developing and using the CBC's models. Chapter 2 details the main instances that require using macroeconomic models. This includes the Monetary Policy Report, which is published four times a year, on the day following the March, June, September, and December Monetary Policy meetings, and which contains an exhaustive analysis of the current and expected state of the economy. In the remaining four policy meetings, the international and domestic short-term scenario forecasts are updated.

Chapters 3 and 4 address the process of analysis and forecast, and describe the models used at the CBC. Finally, Chapter 5 presents the guidelines for a future modeling agenda that is consistent with the newest empirical and theoretical developments and that also aims to achieve a better understanding of the effects of monetary policy, the determinants of inflation and its interaction with employment, the evolution of the financial market and other economic variables.

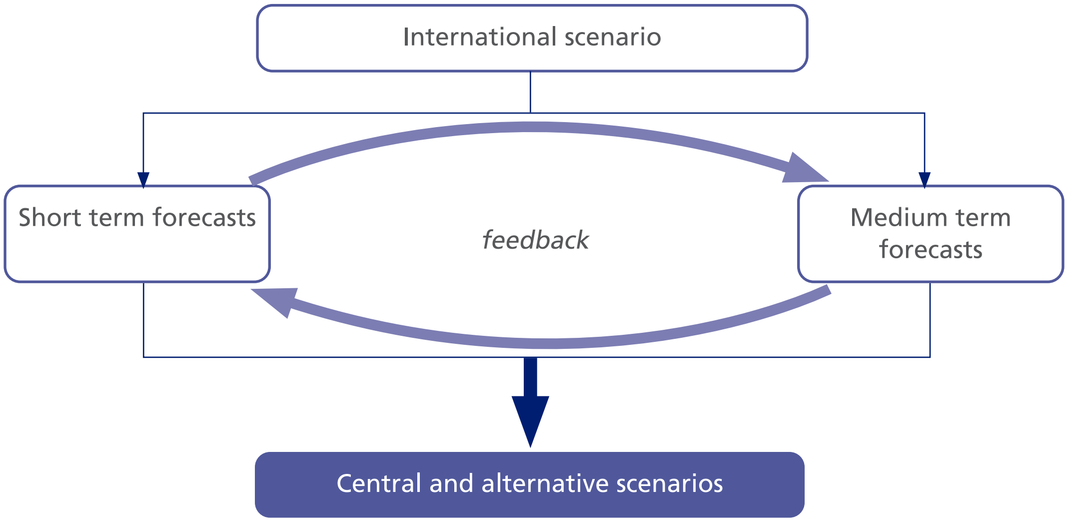
2. FORECAST AND ANALYSIS: MACROECONOMIC MODELS AT MONETARY POLICY MEETINGS AND REPORTS.

The CBC's forecasting process is designed to meet the different requirements dictated by the implementation of the Bank's monetary policy framework. Its ultimate objective is to provide information to the Board on the expected trajectory of activity and prices within the monetary policy horizon. In particular, the process contemplates the generation of a central scenario that is attributed the highest probability of occurrence, in addition to sensitivity and risk scenarios that incorporate possible economic events and developments that, although estimated to have a relevant probability of occurrence, are not included in the central scenario. The baseline scenario and the alternative scenarios based on the most relevant risks and sensitivities, taken together, assist the Board in generating strategies, managing risks, and defining policies.

This section summarizes this forecasting process, emphasizing the role played by macroeconomic models in conjunction with the judgment of staff and Board members in providing inputs to the analysis of the current and future state of the economy. A more detailed description of the structure and use of the various models is presented in sections 3 and 4.

Figure 2.1

The CBC's Forecasting process



Source: Central Bankf of Chile.

The building process of the forecast scenarios is summarized in Figure 2.1 and can be divided primarily into three blocks. First, the construction of a scenario for the external sector. Second, a short-term forecast for the local economy. Finally, a medium-term forecast for the local economy that uses as inputs the results of the two other blocks[8]/. This process, which serves to inform monetary policy decisions, is carried out comprehensively every quarter, coinciding with the publication of the MP Reports. The preparation process of these reports considers four formal meetings of the Board and staff. The first meeting presents the international scenario, with intensive use of the models described in sub-section 3.1. The second meeting focuses on the analysis of the relevant economic background for the domestic economy. The third meeting discusses the short-term scenario developed from the models described in sub-section 3.2 and the medium-term baseline scenario. Finally, in the fourth meeting, the monetary policy options consistent with achieving the inflation target in the baseline scenario are evaluated, and the different risk scenarios are discussed. At this meeting, the analysis is based significantly on the results of the structural and semi-structural models described in sub-sections 3.3 and 4.2.

For those MP meetings that do not coincide with the publication of an MP Report, a simpler exercise is performed, mainly to update the forecasts of the international scenario and the short-term domestic scenario[9]/.

Given the characteristics of the Chilean economy, particularly its comparatively small size relative to the world's economy, the international scenario is considered exogenous, which means that it is not affected by local events. For the international scenario, a series of both econometric and structural models are used. These are reported and complemented with information derived from the asset prices in the global financial markets, which reflect the markets' expectations for the different variables. This process, in turn, is complemented by the judgment of staff and the Board. The evaluation of the external economy that arises from it provides some of the necessary assumptions for the country's short- and medium-term economic outlook[10]/.

The short-term forecasts for the domestic economy use various econometric models developed to better understand the data and make predictions as accurate as possible. The resulting forecasts are then adjusted by judgments to capture relevant qualitative information and meet theoretical constraints not explicitly addressed by the models. The short-term forecasts serve as input to the medium-term models. Over the medium term, the theoretical consistency and the interaction between the monetary policy and the economy become crucial[11]/ in structural and semi-structural models, explicitly incorporating constraints derived from economic theory. Two general equilibrium models estimated with quarterly data are used: the XMAS and the MSEP[12]/. The use of general equilibrium models adds discipline to the process and helps to ensure that the analyses of different variables are consistent. These results are complemented with staff judgment and external information that can inform economic effects unaddressed by these models. An example of the use of external information to inform judgment on forecasts is described in box 2.1.

[8]/ Short term is defined as the current and immediately following quarters, while the medium term considers the trajectory of the variables over a period of up to three years.

[9]/ The BCCh also uses, though to a lesser extent, the economic models for high-frequency monitoring of economic developments, reporting to the Board on a weekly basis.

[10]/ Although a wide range of global economic indicators are monitored, analysed and forecasted, the variables included in the domestic economy forecasting models are mainly linked to our main trading partners' activity, commodity prices, exchange rates and interest rates.

[11]/ For the forecast of certain highly volatile variables that are difficult to model structurally, such as food prices, econometric models are used to report expected short- and medium-term trajectories.

[12]/ XMAS is a stochastic dynamic general equilibrium model, with microfounded equations and strong theoretical constraints. The MSEP is a simple semi-structural model with estimated equations, featuring an IS curve, a Phillips curve, and a Taylor rule. Both models are described in more detail in sub-section 3.3.

In developing the central forecast scenario, given that short-term forecasts determine the initial conditions for the medium-term outlook, the theoretical consistency requirements that general equilibrium models must meet require continuous feedback between the two processes.

The forecasts from the medium-term models provide a view on the outlook for the main variables relating to activity, inflation, the exchange rate, and interest rates. These forecasts are then used as input by the MACRO model[13]/ to obtain disaggregate forecasts for different real and nominal GDP components consistent with the central forecast.

The process of preparing the central scenario just described summarizes the trajectories of the variables of interest assigned the highest probability of occurrence. Despite being the most likely scenario, it is subject to multiple sources of uncertainty, most notably the probability that these variables' trajectories will differ from those assumed in the central scenario. Due to this uncertainty, the forecasting process also considers alternatives to that scenario. Within the set of alternative scenarios analyzed, the subset with the highest probability of occurrence is used to inform the amplitude of the expected inflation and GDP growth ranges reported in the MP Reports. These sensitivities constitute the baseline forecast scenario. The second subset of alternative scenarios, of lower estimated probability of occurrence, is focused on analyzing the risks facing the economy and the monetary policy responses that would be necessary should those risks materialize.

This process becomes the initial proposal from the staff for a central scenario and alternative scenarios based on the most relevant risks and sensitivities. The members of the Board then pass on their judgment in an iterative process with the staff. This process culminates with the publication, in the MP Report, of the board's vision about the current state, expected outlook, and risks for the national and global economy, including the implications that such vision has on a path for interest rates that is consistent with the achievement of the inflation target.

Box 2.1: **Judgment in medium-term forecasting: the role of external information in evaluating the path of mining investment.**

Throughout this book, emphasis is placed on the importance of judgment in the forecast process. Sometimes the judgment is warranted by lack of data, whereas other times, the available data does not allow to clearly distinguish the underlying signals of supply or demand.

[13]/ The Macroeconomic Consistency Model (MACRO) is an analytical tool that allows to ensure that macroeconomic forecasts are consistent with the basic macroeconomic identities that characterize the National Accounts, both in the internal and external equilibriums. Its structure is described in sub-section 3.2.3.

On occasion, the application of judgment is supported by satellite model predictions, which by design have greater detail and rigor in some respects. Using them may be advisable when, for example, their predictions differ significantly from those of the central models. Whatever the reason, allowing --when properly justified-- the central scenario to deviate from the models' forecasts enriches the analysis and helps to enhance the credibility of the Bank's vision on the state of the economy, which ultimately supports its monetary policy decisions. To illustrate how judgment is factored into the forecasts, this box provides a concrete example of its implementation: the treatment of mining investment in medium-term structural models.

A crucial element of monetary policy is to understand the drivers of demand. In Chile, where mining plays a significant role, to understand the role of investment and its relationship with monetary policy, it is advisable to separate investment between mining and non-mining. The reason for this distinction is that the former is typically not guided by the domestic cycle, but by strategic considerations of large corporations, global conditions, or other reasons beyond the reach of monetary policy. Meanwhile, the official publication of mining sector investment data is delivered with a two-year lag. To infer what will happen in the future and to have clarity about what has happened in the recent past, the publication lag makes it necessary to use models and information from sources external to the National Accounts. This external information can be obtained from the balance sheets of mining companies (FECU), the regular survey of the Capital Goods Corporation (CBC), as well as qualitative information from the Business Perceptions Report (IPN), prepared by the CBC based on surveys to selected companies throughout the country.

The CBC's medium-term structural model, XMAS, following the implementation proposed by Fornero, Kirchner and Yany (2015), distinguishes between investment in the mining and non-mining sectors. In the modeling of the mining sector, it is assumed that mining companies take prices as given, that today's production depends on investment previously made, that this investment is optimally determined with the objective of maximizing returns, and that this investment takes considerable time to become productive.

A clear and illustrative example of how judgment is introduced is presented in the MP Report of December 2018[14]/. The external scenario was characterized by cuts in the outlook for world demand and commodity prices, particularly the price of copper. Naturally, this more adverse global cycle led the model to revise mining investment downwards with respect to earlier forecasts. In contrast, the CBC's investment survey showed the exact opposite picture for the mining sector, with investment plans significantly expanding[15]/. This vision was confirmed by qualitative information collected in interviews with firms in the context of the IPN. Consequently, the final mining investment forecast included a judgment informed by the Survey and the IPN, which significantly departed from the original model's forcast. A central forecast was then generated that, through the use of judgment, made compatible the mixed signals from external sources and the general equilibrium model, delivering a coherent macroeconomic and sectoral vision.

[14]/ See box III.2 in the December 2018 Monetary Policy Report.

[15]/ The analysis of the investment survey, which contains information on projects involving amounts of US$5 million and up in various economic sectors, allows anticipating mining investment flows with reasonable accuracy because projects typically mature slowly and are thus very unlikely to be cancelled.

3. MAIN MODELS

Within the structure of the CBC's analysis and forecasting process, the so-called main or central models take on a predominant role. These are the models that are used systematically within the forecasting framework. This chapter is divided into four sections, where the first three describe the models used in each MP meeting or Report, while the fourth describes models used less frequently. Section 3.1 focuses on the models used to analyze the external scenario. Models for the domestic economy are explained in sections 3.2 and 3.3. Section 3.4 describes the models used to estimate the structural parameters of the Chilean economy, such as trend GDP, potential GDP, and the neutral interest rate.

3.1 Models for the external sector

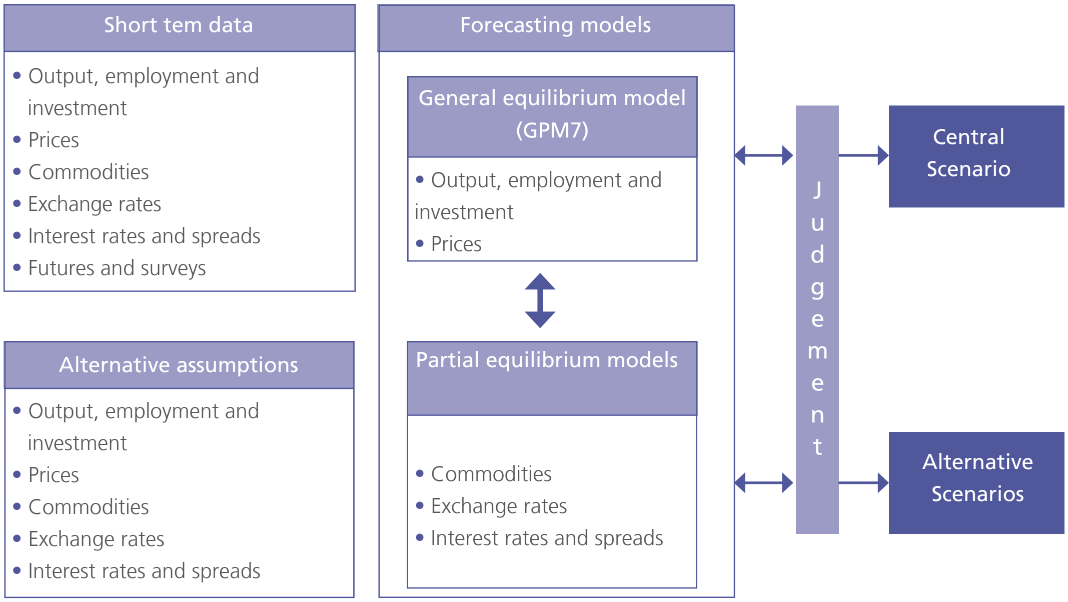
As noted in chapter 2, the central forecast scenario is created in several different stages. The first stage refers to the external scenario, where global macroeconomic variables that are most relevant for the Chilean economy are forecasted. Having realistic and accurate forecasts of such variables is a priority given the nature of the Chilean economy: open to world trade, integrated to financial markets, and significantly reliant on commodity exports.

The results from this first stage are feed into the models used for the short- and medium-term forecast of the domestic economy. These models assume that Chile is a small open economy, implying that, while changes in external conditions impact the domestic economy, changes in the local economy have no significant effects on the rest of the world. Thus, global variables are considered exogenous in the short- and medium-term forecasting models.

The variables projected in the international scenario can be classified into three blocks: (A) the block for global activity and external prices, which is made up of the estimates for GDP growth for the world's biggest economies and regions, and for inflation in Chile's main trading partners; (B) the block for commodities, in which copper, fuel and food prices are forecasted; and (C) the financial block, which contains the outlook for the U.S. 10-year monetary policy and bond interest rates (i.e., the Fed funds rate and U.S. 10-year Treasury Note, respectively), the three-month Libor (London Inter-bank Offered Rate) in dollars, the Chicago Board Options Exchange's Volatility Index (VIX), the sovereign bond risk premium index for Latin America (EMBI Latam), and the multilateral real exchange rate (RER) of the United States. In general, the baseline forecast is made quarterly frequency for a two-year horizon. However, series with monthly and/or annual frequency are additionally provided for some variables, sometimes for more extended periods.

Figure 3.1

Workflow for making the international scenario



Source: Central Bank of Chile.

Although the method of forecasting differs for each variable, the process is carried out in a way that ensures that all forecasts are consistent, on the one hand, with a common conceptual and empirical framework, and on the other, with the judgment of the staff and the Board, an input at different stages of the forecasting process. This section describes the forecasting process —schematically summarized in Figure 3.1— for the main variables of the international scenario, providing a comprehensive and intuitive explanation of how it was developed[16]/.

[16]/ A detailed description of technical aspects of the models for the external sector can be found in Beltrán et al. (2020)

Box 3.1: **The Global Projection Model.**

The Global Projection Model (GPM), originally developed at the IMF, is a stylized model with empirically consistent forecasts and a solid theoretical framework[17]/. The CBC uses the seven-region version of the model (GPM7)[18]/ for its international forecasts where output, unemployment, inflation, interest rates, and exchange rates are jointly determined for all regions. The seven regions are: the United States, the Eurozone, Japan, China, Emerging Asia, LA5, and others[19]/. Combined, these regions represent more than 80% of global GDP.

The GPM7 is a semi-structural model that, like the MSEP model used for the analysis of the domestic economy, proposes a balanced modeling approach, standing between two popular approaches in macroeconomic modeling: dynamic structural, stochastic general equilibrium models (DSGE), in which agents' decisions are micro-founded, with a strong emphasis on theoretical consistency[20]/; and econometric models with greater statistical emphasis, like vector autoregressive models (VAR), where the key feature is the search for empirical accuracy.

The GPM7 is fundamentally a New-Keynesian model of gaps. The evolution of each of the seven regions is represented by a set of behavioral equations that capture the links between output, inflation, interest rates, and exchange rates. The different variables are expressed in terms of gaps or deviations from their trend levels[21]/.

A. Real activity and inflation block

The preparation of the forecasts for the real activity and inflation block is based mainly on the GPM7 model, described in Box 3.1. The model is feeded by forecasts from the commodities block and the financial block. Subsequently, its results are complemented with the judgment of the staff and forecasts from other complementary models.

The forecasting process begins with the compilation of the required inputs for the GPM7 model, combining actual data with informed judgment. Thus, for the current quarter and sometimes for longer terms, the values for some variables are conditioned on data from the quarter's partial statistical information, alternative models, asset prices, and the judgment of the Board and staff.

[17]/ For more information, see https://igpmn.org.
[18]/ For a detailed description of the model, see Blagrave et al. (2013).
[19]/ Emerging Asia: India, South Korea, Indonesia, Taiwan, Thailand, Malaysia, Hong Kong, the Philippines, Singapore (23.4% of the world at purchasing power parity). LA5: Brazil, Chile, Colombia, Mexico, Peru (6.1% of the world at PPP). Others: Russia, United Kingdom, Canada, Turkey, Australia, Argentina, South Africa, Venezuela, Sweden, Switzerland, Czech Republic, Denmark, Norway, Israel, Bulgaria, New Zealand, and Estonia (15% at PPP).
[20]/ One example of these models is the Integrated Global Monetary and Fiscal Model (IMMF), which is a multi-regional DSGE model developed by the IMF's Economic Modeling Division. See Anderson et al. (2013).
[21]/ Each one of these blocs is represented by a model similar to the MSEP, described in greater detail in sub-section 3.3.1.

Once this information is incorporated, the GPM7 is used to generate forecasts of economic activity and prices for the world's main regions. These are complemented with data from other sources and alternative models and with the staff and the board's judgment. The steps of this process are detailed below:

(i) Determining the information to be included in the forecasts: At this stage, the latest available data, usually from the preceding quarter, is gathered for the following series:

- *Regional economic activity and prices: GDP and inflation for each of the seven regions.*
- *International food prices: foods and cereal price indexes as published by the The Food and Agriculture Organization of the United Nations (FAO).*
- *International fuel prices: prices for WTI and Brent oil, diesel, gasoline, liquid petroleum gas (LPG), and kerosene.*
- *International financial conditions: monetary policy rates for the United States, the Eurozone, and Japan, plus indicators of financial market tightness for these three blocks*[22]/.

(*ii) Forecasts by external sources: At this stage, trajectories are imposed for the initial quarters of the forecast horizon for some variables. In addition, external trajectories are imposed for the first one or two quarters for series of economic activity and prices and eight quarters for other types of variables. These external forecasts are obtained from the following sources:*

- *Regional activity and inflation: Judgment of the staff based on actual information of the current quarter and market projections.*
- *International food prices: Prices of market futures.*
- *International fuel prices: Prices of oil and its derivatives, together with forecasts from models based on those market's futures.*
- *International financial conditions: For the Fed funds rate (FFR), forecasts are based on the dots provided by the Federal Open Market Committee (FOMC), asset price figures, market operator estimates, and staff judgment (see subsection on international interest rates). For the monetary policy rates of the European Central Bank and the Bank of Japan, the staff's judgment is used, complemented with information from market analysts.*

(*iii) GPM7-based general equilibrium projections:* At this stage, the model's forecasts, conditional on the information described above, are obtained. The main variables forecasted are GDP growth and inflation for each of the regions for an eight-quarter horizon. Additionally, the GPM7 provides forecasts for potential GDP, the effective and natural unemployment rate, the monetary policy rate, core inflation, and the financial conditions in the seven regions, as well as for the international prices of fuels. These results are compared with the trajectories from external models to ensure consistency between both methodologies. The forecast assumptions are then adjusted as necessary until said consistency is obtained.

(*iv) Construction of variables of interest:* At this stage, trajectories for variables of interest that are not directly obtained from the model are constructed. As an example, the GDP for Chile's main trading partners is not a direct output from the model, but a proxy measure can be built from the model region's forecasts. This is done by averaging and reweighting the different regions' forecasts as needed to obtain the most relevant series for the domestic monetary policy analysis[23]/. These variables of interest are:

- *GDP growth: The GDP growth rates are aggregated by weighting each country according to its GDP at purchasing power parity (PPP) and, alternatively, using a multilateral exchange rate (MER) common for all the countries[24]/.*

- *External prices: Analogous to the GDP growth treatment, the results delivered by the GPM7 are used to forecast the evolution of the External Price Index (IPE)[25]/. To calculate it, the producer price indexes (PPI) of each country, measured in dollars, and weighted by their trade with Chile, are averaged geometrically. In turn, the PPIs are constructed based on the inflation and oil series. Each region's PPI is regressed on its own lag, the Consumer Price Indexes (CPI) from each GPM7 region, and the oil price forecasts from different models. The exchange rate trajectory of each region is estimated from exchange rate forecasts contained in the Consensus Forecast reports and other market analysts. This approach is complemented with staff judgment to ensure that these results are, on aggregate, consistent with the estimates derived for the forecasted real multilateral dollar estimates[26]/. This considers the inflation differentials obtained from the model.*

(*v) Final forecast adjustments:* Once an initial forecast is obtained for economic activity and price indexes, it is compared with counterparty forecasts (the IMF's WEO, Consensus Forecast, investment banks —Barclays, Deutsche Bank, J.P. Morgan, and Morgan Stanley—, and Bloomberg surveys) and staff judgment. If deemed necessary, adjustments are made to the forecast assumptions, generating a new scenario consistent with those assumptions. Finally, the forecasts are discussed with the Board, who may propose new revisions that would lead to further adjustments in the model assumptions. This method ensures that the forecasts are consistent both with the judgment of the Board and the staff and with the general equilibrium structure imposed by the GPM7.

B. Commodities block

The commodities block includes forecasts for the prices of copper, fuels, and foods.

[23]/ In general, forecasts are constructed for the global economy, developed and emerging countries, and Chile's main trading partners.
[24]/ For the case of India, which cannot be directly identified in the regional GPM7 projections, an external forecast is made using data from the last quarter, counterparty reports (e.g., IMF, main investment banks, Consensus Forecast) and staff judgment.
[25]/ The IPE index measures the international prices of goods traded with Chile's main trading partners. See methodological note "Índices de Tipo de Cambio y Precios Externos, Distintas Medidas" at the CBC's website (http://www.bcentral.cl/).
[26]/ See the sub-section "U.S. Multilateral Real Exchange Rate Projection".

Copper price

Due to the reliance of the Chilean economy on copper exports, the forecast of the copper price is one of the most important variables from the CBC's global scenario. Forecasts are made on monthly, quarterly, and yearly frequencies. The quarterly forecast is based on an error correction model[27]/. In the model[28]/, the real price of copper is explained, mainly, by the ratio of LME copper inventories to global GDP (as a proxy for global copper demand) and by the U.S. real exchange rate. The model also uses as inputs the GPM7 forecast for China's growth (weighted by its share of the global copper market) and world growth. Additional variables, such as the global VIX and/or the China Manufacturing Outlook Index (PMI), are included when deemed appropriate.

In the short term, the quarterly forecast is conditioned on the forecast from an error correction model of monthly frequency, where a primary role is assigned to financial variables —proxied with the VIX— and to the speculative net positions of the copper futures markets[29]/.

Finally, the long-term copper price is forecasted with an error correction model of annual frequency, where the commodity's demand from the major economies is considered[30]/.

The final assessment on copper price prospects is generated by contrasting the models' forecasts with the judgment of the staff and a thorough review of specialized counterparties, namely Consensus Forecast, the Copper Research Unit (CRU), and selected investment banks.

Fuel prices

The forecasts for fuel prices are of great importance due to their effect on inflation and GDP growth —both external and domestic— and are updated weekly. The forecasted variables include oil prices (WTI and Brent), gasoline, diesel, propane, and kerosene.

Forecasts for WTI and Brent oil prices, gasoline and propane, are constructed based on contracts from the relevant future markets within the policy horizon of 24 months. In order to smooth out daily fluctuations, a ten days moving average is used as a reference price.

Finally, error correction models are used to project diesel and kerosene prices. Short-run equations are estimated, including, as independent variables, the lags of such prices, the Brent oil price and inventory projections[31]/.

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[27]/ Error correction models establish dynamics that in the long term revert to a proportionality relationship between different variables. See Engle and Granger (1987) for more details on the methodology.
[28]/ The model specification follows De Gregorio (2005).
[29]/ Speculative net positions are computed as the difference between the total values of "long" and "short") copper operations which expect the price to go up and down, respectively, in the futures market.
[30]/ See López et al (2009) for details.
[31]/ For further information on these models, see García and Jaramillo (2007).

Food prices

The international food price index is forecasted with monthly frequency. The index is constructed based on a weighted average of each of its components (i.e., cereals, sugar, oil, and meat). These, in turn, are obtained from the prices of futures traded on the most relevant international farming and livestock markets[32]/.

C. Global financial conditions block

The objective of the third block of forecasted variables is to provide insights on the external financial conditions that the Chilean economy will most likely face during the forecasting horizon. The forecasted variables in the block include world interest rates and indicators of financial volatility and sovereign risk.

International interest rates

Three interest rates are included in the forecast: the FFR, the 10-year U.S. Treasury bond rate, and the three-month U.S. dollar Libor rate.

The FFR's forecast is generated based on several informational sources. First, a series based on an estimated Taylor rule for the United States, which draws from the CBC's own forecasts for the US GDP and inflation. In addition, the U.S. Federal Reserve's, after its meetings of March, June, September, and December, publishes the distribution of the FFR forecasts of the twelve members of the Committee for the end of the current year, the following three years, and the long term. A third source comes from data implicit in asset prices[33]/. Finally, a fourth source comes from survey data reported by Consensus Forecast.

Although this information is an essential input in the final FFR forecast, the judgment that emerges from the ongoing analysis of the U.S. economy is also a central element in assessing the expected FFR trajectory.

The methodology used to forecast the 10-year U.S. Treasury bond rate is based on the decomposition of the rate into a term-premium-free component (the expected monetary policy rate path) and a term-premium component. The final forecast is constructed by summing up these two components. In this methodology, explained in detail in Adrian et al. (2013), the term-premium-free component is computed, for each moment of the forecast horizon, as a geometric average of the annualized expected short-term rates. For this purpose, it is assumed that the FFR converges to the long-term level reported in the FOMC dots. On the other hand, the term premium is forecasted using the historical gap between the 10-year rate and the FFR. Thus, the methodology assumes that the current term premium converges to its historical average in roughly three years. The assumptions regarding convergence speed may change over time, as it is reevaluated every time the forecasts are updated[34]/.

[32]/ For cereals, for example, the futures of soybean, corn, rice, and wheat available in Bloomberg are used.
[33]/ Specifically, the Fed Fund futures, which are traded monthly for maturities of up to 36 months. The rates implicit in these contracts at any moment in time provide information about the effective average FFR that the market expects for each one of the next 36 months.
[34]/ Recently, these premiums have remained in negative territory and near their all-time lows. Hence, its trajectory considers this initial point and then seeks its convergence within the projection horizon, depending on the likelihood of a withdrawal of unconventional or quantitative easing ("QE") and the convergence of U.S. inflation to its target level.

The three-month Libor rate in U.S. dollars corresponds to the average interest rate at which the leading banks in the London market lend in that currency and term. The methodology used to forecast this rate is similar to the one used for the 10-year rate. First, the rate is decomposed between a term-premium-free component and a term premium component. Each component is then forecasted separately, and finally, those two components are summed over to obtain the final forecast. For each quarter of the forecast horizon, the first component is the geometric mean of the FFR projection in that quarter[35]/. The term premium is obtained by assuming a gradual convergence from the observed difference between the Libor and the FFR towards its historical average[36]/.

Market volatility index

The VIX captures the expected 30-day stock market volatility. The forecast assumes that the index will converge to its historical average, excluding crisis episodes, within the forecast horizon of 24 months. Depending on the situation, the forecast may be conditioned on additional information for the first two quarters.

Latin America sovereign risk premium index (EMBI Latam)

An additional financial variable regularly forecasted is the average sovereign risk index for Latin American emerging economies (EMBI Latam[37]/), excluding Argentina and Venezuela, as calculated by J.P. Morgan. It is forecasted using vector autoregressive models (VAR), as described in Muñoz (2014). The model yields a forecast for the sovereign risk trajectory of each economy in the region using as exogenous variables the world's GDP, commodity prices, the VIX, and a stability index for each country published by The Economist Intelligence Unit. The EMBI Latam is computed as the average of the forecasts for each economy using the weights reported by J.P. Morgan (excluding Argentina and Venezuela), which are updated monthly to capture short-term fluctuations. The final forecast also considers the judgment of the staff and the Board.

Multilateral real exchange rate of the United States

The U.S. multilateral RER is a critical piece in constructing the international scenario, as it is one of the variables used as input for forecasting economic activity and inflation rates. Additionally, this variable is used to verify the consistency of the domestic exchange rate forecasts used to calculate international price indices and forecast the copper price.

The expected trajectory for the multilateral RER is determined using a BEER model[38]/. In the model, the U.S. multilateral RER is explained based on: i) the terms of trade of the U.S.; ii) domestic absorption (adding up consumption, iii) investment and public expenditure) as a percentage of GDP; iv) the 10-

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[35]/ Unless a change in the FFR is foreseen for a particular quarter, the term-premium-free component of the Libor rate will be the FFR projection for the quarter.

[36]/ The speed and duration of the term premium's convergence to its historic average at each period is reassessed each time the projections are updated.

[37]/ The EMBI Latam includes Argentina, Brazil, Colombia, Ecuador, Mexico, Panama, Peru and Venezuela.

[38]/ The behavioral equilibrium exchange rate (BEER) models originally developed by Clark and MacDonald (1999), allow estimating the exchange rate's deviations from its fundamental-consistent level.

year interest rate differential between the U.S. and the Eurozone; and v) the size of the balance sheets of the Federal Reserve and the European Central Bank as a proportion of GDP[39]/. The model forecast is then complemented with staff judgment based on the RER's historical behavior, the forecast of market analysts and other relevant counterparties, and the GPM7's projections for the U.S. multilateral RER.

3.2 Econometric models for the domestic economy

The domestic short-term central scenario is generated by combining multiple forecasts based on different econometric models. These models draw from short-term external information and staff judgment[40]/. A broad description of the models used in the regular short-term forecast process is given in this section. In addition, the econometric models used to do estimates at longer horizons are also described.

3.2.1 Models for GDP

This section describes the different methodologies used at the CBC to forecast the aggregate GDP and its components. Disaggregating GDP into its components has two advantages: first, it enables a more detailed analysis of the particular dynamics of the different economic sectors; second, the aggregation of forecasts for the different components delivers an alternative projection for total GDP, an approach known as "bottom-up" (BU).

It should be clarified that while all the models presented in this section are used to forecast total GDP and non-mining GDP, not all are used to estimate their main components. Moreover, some approaches are used solely to forecast from the expenditure perspective, while others are used to forecast from the production perspective. Some models do both.

Most of the models presented below are estimated using seasonally adjusted series[41]/. The seasonal adjustment process is done using the X13-ARIMA-SEATS program (U.S. Census Bureau, 2017), which is widely used in central banks and statistical institutions. In a second stage, the forecast for the original series is recovered by reintroducing the seasonality from the seasonally adjusted series.

[39]/ These variables are introduced interacted with variables indicating the periods in which said central banks implemented their unconventional monetary policy measures.
[40]/ A more detailed description of the activity models utilized can be found in Cobb and Peña (2020), and in Carlomagno and Torres (2020) for the inflation models.
[41]/ Seasonal adjustment is a statistical procedure designed to remove seasonal patterns form time series (see Granger, 2001).

D. Models for supply components

All the models presented in this section are estimated quarterly or monthly using the monthly index of economic activity (Imacec) as a proxy for GDP[42]/. The quarterly GDP series are obtained by aggregating the Imacec over time. These models are used to forecast total GDP, non-mining GDP (aggregate GDP minus the mining sector) and, in some cases, the GDP components by class of economic activity, i.e. mining, agriculture and forestry, fishery, manufacturing, EGW (electricity, gas, water and waste management), construction, retail, restaurants and hotels, transportation, communications and information services, financial services, business services, housing and real estate services, personal services, public administration, value added tax and import duties.

(i) Seasonal ARIMA models with automatic selection

Due to their simplicity and performance, the seasonal ARIMA models (SARIMA) are widely used to forecast time series. These models are a generalization of the traditional ARIMA models[43]/, and they allow working directly with non-seasonally adjusted series by estimating the seasonal components within the same algorithm[44]/. In this context, automatic model selection routines have been developed that make it possible to process a significant number of series without the need for manual interaction.

A SARIMA model (p, d, q) (P, D, Q) can be expressed as:

$$(f_P f_p f_D f_d) y_t = (f_q f_Q) \varepsilon_t$$

where y_t is the forecasted variable; $f_P = (1-\Phi_1 L^s-...-\Phi_P L^{sP})$ is a seasonal autoregressive operator of order P; $f_p = (1-\phi_1 L-...-\phi_P L^p)$ is a regular autoregressive operator of order p; $f_D = (1-L^s)^D$ is a seasonal difference operator of order D; $f_d = (1-L)^d$ is a regular difference operator of order d; $f_Q = (1-\Theta_1 L^s-...-\Theta_Q L^{sQ})$ is a seasonal moving average operator of order Q; $f_q = (1-\theta_1 L-...-\theta_q L^q)$ is a regular moving average operator of order q; ε_t is a random process; s is the seasonality order (four for quarterly series and twelve for monthly series); L is a lag operator.

The CBC uses SARIMA models to estimate total GDP, non-mining GDP, the 17 supply-side components, and two additional sub-aggregations, namely natural-resources (NR) GDP (NR) and non-natural-resources (NNR) GDP[45]/. Thus, forecasts for total GDP are obtained from direct estimation, aggregating the 17 components, and incorporating the NR and NNR GDP with the VAT and import duty forecasts.

[42]/ The Imacec is an estimate that summarizes the activity of the different sectors of the economy in a given month; its interannual variation is a proxy of the evolution of the respective sector's monthly GDP. The Imacec's historical series are subsequently calibrated to make them coincide exactly. The National Accounts calculation methodology in its different frequencies, is contained in the document "Cuentas Nacionalesde Chile: Métodos y fuentes de información" (CBC,2013).
[43]/ ARIMA models project time series based on a linear combination of their past values, in addition to past prediction errors. For more details on the methodology, see Box and Jenkins (1976).
[44]/ The X13-TRAMO-SEATS program, used by the CBC to deseasonalize time series, contemplates using SARIMA model projections within the process of determining the seasonality of the series.
[44]/ The NR GDP is derived from aggregating Fishery, EGW and Mining. NNR GDP is defined as total GDP minus NR GDP, VAT and import duties.

(ii) Single-equation models

The models in this section seek to benefit from simple relationships between variables that have been established over time based on economic theory and empirical observations of the correlation between variables.

Generally, these single-equation models can be expressed as:

$$y_t = \beta X_t - \varepsilon_t$$

where y_t is the variable to be forecasted, β captures the relationship between the variables in X_t and y_t; X_t contains a group of variables that explain the behavior of y_t, and ε_t is a stochastic autoregressive moving average process.

Some specifications are estimated using the seasonally adjusted series, while others use the non-adjusted version of the series. For the forecasts two periods ahead and further in the future, the exogenous variables are forecasted using SARIMA models. The specifications presented in table 3.1 are used to forecast the Total GDP and non-mining GDP.

(iii) Bayesian VAR with a large number of regressors

Traditional VAR models allow to simultaneously estimate contemporary and intertemporal correlations among a set of variables.

Typically, a VAR model of order p can be expressed in reduced form as

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + \varepsilon_t$$

where y_t is a vector that contains the values of the variables of the model for the period t; c is a vector of constants; A_i are matrices that capture the direct effects of the lagged variables on y_t; and ε_t is a matrix of stochastic processes.

The number of variables to be included in these models is restricted to a small amount. The reasoning behind that decision is that the number of parameters in the model grows exponentially as more variables are included, difficulting the estimation process. To allow for the estimation of specifications with many variables, Banbura et al. (2010) developed a Bayesian VAR methodology that allows incorporating a large number of regressors simply and efficiently. The implementation of the methodology used in the CBC for estimating activity variables is described in detail in González (2012), and its fundamental characteristics are presented below.

Table 3.1

Specifications for aggregate GDP forecast models (1) (2) (3)

	dlog (GDP, Seasonally adj.)				dlog (GDP, no adj.)							
Regressors	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
dlog(seas. factor)				x	x	x	x	x	x	x	x	
dlog(cal. factor)				x	x							
dlog(SIC)		x				x	x	x	x			
dlog(SING)			(-1)		x	x	x	x				
dlog(energy)				x								
IMCE		x	x			x		x	x			
IMCE(w/o min.).						x						
dlog(IMCE.Ind.Cap)		x	(-1)			x			(-1)			
dlog(RER)		x	x			x			x	x		
dlog(CPI)						x			x			
dlog(min.Exp.)							x		x			
dlog(Imp.int)							x		x			
dlog(super.INE)									x			
dlog(GDP(-1))		x	x									
AR(1)	x					x	x	x	x	x		
MA(1)	x	x	x			x	x	x	x			

(1) "x" denotes contemporaneousness, (-1) denotes variable lagged one period.
(2) All the specifications include a constant.
(3) dlog() = difference of the natural logarithm, des. GDP = deseasonalized GDP; orig. GDP= GDP not seasonally adjusted; seas.factor = seasonal factor obtained from the deseasonalization process; cal. factor = factor of the calendar effect obtained from the seasonal adjustment algorithm; SIC = electric generation of upstream companies that used to be part of or belong geographically to the former Central Interconnected System; SING = electric generation of upstream companies that used to be part of or belonged geographically to the former Norte Grande Interconnected System; total ener = total electric generation; IMCE w/o Min. = IMCE excluding mining; IMCE.Ind.Cap = IMCE Industrial capacity utilization; RER, CPI; Min.exp = nominal mining exports in dollars; Imp.int = intermediate imports in dollars; super.INE = INE's supermarket sales index; GDP(-1) = previous period GDP; AR(1) = residual autoregressive term; MA(1) = moving average for the residual.
Source: Cobb and Peña (2020).

For total GDP and non-mining GDP, four VAR specifications are estimated where the aggregate projections are directly obtained in addition to two specifications where the aggregate projections are achieved from the BU approach. All the variables that merit it are used in seasonally adjusted terms.

The forecast specifications have the following logic: Starting from a baseline specification with a reduced set of variables, the size of the VAR is expanded by sequentially adding blocks: first a block of external variables; then a block of financial conditions and trade; and, finally, a block of domestic prices and sectoral activity. Thus, the final specifications are as follows:

(i) Small VAR (5 variables): GDP, CPI, MPR, real exchange rate, and electric generation.

(ii) Medium-sized VAR (11 variables): small VAR + Baltic dry index, external price index, broad dollar index, FFR, WTI oil price, and LME copper price.

(iii) Large VAR (47 variables): medium-sized VAR + monetary aggregates (cash, M1, M2, M3), stock of real loans (total, housing, retail, foreign trade, consumption, corporate, persons), averaged 30-to-89-day nominal lending rates, averaged nominal and real lending rates (90 days to 1 year, 1 to 3 years, more than three years), the exchange rate (observed and multilateral), Libor, VIX, BBA-AAA (U.S.) risk premium, IPSA, goods exports (totals, agricultural, copper, manufacturing, mining) and goods imports (totals, capital, consumer, intermediate, fuels, oil and other).

(iv) Giant VAR (72 variables): Large VAR + core price index, goods, services, core goods, core services, sectoral GDP (17 components, NR GDP, and NNR GDP).

The two specifications that follow the BU methodology are based on the giant VAR where certain aggregates are removed:

(i) Bottom-up full VAR: Giant VAR excluding total GDP, NR GDP, and NNR GDP.

(ii) Partial Bottom-up VAR: large VAR excluding total GDP and including price indexes, NR GDP, NNR GDP, and import duties.

(iv) Dynamic factor models

Dynamic factor models allow for an efficient use of large amounts of data. The extra efficiency is gained by compressing large datasets and multiple sources into a small number of factors[46]/.

Generally speaking, dynamic factor models can be expressed as:

$$y_t = A_0 f_t + A_1 f_{t-1} + \ldots + A_{Py} f_{t-Py} + \varepsilon_t$$

$$f_t = B_1 f_{t-1} + B_2 f_{t-2} + \ldots + B_{Pf} f_{t-Pf} + \eta_t$$

where the variables of interest are contained in the vector y_t. Unlike the VARs described above, they do not depend on the lags of the same variables of y_t, but on the contemporary and lagged values

[46]/ As explained in detail in Stock and Watson (2016), the main premise for dynamic factor models is that a considerable part of the common dynamics in large sets of time series comes from a limited set of unobserved factors, which in turn evolve over time and can be estimated.

of a reduced number of factors contained in the vector f_t. The structure of these latent factors, which capture in a few variables the co-movements of the variables from y_t, follows a VAR type structure. In this specification, A_i and B_i matrices capture, respectively, the effects of the factors in y_t, and the effects of the lagged factors on themselves. Vectors ε_t and η_t follow stochastic processes.

The methodology is used to forecast total GDP and non-mining GDP. The factors are drawn from the same blocks of information as in the Bayesian VARs with large numbers of regressors previously presented. A total of eight specifications are estimated for aggregate GDP and eight for non-mining GDP. The different specifications are obtained by estimating first- and second-order autoregressive processes for the dependent variable, each with four factor alternatives, namely: a single factor extracted from the variables included in the small VAR, two factors extracted from the medium-sized VAR set, three factors extracted from the large VAR set, and four factors extracted from the large VAR set plus the price indexes. In all cases, GDP is excluded from the set of variables from which the factors are extracted. All the variables that warrant it are adjusted for seasonality.

(v) Bottom-up forecast with single-equation factor-augmented autoregressive models

Bermingham and D'Agostino (2014) propose a way to combine the simplicity of uni-equational models with the possibility of allowing interaction between different components of GDP. In their proposal, for each component of GDP, an autoregressive specification[47/] is augmented with latent factors extracted from the group of remaining components.

The methodology is used to forecast each of the 17 components of GDP under four different specifications. Like the dynamic factor models described above, the different specifications consider both first- and second-order autoregressive processes for the dependent variable and two alternative ways for extracting the latent factors from the remaining GDP components: a single factor and the two factors. The factors are extracted with principal components following the methodology described by Stock and Watson (2002). All variables that merit it are seasonally adjusted. Finally, the forecasts for total GDP and non-mining GDP are obtained by aggregating the forecasts of all the different components.

(vi) Bottom-up forecast with factor-augmented autoregressive models and exogenous information

The methodology from Bermingham and D'Agostino (2014) can be extended to incorporate information from additional variables into the estimation. Thus, the models presented in this subsection add, for each of the specifications previously described, factors from the sets of variables used in the Bayesian VARs from (iii).

Then, as in (iv), a single factor is extracted from the variables included in the small VAR, two factors from the medium VAR set, three factors from the large VAR set, and four factors extracted from the large VAR set plus the price indexes. In all cases, GDP is excluded from the set of variables from

47/ An autoregressive model can be understood as a particular case of SARIMA model as described above.

which the factors are extracted. All variables that warrant it are used in deseasonalized terms.

The procedure results in 16 specifications to forecast each of the 17 components, which are then used to build aggregate forecasts.

(vii) Bottom-up forecasts using Bayesian VARs with variable coefficients

Given that the relationships between variables may change over time, when estimating the relationship between different GDP components to build an aggregate forecast, it may be appropriate to allow for some additional model flexibility. In this BU approach, the implementation described in Koop and Korobilis (2013) is used to estimate a Bayesian VAR containing all 17 GDP components, allowing for both the coefficients and the variance of the innovations to change over time.

Three specifications are used: a VAR with fixed coefficients; a VAR with variable coefficients; and a dynamic selection of models with fixed coefficients, variable coefficients, constant volatility, and stochastic volatility. All variables that warrant it are adjusted for seasonality. A detailed description of the methodology is presented in Cobb (2020).

E. Models for demand-side GDP components

GDP models from the demand-side perspective are estimated to forecast quarterly variables only. When monthly series are needed as independent variables, they are converted to quarterly frequency. All the models in this section are used to forecast total GDP, non-mining GDP, private consumption, gross fixed capital formation (GFCF), exports, and imports.

(i) MIDAS regression models

Recent times have seen a significant development of methodologies that use higher-frequency variables to forecast lower-frequency ones. One example is the mixed data sampling approach (MIDAS) developed by Ghysels et al. (2004). The methodology allows for the use of variables at different frequencies in the same model, establishing flexible temporal aggregation structures to transform them to the frequency of the variable of interest.

To forecast GDP from an expenditure perspective, we follow the approach of Marcellino and Schumacher (2010), where high-frequency series are dynamic factors extracted from a set of relevant variables. A detailed description of the implementation is given in Ghysels (2013). Several different specifications are estimated, and then the median of the forecasts is used. The specifications considered include independent variables in quarterly frequency, plus one or two factors extracted from the monthly variables. Table 3.2 shows the variables used in each specification.

Since the regressions are based on exogenous information, the forecast is done using a direct approach. In other words, for each period, a new model is estimated that links the specific forecast horizon to the mixed-frequency database. The amount of monthly information used is determined by the variable included with the longest publication delay, typically activity and employment.

The estimation is done using two different approaches. One uses annual variations of non-seasonally adjusted series for all data requiring differentiation; the other considers the first differences of the seasonally adjusted series in their original frequency.

(ii) AR-MIDAS models

As mentioned above, the monthly information used in each of the MIDAS specifications is determined by the variable with the longest publication lag. In the AR-MIDAS approach, the monthly information set includes all the available data. The unavailable variables are forecasted using the method described in the section about SARIMA models. Based on the latest monthly data and similar to the implementation for the MIDAS models, a direct approach is applied both for the annual change of the non-seasonally adjusted series and for the first differences of the seasonally adjusted series.

(iii) *Bridge-Models*

Another methodology that uses higher-frequency variables to forecast lower-frequency ones is that of bridge models. The procedure involves the traditional estimation of relationships between variables of the same frequency, where homogenization at the lower frequency results from the time-based aggregation of higher-frequency indicators. Unlike the MIDAS models presented above, bridge models assume stable relationships over time. Also, by avoiding the use of reduction methods, as dynamic factor models do, it is still possible to interpret causal relationships.

As detailed in Cobb et al. (2011), the procedure used at the CBC takes a dynamic forecasting approach, using the same model for the entire forecast horizon. Forecasts for the most immediate periods are introduced as input for the more distant estimates, and the exogenous series are forecasted using SARIMA models to obtain the necessary information. While primarily used to forecast GDP from the expenditure perspective, bridge models are also used to forecast the mining, construction, retail, and manufacturing sectors.

(iv) Bridge models with automatic selection of exogenous variables

As the relationships between variables may change over time, the automatic selection of variables and lags has become a popular strategy in empirical work. Here, as a complement to the bridge model approach of the previous section, a stepwise regression approach is used for variable and lag selection. In the stepwise methodology, variables and their lags are added or removed from the regression based on the change in the model's explanatory power and the corresponding t-statistic,

Table 3.2

Variables included in MIDAS models for each component

	Cons. Priv.	Cons. Frec.	Cons. Non Dur.	Cons. Dur.	Cons. Gov.	Cons. Total.	GCF Cons.	GCF M&E	Comex Exp.	Comex Imp.	GDP Tot.	GDP Non Min.
Quarterly variables												
GDP					X							
GDP (commercial partners)					X				X	X	X	X
GCF Def./ GDP Def.						X						
GCF (Const.) Def./ GDP Def.							X					
GCF (M&E) Def./ GDP Def.								X				
Exports Def./ Imports Def..									X	X	X	X
Monthly variables												
Employment	X											
CMO (real)						X						
Comex credit								X				
Consumption credit		X	X	X								
Housing credit						X	X					
Employment (commerce)		X	X									
Employment (construction)						X	X					
Total Exports									X		X	X
Government spendingsl					X							
Electric generation (SIC+SING)											X	X
IMACEC					X							
IMCE											X	X
IMCE retail inventories										X		
IMCE retail investment						X						
IMCE construction							X					
IMCE industry inventories										X		
IMCE industry investment						X						
Capital imports						X		X		X	X	X
Consumption imports	X	X	X	X						X		
Intermediate goods imports										X		
Construction activity index							X					
External risk index									X			
Domestic risk index											X	X

Continuation

	Cons. Priv.	Cons. Frec.	Cons. Non Dur.	Cons. Dur.	Cons. Gov.	Cons. Total	GCF Cons.	GCF M&E	Comex Exp.	Comex Imp.	GDP Tot.	GDP Non Min.
Supermarket sales index (INE)	X	X	X									
Government income (total)					X							
Government income (taxes)					X							
Government income (inves-tments)					X		X					
CPI Fuels		X	X									
IPEC	X	X	X	X							X	X
IPEC housing goods				X								
IPEC automobiles				X								
IPEC housing goods				X								
IPSA											X	X
IPSA real	X	X	X	X		X	X	X				
IVCM	X									X	X	X
IVCM durables				X							X	X
IVCM non durables		X	X									
Total wages/Consumption deflator	X	X	X	X								
Copper price					X	X	X	X	X			
Manufacturing activity									X			
Mining Activity (INE)								X	X		X	X
Credit interest rates (1 to 3 years)							X	X				
Credit interest rates (3+ years)	X	X	X	X		X			X	X		
Unemployment rate					X						X	X
Libor rate 6 month									X	X		
RER	X			X		X	X	X	X	X	X	X
Automobiles sales	X			X						X		
VIX				X	X	X	X	X	X			

which leads to a tendency to pick variables with greater explanatory power and lower correlation with other explanatory variables. The total pool of variables the algorithm picks from is the same as in the baseline bridge model specification, except that the variables are tested contemporaneously and with lags of up to four quarters. As in the previous implementation, a dynamic approach is used, forecasting the exogenous series with SARIMA models to complete the necessary information for the whole forecast horizon.

(v) SARIMA models with and without exogenous information

SARIMA models are widely used to forecast time series. Two approaches are applied to the forecast of GDP's demand components. The first one is the same previously described as "Seasonal ARIMA models with automatic selection." The second one consists of using the specification found by using the methodology described for the bridge models with automatic selection of variables in the previous section and adding SARIMA components employing the automatic routine described above.

3.2.2 Models for Inflation

As has been noted, in an inflation targeting regime, it is essential to forecast the evolution of prices. Usually, it is useful to analyze both total CPI and its various components separately. A particularly important subset of prices, which is highlighted in box 3.2, is core inflation, which exhibits greater stability and is highly correlated with longer term inflation. Although important, core inflation is not the only studied component. When analyzing the inflation outlook, the evolution of the all the items in the consumption basket are taken into consideration. This section describes the econometric models that are used for the short-term forecasts of the different inflation components, and, in the case of food inflation, also used for the medium-term forecasts. Econometric models are used to also forecast medium term food inflation due to the difficulty of structural models to replicate the irregular dynamics of food prices, which can be better predicted with purely empirical models.

(vi) Short-term forecasting models for inflation and its sub-components

The CBC forecasts inflation, as it does GDP, both by directly estimating the aggregate series and by using indirect procedures, where the different components are forecasted and then aggregated with a BU methodology to generate a forecast for headline inflation. For the BU forecast, 53 sub-components and six intermediate CPI aggregates are estimated[48]/.

The BU strategy poses three major challenges. First, disaggregate CPI series are typically substantially more volatile than aggregate CPI, as they are subject to greater measurement errors, sectoral supply shocks and methodological changes. In econometric models, these events are reflected in the emergence of outliers and breaks in the unconditional means. Second, there is the challenge of identifying which macroeconomic variables are relevant for predicting each of the 53 components, the intermediate aggregates, and the aggregate CPI. As predictors of inflation, the CBC focuses mainly on activity and financial indicators, both domestic and international. Figuring out which components of inflation are also relevant for predicting others is the third challenge to be solved.

These three challenges are resolved in a comprehensive manner by applying the Autometrics selection algorithm (see Doornik, 2009). In Autometrics, the starting point is a general model that includes all possible regressors, where the number of regressors may even exceed the number of observations. The initial specification is then reduced, using a multipath decision tree, to a simpler final representation[49]/.

To address the problem of outliers and mean breaks, the impulse-indicator saturation (IIS) and step-indicator saturation (SIS) techniques proposed and analyzed by Doornik and Hendry (2016) and Castle et al. (2015) are adopted A central feature of these strategies is that they allow for jointly selecting the model and identifying outliers and structural breaks[50]/.

Within this general modeling framework, three alternative strategies are considered for each of the 53 components, the intermediate aggregates and the aggregate CPI, which differ in the pool

[48]/ It is worth noting that the 53 sub-aggregations are not necessarily independent elements that are useful to build total CPI. In other words, some sub-aggregations have some elements in common and the 53 sub-aggregations do not add up to equal total CPI.

[49]/ The validity of the final representation, i.e., that the final models can explain all the characteristics of the dependent variable that explains the original model, is ensured by encompassing methods, described in detail in Bontemps and Mizon (2008) and Hendry, Marcellino and Mizon (2008).

[50]/ See also the discussion in Peña et al. (2011) on the problem of identifying this type of events in statistical models.

of potential regressors considered: (i) including only lags of the dependent variable; (ii) including lags of the dependent variable and of the remaining components and intermediate aggregates; and (iii) including lags of the dependent variable, of the remaining components and intermediate aggregates, and of the 10 macroeconomic variables included in Table 3.3.

Table 3.3

Financial and activity variables used in forecasting inflation

Variables
Non-Mining IMACEC
Employment cost index (ICMO)
Unemployment rate
Nominal exchange rate (NER)
Oil prices (WTI, Brent)
Foreign price index (IPE)
Food price index (FAO)
Federal Funds rate (FFR)
Global industrial production
MPR

Source: Carlomagno and Torres (2020).

These three strategies plus the different alternatives for aggregating the components provide a set of different forecasts that are monitored periodically.

(vii) Medium-term forecasting models for food prices

Due to the difficulty for structural models to provide accurate predictions for food inflation, econometric models are used for this variable not only for short term forecasts, as is the case for the rest of the variables, but also for the medium term. Given the need for longer term forecasts, the forecasting strategy for food's prices[51]/ considers error correction models that simultaneously incorporate short- and long-term relationships. Error correction models explain the short-term relationships between variables, correcting them to dynamically undo deviations from their long-term relations.

In general terms, the error correction models used to forecast food prices can be written as:

$$dy_t = \beta dx_t^{cp} - \theta_1 (y_{t-1} - \theta_2 x_{t-1}^{lp}) + \varepsilon_t$$

where y_t is the forecasted variable; d is a difference operator, x_t^{cp} contains the variables that explain the short-term behavior of y_t; x_t^{lp} contains the variables which, weighted by the parameters of vector θ_2 , define the long-term relationships of y_t ; θ_1 determine how fast the deviations of y_t with respect

[51]/ This subdivision, which represents 16.5% of the CPI according to the 2018 basket, includes all the products of the "food" group defined by the INE, excluding a subset of its more volatile elements (fresh fruits and vegetables, i.e., 2.8% of the 2018 basket), which is forecast through a simple process of convergence to the inflation target.

to its long term relationship with x_t^{lp} are corrected; while ε_t is a stochastic process. In this model, the relationship between y_t and x_t^{lp} define the long-term conditions, while short term dynamics are defined by the relationship between y_t and dx_t^{cp}, corrected to compensate past deviations from their long-term relationship.

Food prices are forecasted in a two-stage process using the co-integration technique developed by Engle and Granger (1987). This allows for a valid representation of the data-generating process by means of an error correction model, which will avoid problems of spurious correlations when the set of variables contained in a vector are co-integrated. In the first stage, long-term relationships are estimated under a co-integration scheme. In the second stage, using Granger's representation theorem, an error correction model is constructed that incorporates the steady-state deviations of the set of long-term determinants obtained in the previous stage.

A set of co-integration models are estimated for six sub-components of the food CPI: meats; dairy and dairy by-products; bread and cereals; sugar and cocoa; and oils and fats. For each group, six specifications with different combinations of lags are estimated, both for the independent variables (the prices of the different groups), and for the rest of the dependent variables, which are detailed in Table 3.4. The

Table 3.4

Variables used for forecasting food inflation

Group	Variables
Meats	CPI (meats) FAO meats index CPI (grains and cereals) CPI (electrical rates) ICMO NER
Dairy	CPI (dairy) FAO dairy index CPI (grains and cereals) ICMO NER
Grains and cereals	CPI (grains and cereals) FAO cereals index CPI (electrical rates) CPI (fuels) ICMO NER
Sugar and Cocoa	CPI (sugar and cocoa) FAO sugar index Brent oil price ICMO NER

Continuation

Group	Variables
Oils and butter	CPI (oils and butter)
	FAO oils index
	CPI (electrical rates)
	CPI (fuels)
	ICMO
	NER

Source: Carlomagno and Torres (2020).

estimation sample starts at the year 2000 and includes information up to the last available data release. Forecasts are evaluated at one, two, four and eight quarters ahead, the latter coinciding with the policy horizon of the CBC. The best performing models are then used to make the aggregate forecast.

Box 3.2: **The importance of core inflation for inflation-targeting Central Banks**

Box IV of the December 2019 MP Report includes a discussion on the importance of core inflation in an inflation targeting scheme. It explains that, although the monetary policy of the CBC is aimed at having expected headline inflation stand at 3% over a two-year horizon, the analysis of the evolution of prices must consider that, in the short term, movements in the total CPI tend to be noisy. Even correcting for seasonality, sharp fluctuations in monthly inflation are usually not associated with the business cycle, but rather with other types of factors, such as transitory supply shocks in specific sectors (e.g., climatic contingencies, accidents, geopolitical events that cause temporary effects on oil prices) and measurement errors.

In this context, when evaluating the current and future trajectory of the change in the price level, central banks typically pay attention at the evolution of the so-called core-inflation indicators[52]/, that seek to identify the medium-term inflationary trends (the underlying inflationary signal corrected for the short term "noise") associated to the business cycle and with respect to which monetary policy can act more efficiently. Unfortunately, it is not possible to identify with certainty the noise component, which has led central banks to look at a broad set of indicators intended to eliminate unwanted noise in alternative ways[53]/.

The literature distinguishes two major methodological alternatives to the problem of separating the signal from the noise. The first consists of reweighting the CPI components according to the "amount of noise" contained in their variations, assigning lower weights to the noisier items. The second uses statistical time-series smoothing methods to extract a stable inflation signal.

[52]/ Clark (2001) provides a general description of the core measures. Hogan et al. (2001), Roger (1997), Shiratsuka (1997) and Cutler (2001) argue that core inflation should be the object of interest in monetary policy decision making.
[53]/ An analysis for a broader set of core measures can be found in box V.1 of the March 2015 Monetary Policy Report, and in Córdova et al. (2008).

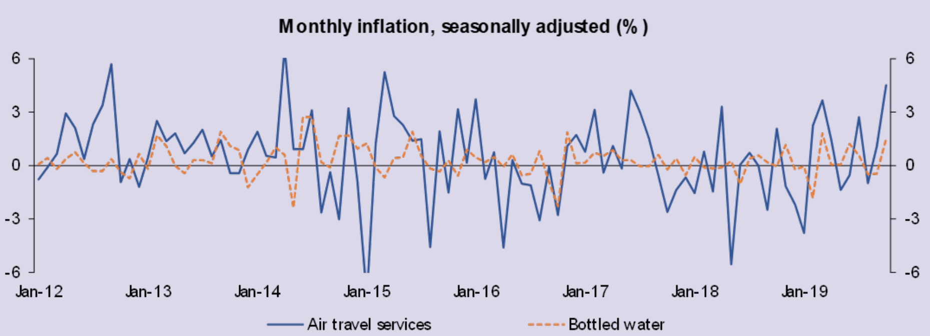
The most widespread practice among central banks is to focus on the first alternative because the measures it delivers are easier to communicate and the markets can therefore adopt them more easily to form their expectations. Cases of this alternative are exclusion measures, in which the noisiest components are directly deleted from the calculation (given zero weight). The deleted components can either be always the same (fixed exclusion) or change every month (variable exclusion).

The main core inflation indicator of current use at the CBC is one of fixed exclusion that excludes all food and energy prices (CPIEFE)[54]/. Its main advantage is the simplicity of its calculation and communication to the public. However, this advantage comes with two limitations. First, although the transitory shocks that motivate the construction of the underlying indicators do not always affect the same components, the items removed from the CPIEFE are always the same. Thus, the CPIEFE basket could include some components that are affected by transitory shocks and exclude others that are not. This limitation is common to all fixed-exclusion indicators. Second, even restricting the analysis to only fixed-exclusion indicators, the criterion of excluding all food, all energy and no other component is not necessarily optimal. As an example, the CPIEFE excludes bottled water, which is a "low noise" component, but includes air travel services, which is a "very noisy" component (Figure 3.2). These limitations are not merely conceptual, but, as we will discuss below, significantly affect the statistical properties of the CPI-EFE.

To overcome the limitations of the CPI-EFE, Carlomagno and Sansone (2019) propose an alternative indicator based on automatic component exclusion mechanisms, whose selection criterion is based on the desirable properties that a core inflation indicator should have. In this methodology, the components that deliver the indicator with the best possible properties are the ones that are chosen. The main five desirable properties that are identified in the literature are:

Figure 3.2

Volatility of components included and excluded from the CPI-EFE index (1)



(1) CPI-EFE excludes bottled water but includes air travel services.

Source: Central Bank of Chile and Instituto Nacional de Estadísticas.

[54]/ For a full description of the calculation of the CPIEFE, see appendix 6 in Instituto Nacional de Estadísticas (2019).

(i) Absence of bias: Since the Central Bank's objective is of headline inflation and not core inflation, the average value of the latter must be as close as possible to that of headline inflation.

(ii) Persistence: If the core inflation indicator filters out adequately for transitory shocks not associated with monetary policy, the oscillations around its average level should be "smooth". In other words, convergence to the mean should be relatively slow.

(iii) Low volatility: In addition to a relatively slow convergence to the mean, the convergence path should be as stable as possible, meaning that the volatility of the oscillations of the core inflation indicator should be low.

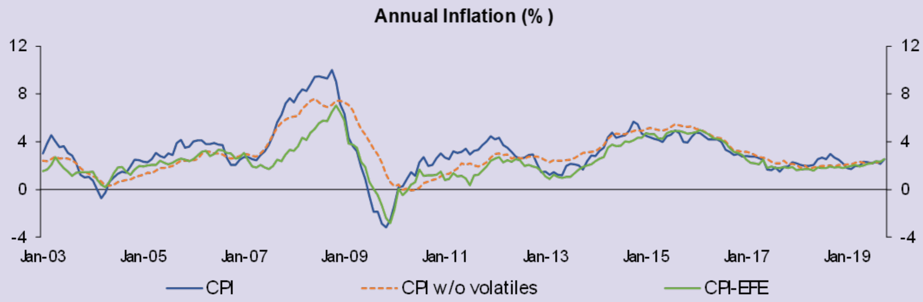
(iv) Correlation with the GDP gap: If the core inflation indicator does reflect fundamental inflation movements, it should be significantly correlated with the GDP gap.

(v) Predictive power: It is desirable for the core inflation indicator to contain relevant information that allows to anticipate future inflation.

Carlomagno and Sansone (2019) propose a strategy to summarize these five properties into a single indicator and a procedure to select which components to exclude so that said indicator is optimal. The procedure allows for exclusion to be either fixed or variable. Figure 3.3 shows how the fixed exclusion version of this indicator, called non-volatile CPI, compares with the CPIEFE and headline CPI. Table 3.5 shows that the non-volatile CPI im prove on the CPIEFE in the five dimensions considered, resulting in a less biased, more persistent, and less volatile indicator, with higher correlation with the activity gap and greater predictive power.

Various measures of core inflation are monitored by the CBC can be useful as forecasting tools. However, the empirical evidence shows that no instrument gives the right signals every time, so, in the CBC's economic analysis, these indicators are used and interpreted with caution along with other tools and measures.

Figure 3.3
CPI, CPI-EFE and CPI without volatile components



Source: Central Bank of Chile and Instituto Nacional de Estadísticas.

Table 3.5
Properties of selected inflation measures (1)

	CPI w/o volatiles	CPI-EFE	CPI
Bias	**	*	***
Persistence	***	*	**
Volatility	***	**	*
Corr. w/ GDP gap	***	*	**
Prediction	***	**	*

(1) The number of stars denotes the relative goodness, for each dimension, of the different measures of inflation, where *** represents the best performing measure.

Source: Carlomagno and Sansone (2019).

3.2.3 Medium-term models for the current account and the demand components of GDP

As explained in section 2, the CBC's structural and semi-structural models produce the medium-term forecasts by modeling a simplified abstraction of the economy, aiming at having representations for the main real variables, inflation, the monetary policy rate (MPR), and the real exchange rate.

The macroeconomic consistency model (MACRO) is a set of macroeconomic identities that mimic the approach used to construct the national accounts. It is an analytical tool that allows to ensure consistency between the macroeconomic forecasts with the basic macroeconomic identities that characterize the national accounts, in both the domestic and the external sectors[55].

Compared with the version described in Central Bank of Chile (2003), the current version of the model features various improvements and updates, among which the following stand out: (i) the use of chained indexes in the real aggregate flows (built from disaggregate ones, with a BU approach, to replicate the demand structure as published by the national accounts); (ii) the use of time series satellite models to forecast the main components of aggregate demand; and (iii) the use of dynamic general equilibrium models, such as XMAS and other satellite models to condition the aggregate supply, inflation, exchange rate and MPR forecasts.

The MACRO model yields the following forecasts:

(i) Real aggregate demand and all its components conditional on aggregate supply forecasts from the XMAS and MSEP models. Forecast for inventory variations are obtained as residuals.

(ii) Nominal demand and all its components. Based on the forecasted inflation, exchange rate and wages from the XMAS and MSEP models, each sector's price deflator is calculated, allowing for the conversion of real aggregate demand into nominal values.

(iii) Exports of goods by economic sector and imports of consumption goods, capital goods and other intermediate products. Exports and imports of services are also forecasted. The forecasts of relevant international variables, indicators of sectoral activity and the forecasts from the XMAS and MSEP models are used as inputs.

(iv) Unitary value indexes for exports and imports of goods and services, from which the terms of trade in pesos can be deducted. The forecasts are conditioned on international variables such as external inflation, commodity prices and local costs.

(v) Current account based on accounting identities and forecasts for the trade balance, rents, and net transfers.

(vi) Gross national disposable income and the savings-investment identity.

3.3 Structural models for the domestic economy

The CBC has two medium-term models for the local economy: the semi-structural projection model (MSEP), and the extended structural model for analysis and simulation (XMAS). Both approaches seek to contribute to a better understanding of the forces that guide the expected evolution of the economy, considering interrelations between key economic variables, such as output, inflation and interest rates. In general terms, structural models such as XMAS are anchored in parametric constraints and between equations based on economic theory fundamentals, making them more robust to the Lucas critique, and

[55]/ The forecasts must be consistent with the expected evolution of the balance of payments, especially with the balance of the current account, which is important for estimating the savings share of national residents necessary to finance the expected investment flow (the savings-investment identity).

allowing robust assessments of policy and counterfactual scenarios. Also, semi-structural models such as the MSEP place greater emphasis on the econometric adjustment to the data, at the expense of relaxing some theoretical constraints and greater vulnerability to the Lucas critique. Another difference between the two models is their scale. While the XMAS has a more complex structure, thus allowing a more detailed analysis of different shocks and propagation channels, the MSEP model is simpler, prioritizing parsimony and flexibility over complexity, facilitating follow-up of the transmission mechanisms modeled. As noted in Box 3.4, the complementary use of models with different characteristics, such as the MSEP and the XMAS, is guided by the search for greater robustness in the analysis and forecasts, providing different perspectives which, together with the judgment of the Board and the economic staff, help to generate an overall vision of the economy's current state and future outlook.

At the CBC, these models play essentially two roles. First, they serve to generate the central projection scenario for the medium term. For this, they use as input the short- and medium-term forecasts for the international sector, and short-term forecasts for local activity and inflation, along with the judgment of the technical staff and the Board members. Second, this type of model is used for the analysis of alternative scenarios and to evaluate the monetary policy consistent with said scenarios. This section provides details on the structure of the two main medium-term models in use at the CBC: MSEP and XMAS.

3.3.1 MSEP: A semi-structural projection model

The MSEP model, as described in detail in Arroyo et al. (2020), represents a step forward from the MEP model documented in Central Bank of Chile (2003) and García et al. It is a simple stylized model, adapted to the Chilean reality, which includes a series of relations estimated econometrically and which is part of the so-called gap models. These models explain the cyclical dynamics of an economy, that is, when certain variables are located above or below their trend values, thus showing positive or negative "gaps". As the model is written in gaps, the trends of the variables are calculated at a stage prior to the use of the model, and the relationships between the different variables are restricted to their cyclical components[56]/.

Semi-structural models such as the MSEP have two main advantages over structural models such as the XMAS: the first is parsimony: greater simplicity implies reduced reliance on assumptions, which facilitates the interpretation of results; the second is versatility: by allowing the rapid implementation of new relationships between variables, the model can be easily adapted to analyze new hypotheses.

Model Structure

The core of the MSEP is made up of the three fundamental equations of the basic new-Keynesian model[57]/: an IS curve, a Phillips curve and a central bank reaction function given by a Taylor type rule:

[56]/ Although the model does not generate endogenous movements in the variables' trends, it can be used to analyze the implications of exogenous movements of the productive potential. For example, in the June 2019 MP Report, as part of the analysis of the effects of migration, potential GDP was reestimated to accommodate an increase in the economy's productive capacity by a larger labor force. The updating of potential GDP allowed for the use of the MSEP to generate forecasts that reflected the immigration shock.
[57]/ Galí (2015) present a complete derivation of the basic equations of the neo-Keynesian model.

(i) *IS Curve*: The IS curve connects the dynamics of demand with the expected trajectory of the real exchange rate. The theoretical motivation of the equation is in the choice of the present and future consumption profile of rational agents, and is often expressed as:

$$y_t = E_t(y_{t+1}) - a_1(i_t - E_t(\pi_{t+1}) - r^n_t)$$

where y_t represents the output gap (the difference between effective and potential GDP), $E_t(y_{t+1})$ and $E_t(\pi_{t+1})$ are, respectively, expectations for future gap and inflation, while it and rnt denote, respectively, the nominal interest rate and the neutral real interest rate. The parameter $a_1>0$ shows the degree of negative causality between changes in the interest rate gap (the difference between the real and the neutral interest rates) and the activity gap. It is a simple idea: when faced with a higher real interest rate, households prefer to increase their savings by reducing their present consumption and increasing their future purchasing power.

(ii) *Phillips curve:* The Phillips curve relates the inflation expectations with the output gap. It is generally expressed as:

$$\pi_t = b_1 E_t(\pi_{t+1}) + b_2 y_t$$

where parameters b_1,$b_2>0$ reflect the positive causality between movements of the output gap —present and expected—and inflation[58]/. This relationship is motivated by the idea that production costs increase with the level of economic activity, i.e., costs are higher in periods of low unemployment. As companies adjust their prices to adapt them to changes in their production costs, direct effects on inflation are generated. In turn, the assumption that producers face costs or barriers to change their prices[59]/ justifies inflation being affected not only by current costs but also by their expected future level (and their effects on future inflation).

(iii) *Taylor rule:* New-Keynesian models usually assume that the central bank follows a Taylor rule[60]/ , expressed as a simple dual-purpose rule, namely, to stabilize activity and inflation, which in its simplest form is often written as:

$$i_t = c_1 \pi_t + c_2 y_t$$

where parameters c_1, $c_2>0$ show the positive causality between movements of inflation and the activity gap and changes in the level of the interest rate established by the monetary authority. In this way, this simple rule instructs the central bank to raise the interest rate whenever the output gap or inflation increase, which, given the relationships specified in the IS and Phillips curves, will contribute to stabilize activity and prices.

58/ This expression of the Phillips curve can be written recursively as $\pi_t = b_2 \Sigma_{i=0}^{\infty} b_1^i E_t(y_{t+i})$, thus directly linking inflation with the expected future output gap.
59/ This is one of many ways of building a Phillips equation. Lucas (1972), for example, builds a Phillips curve using other mechanisms, such as distortions in how prices are perceived.
60/ This type of simple rules, which became popular after the work of Taylor (1993), have proven to be a good proxy for the complex process of decision making by central banks.

In the MSEP, the specification just described is modified to improve the adjustment to the data and to introduce relevant channels for a small open economy like Chile. Thus, world trade related aspects are included in order to capture the high degree of openness of the Chilean economy. Small economy considerations lead to modeling the relationship with the external scenario in a unidirectional way. External shocks affect the local economy, but what happens at home does not impact activity or external prices. Thus, the model allows for changes in international conditions to have significant effects on the domestic economy. Variables such as external demand --from both advanced and emerging countries--, the real exchange rate, the terms of trade --defined as the ratio of export to import prices-- and the trading partners' activity directly affect the domestic sector.

Regarding the canonical model described above, the IS curve is simplified by replacing future activity and interest rate expectations with past and contemporary values. Meanwhile, the specification is extended to incorporate direct effects of global factors on domestic activity. In addition, the movements of the activity gap predicted by the IS curve allow obtaining predictions for the unemployment rate through Okun's law[61]/, which links productive and labor gaps.

Inflation, which in the canonical model is represented by a Phillips curve that links inflation to expected changes in the firms' production costs, is classified into core[62]/, food, energy, and other volatiles. The first one is subdivided into the inflation of tradables and non-tradables. The Phillips curve for the non-tradable sector maintains a structure similar to the formulation of the canonical model, but modified in two dimensions. On one hand, the coefficient that accompanies expectations is estimated instead of being restricted to values consistent with the households' discount rate, a parameter that links the value given to future utility with respect to present utility[63]/. On the other hand, past values are allowed to influence the level of contemporary inflation. The Phillips curve of the tradable sector, meanwhile, does not consider a role for inflation expectations and is extended with respect to the baseline formulation to incorporate the direct influence of exchange rate movements. Regarding the non-core components of inflation, food prices are modeled based on past inflation and the activity gap, while the energy sector's inflation is modeled based on the fluctuations of the world price of oil, measured in domestic currency and smoothed out in order to replicate the fuel price stabilization mechanism (MEPCO) in reduced form. For the inflation of the most volatile components of the CPI, i.e., excluding core, food and energy inflation, it is assumed that it does not depend directly on the activity gap and is modeled as a function of the exchange rate and its past values.

The Taylor rule, in turn, is modified with respect to the specification described above, in three dimensions. First, the rule is specified in terms of the interest rate gap with respect to its neutral level. Second, with the objective of including some degree of graduality and persistence in the rate movements, lagged values of the interest rate gap are incorporated to the rule. Finally, the response to inflation is specified in relation to the expected annual core inflation, in terms of deviations from the target.

The exchange rate modeling is based on an uncovered interest rate parity, where the expected

[61]/ Okun's law refers to the empirical relationship, initially observed by Arthur M. Okun in 1962, between GDP growth and the evolution of unemployment.

[62]/ In the MSEP, core inflation is associated with inflation without volatiles described in box 3.2.

[63]/ Box 3.4 presents a discussion about the implications of this assumption.

depreciation depends on the risk-adjusted difference between domestic and foreign currency interest rates. This relationship is modified to allow for a direct influence of the terms of trade and other idiosyncratic deviations.

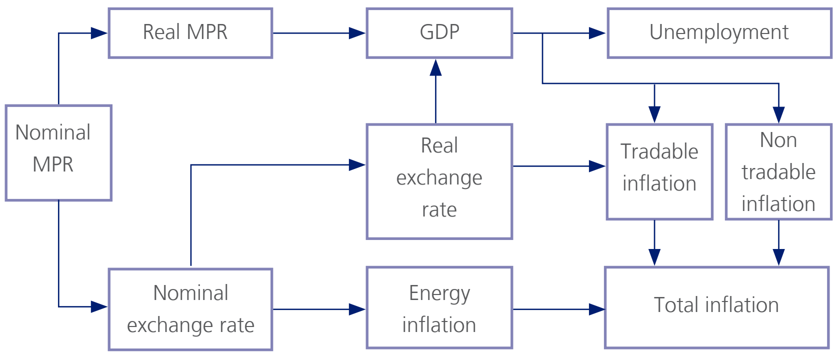
As for the evolution of the potential GDP and the real neutral rate[64]/, the former is specified as an exogenous autoregressive process, where the disturbances are chosen for the series to coincide with the estimates of the models described in sub-section 3.4.1. Meanwhile, it is assumed that the real neutral rate's evolution is proportional to the expected growth of potential GDP, and the proportionality factor is calibrated so that in the long term the model's rate's a value is equivalent to the neutral rate as estimated by external models. Finally, the external variables, including the trading partners' output gap, whether emerging and advanced, the oil price, imports and exports, the external interest rate, external inflation, and the country risk premium, are modeled as simple stochastic autoregressive processes.

Monetary policy transmission mechanism

In the MSEP model, as summarized in figure 3.4, the monetary policy affects the economy by two distinct channels: a demand channel and an exchange rate channel.

In the first one, an increase in the MPR translates into an increase in the real monetary policy rate (RMPR). These tighter financial conditions, by way of the relationship described in the IS curve, contract aggregate demand, which, through the relationship described in Okun's law, also raises the unemployment rate. Simultaneously, the increase in the interest rate affects the exchange rate through the uncovered interest rate parity condition, instantly appreciating the nominal exchange rate (NER), and then an expectation of a depreciation. The exchange rate appreciation affects inflation directly and indirectly. Directly because the imported cost component of firms decreases,

Figure 3.4
Monetary policy transmission mechanisms in the MSEP model



Source: Based on Arroyo *et al.* (2020).

64/ The nominal neutral rate is defined as the real neutral rate plus the inflation target.

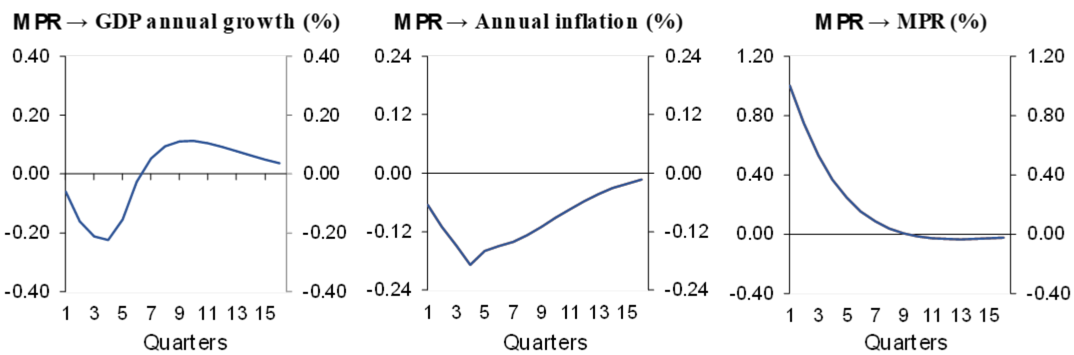
and indirectly through a demand reduction due to the effect of currency appreciation on the export sector's competitiveness.

Both the drop of output and the exchange rate appreciation put downward pressure on the price level. In the case for the tradables component of inflation, the two effects interact. The non-tradables component is primarily affected by the demand channel. Finally, the energy inflation component is influenced only by the exchange rate channel[65]/.

The dynamic effects of an unexpected and non-persistent MPR shock are illustrated in Figure 3.5. The model predicts a maximum effect in four quarters for both inflation and GDP growth.

Figure 3.5

Effects on GDP and prices of a sudden interest rate hike in the MSEP model (1)



(1) A one-period monetary shock is simulated, without persistence, and whose size is calibrated to generate a 1% increase (100 basis points) on impact on the MPR.

Source: Based on Arroyo et al. (2020)

[65]/ The energy price is assumed to depend exclusively on the international oil price and the exchange rate.

Data and Estimation

The MSEP is estimated using quarterly data for the Chilean economy and the rest of the world in the period spanning from 2001 to 2019[66]/. The starting point of the sample coincides with the moment in which the CBC officially adopted the inflation-targeting regime.

The chosen series consider, among other variables, local activity indicators, prices, employment, interest rates, terms of trade and exchange rate. Also included are indicators of the global economy such as commodity prices, interest rates and activity in emerging and advanced economies. All these series are introduced into the model in the form of gaps with respect to their levels or trend variation rates[67]/.

With the purpose of obtaining consistent projections among the different medium-term models of the CBC, the parameters associated with exogenous variables shared with the XMAS model are calibrated according to the values estimated for the latter model. This allows for a common interpretation of, for example, what a shock to external interest rates means. The rest of the model parameters are estimated together, using Bayesian techniques.

3.3.2 XMAS: An extended model for analysis and simulation

The XMAS is a structural model that extends the MAS model developed by Medina and Soto (2007), and previously used for analysis and forecasting at the CBC. This section provides an overview of the structure and transmission mechanisms of the model. A more detailed description can be found, for its baseline version. García et al. Garcia and Guerra-Salas (2020) describe an extension of the model that allows for exogenous changes in the level of the labor force, developed to analyze the macroeconomic effects of immigration and its implications for the conduct of monetary policy.

Unlike other empirical models of a purely econometric nature, structural models such as the XMAS are based on the explicit modeling of the behavior of different economic agents, relying on the fundamentals of economic theory with respect to the decisions of households and firms. This allows not only to generate a probable path for the future of the economy, but also to provide a more complete interpretation of the forces underlying the projections. In addition, this kind of model allows generating alternative policy scenarios, in which households and firms adjust their behavior according to the change in policy. In this sense, as discussed in more detail in box 1.1, these models are highly robust to the so-called Lucas critique.

The model incorporates a strong empirical component, where parameters are estimated to ensure

[66]/ The MSEP is estimated using data on GDP, potential growth, total inflation, core inflation, non-volatiles core inflation (tradable and non-tradable), food and energy, other prices, monetary policy rate, real exchange rate, terms of trade, output gap of advanced and emerging trading partners, EMBI Chile, external rate, oil price, copper price, external inflation, and unemployment rate. The methodology used for the calculation of core inflation is described in Carlomagno and Sansone (2019).

[67]/ Trends are obtained either from external models (e.g. the neutral rate and potential GDP, as described in section 3.4); from policy values (e.g. the inflation target); from simple statistical filters (e.g. commodity prices); or proxied from sample averages (e.g. the RER).

the most accurate adjustment possible to the true behavior of the economy in recent years. This allows for a quantitative view of the functioning of the Chilean economy, both for the generation of forecasts and for other types of analysis (see box 3.3).

General structure

The XMAS is a neo-Keynesian model of general dynamic stochastic equilibrium (DSGE). As a general equilibrium model, supply and demand conditions must be met simultaneously in all markets, with prices reflecting the balance between the two. Being a dynamic model, equilibriums are not only considered for the current period, but they also define expected future paths for all the variables. Finally, since it is a stochastic model, it is assumed that the forces that generate fluctuations in the economy around its long-term equilibrium are determined by exogenous random processes. The name new-Keynesian is applied to models such as the XMAS, which combine in their structure characteristics of neoclassical and Keynesian economic theories, where the assumptions of optimizing rational agents include considerations of imperfect competition between firms and nominal rigidities in prices and wages. It is these rigidities that allow MPR shocks to have effects on real variables such as GDP. If prices cannot be adjusted in the short term, the balance between supply and demand will be achieved via an adjustment in quantities.

In addition, the XMAS is a model for small, open economies. This means that the Chilean economy is open to the world, but small in the global context. Therefore, local economic developments require not to affect international variables, while allowing a significant influence of global economic shocks on the domestic economy.

In its current formulation, the XMAS structure is comparable to that of the main models used by other inflation-targeting central banks. Furthermore, the model considers some idiosyncratic characteristics, such as a more developed mining sector and a treatment of fiscal spending consistent with the government's structural balance rule. Of course, it has important limitations, including a limited role for financial frictions, a dependence on rational expectation assumptions and bounded heterogeneity of agents, among others. However, these limitations are roughly considered in complementary models such as those detailed in section 4 of this book, or in future projects of the modeling agenda, described in section 5.

Economic agents

The model considers a local economy and an external sector. The local economy interacts with the rest of the world in two dimensions: in the real sector by importing and exporting goods and services, and in the financial sector by exchanging such assets.

Participating agents in the domestic economy are households, firms, the government, and a central bank.

A fraction of households are financially constrained. They consume goods and services produced by firms and those delivered by the government; they supply jobs, pay taxes and receive transfers from the government. The fraction of households that is not financially restricted can, in addition to the above, smooth out their consumption trajectory by saving and borrowing, in both local and foreign currency. In addition, these households invest in capital goods and receive dividends and other earnings from the firms they own (both in Chile and abroad).

Firms or companies are in charge of production, and there are several types. In the production structure of the non-mining sector, capital and labor are used as inputs, and pricing is subject to nominal rigidities. A second type of company sells imported goods on the domestic market and is also subject to nominal rigidities. The assumption of rigid prices in local currency allows an incomplete exchange rate pass-through, in line with empirical evidence. Profits generated by non-mining firms are delivered in the form of dividends to their owners, which are those households that are not financially restricted. The mining sector, on the other hand, is modeled as a representative, capital-intensive exporting company, with shared ownership between the government and foreign agents.

The government follows a structural balance rule, according to which each period's public spending is determined by structural or long-term revenues. Expenditures are split between government consumption, investment in public goods and transfers to households. These outlays are financed with tax collections, income from property in the mining sector and debt issuance. In addition, In addition, the government has in place a program to smooth out the prices of fuels and reduce volatility (MEPCO), which involves a variable combination of fuel taxes and subsidies.

The central bank conducts monetary policy based on a Taylor-type policy rule. Under this rule, the interest rate responds to deviations of inflation from the 3% target and of output growth from long-term growth. When evaluating inflationary pressures, the central bank responds to a weighted average of present and expected inflation, core and headline[68]/. Also, it is permitted that the effective rate deviates transitorily away from what the rule prescribes. The rule's specification, consistent with results obtained by Arias and García (2018), the autocorrelation of these deviations is allowed to be different from zero[69]/.

In the external sector, the prices of commodities (copper and oil) and imported goods (excluding oil) are modeled as exogenous, together with our trading partners' growth and inflation, and a risk-free external rate. The exchange rate is determined through an arbitrage relationship between local and foreign currency interest rates, while the net external debt, as a percentage of GDP, determines the country risk.

Productive structure

The productive structure of the model, which is summarized in table 3.6, imposes balanced growth among the different sectors of the economy. In the long run, it is assumed that the share of the different sectors in GDP remains constant, which implies imposing restrictions on productivity in each of the economic sectors (e.g. mining and non-mining). In turn, productivity growth must be assumed to be the same in all the productive sectors over the long run. Five layers can be

[68]/ Core inflation is the price change of regular consumer goods, without agricultural goods and derivatives of imported oil. In the data, this variable is associated to the CPIEFE, i.e. the consumer price index excluding foods and energy.
[69]/ The authors analyze, for the Chilean case, more than 200 simple monetary policy rules, considering variations in the set of variables to which the interest rate reacts, its lags, and in the specification of the policy shock. They find that including autocorrelation in the policy shocks allows to systematically improve the adjustment of the model to the historical data.

distinguished in a circular production process: i), the production of physical capital using investment goods as inputs; ii), the production of homogeneous goods using capital, labor and oil as inputs; iii), the production of differentiated goods based on homogeneous goods; iv), mixed goods produced from the combination of different varieties of differentiated goods; and v), mixed goods of domestic and external origin combined to produce goods for consumption and investment.

Table 3.6

Productive structure in the XMAS model

	Inputs		Outputs
Capital goods:	Mining investment good	→	Mining capital
	Non-mining investment good	→	Non-mining capital
	Public investment good	→	Public capital
Homogeneous goods:	Labor, public and non-mining capital, oil	→	Homogeneous domestic good
	Mining capital	→	Exportable mineral good
Diferenciated goods:	Homogeneous domestic good	→	Diferenciated domestic good Diferenciated exportable good
	Non-oil imports	→	Diferenciated foreign based good
Composite goods:	Diferenciated domestic good	→	Composite domestic good
	Diferenciated exportable good	→	Composite exportable good
	Diferenciated foreign based good	→	Composite foreign based good
Final goods and services:	Domestic and foreign based composite goods	→	Core consumption good Agricultural consumption good Government consumption good Mining investment good Non-mining investment good Public investment good
	Core consumption good, agricultural good, oil	→	Final consumption good

Source: García *et al.* (2019).

Three classes of capital are modeled: mining, private non-mining, and public, generated on the basis of investment goods specific to each class. The level of private non-mining investment is optimally determined by households that are not financially constrained. They take into account the direct and alternative costs of the investment (the cost of the investment goods, the interest rate and the marginal utility of the consumption expenditure) and the expected benefits (expected future price of the capital income). The optimal mining investment is decided by the manager of the representative mining company. The main determinants considered in such decision are the costs of the mining investment assets, the present and expected interest rates, and the expected benefits of the investment. The latter are largely determined by the expected price of the mining asset in the world markets. Finally, investment in public goods fluctuates stochastically around a level consistent with a structural balance rule for government spending.

To prevent the model from generating excessive and unrealistic fluctuations in non-mining investment decisions, in the production function of such capital it is assumed to be costly to adjust the level of investment with respect to the immediately preceding period. For the production of mining capital, additionally a dependence of the sector on long term projects is modeled, assuming that investment projects take considerable time to be transformed into productive capital.

A second layer in the production structure is made up of homogeneous goods, produced by representative companies that require capital goods as input. The company producing the homogeneous domestic goods uses as inputs the labor supplied by the households, in addition to public capital, private non-mining capital and imported oil. The production of the exportable mining good, on the other hand, incorporates as inputs the mining capital in addition to a fixed factor. In both sectors, the production function is subject to stochastic productivity shocks that mean that, even with the same set of inputs, production can differ in different periods.

The differentiated goods are produced by groups of companies that, by differentiating their products from those of the competition, acquire market power and can sell at prices above the marginal production cost. These firms use homogeneous goods as inputs and are capable of transforming them one by one into differentiated goods. The homogeneous domestic good is used in the production of differentiated goods for domestic use and for export. Imports of homogeneous goods are used to produce differentiated goods of external origin.

Mixed goods, on the other hand, are produced by combining different varieties of differentiated goods. A representative company decides on the intensity of use of each variety with the purpose of minimizing costs and considering both the relative prices and the degree of substitutability of each of the inputs. The production of mixed goods for domestic use --of local and external origin-- and for export is modeled.

Likewise, representative companies combine mixed goods of domestic and external origin to generate consumer goods --regular, agricultural and government-- and investment goods -mining, non-mining and government. In the modeling of the agricultural sector, an additional productivity shock is introduced in order to factor in the increased volatility of the sector due to weather and other phenomena that periodically affect crop yields. Finally, regular and agricultural consumer goods are combined with oil imports to generate a good representative of the household consumer basket.

Labor market

The labor market is modeled on search and match frictions of the Mortensen and Pissarides type (1994). In this type of labor market specification, firms publish vacancies to hire workers and the unemployed look for jobs[70]/, the labor market is modeled on search and pairings frictions of the Mortensen and Pissarides type (1994). In this type of labor market specification, firms publish vacancies to hire workers and the unemployed seek employment, which allows inputting an unemployment rate and other relevant labor market variables into the model. In addition, pairings are allowed to be broken both endogenously, as they respond to economic shocks, and exogenously. Financially constrained and unconstrained workers have the same productivity. For simplicity it is assumed that an agent negotiates on behalf of workers a single contract based on the average productivity and alternative cost of the workers employed. In this context, all the workers receive the same salary and work the same number of hours.

The evolution of employment, on the other hand, depends on the number of employees who lose their jobs and on new pairings. The latter are a function of the number of unemployed and the vacancies that companies decide to open. The greater the number of workers looking for work and the greater the number of vacancies available, the greater the creation of new jobs.

Price determination: goods, wages, and the exchange rate

Like every economic model, in the XMAS resource allocation is essentially determined by the relative prices of the different goods, factors, and assets.

In sectors that sell differentiated goods, firms are assumed to operate in an environment of monopolistic competition, which allows them to set prices above their marginal costs. As in most new-Keynesian models, pricing assumes nominal rigidities of the Calvo type (1983), where firms cannot continuously update their prices as demand changes. This allows monetary stimuli to generate real effects on activity. The greater the fraction of firms that are unable to re-optimize their prices in each period, the greater the price stickiness and the greater the effects of fluctuations in demand on activity. Additionally, firms that cannot re-optimize are allowed to passively update their prices in response to past inflation. This indexing process generates an additional effect on the dynamic properties of inflation.

A very relevant price in any economy open to the world is the exchange rate. In the model, it is determined based on the assumption of uncovered interest rate parity. Specifically, this implies that agents should a priori be indifferent between having their debt denominated in local or foreign currency. In equilibrium, this implies that the expected exchange rate depreciation will be that which equals the returns on debt instruments in pesos and in dollars, measured in the same currency. Yields on peso bonds are assumed to depend on what the central bank decides when setting the monetary policy rate, which reacts to developments in inflation and activity growth. On the other hand, the interest rate of the debt denominated in foreign currency has an exogenous component that does not respond to what happens in the domestic economy, and a component that depends on the country risk, as summarized in the model by the net national debt as a percentage of GDP.

[70]/ It is assumed that those not working are actively searching for a job, and no endogenous movements occur either within or outside the labor force.

In the labor market, workers and companies negotiate contracts so that the surplus generated by the work relationship is divided between them according to their relative bargaining power. This contract specifies the hours to be worked and the salary to be paid. According to Hall (2005), and in order to obtain wage and employment dynamics similar to those observed in the data, a process of smoothing out the evolution of wages is imposed.

The rest of the production structure occurs in a competitive environment where the final price is simply defined to equal the marginal cost of production. This is the case of homogeneous, mixed and final goods. Other prices, particularly those related to the global economy, are defined exogenously and do not respond to the supply and demand conditions of the local economy.

Shocks and transmission mechanisms

The dynamics in DSGE-type models are caused by shocks that generate deviations from the normal operating rules of the agents and the technological processes. For example, a shock to the households' inter-temporal preferences causes them to temporarily value present consumption over future consumption; a shock to fiscal expenditure temporarily causes the government to spend more than the structural balance rule prescribes; a shock to productivity temporarily makes the economy capable of producing more using the same inputs. Thus, XMAS includes 24 shocks that allow us to approximate the dynamics of the main economic variables[71]/.

Shocks of higher demand for goods will tend to create greater pressure on production, raising costs and prices, and stimulating demand for factors such as capital and employment. Conversely, shocks of higher supply will reduce marginal costs, putting downward pressure on prices and increasing production.

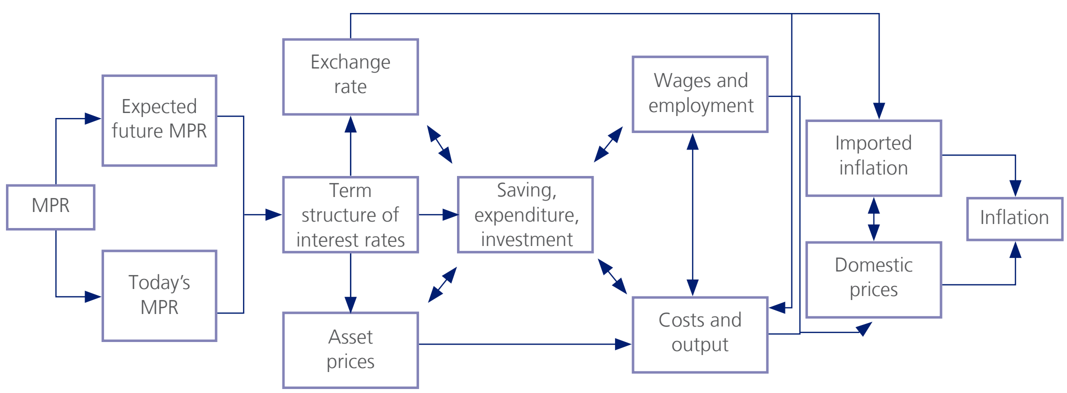
In this way, the different shocks that define the dynamics of the model can be classified as either demand- or supply-side, shocks, depending on the main transmission channels through which they affect the economy. For example, preference and fiscal expenditure shocks are classified as demand-side shocks and productivity shocks as supply-side shocks. The former will stimulate demand for goods and will tend to result in greater activity and higher inflation. The latter will lower production costs, resulting in greater output and lower inflation.

[71]/ The XMAS incorporates shocks to the inter-temporal preferences of households, the marginal productivity of mining and non-mining investment, the transitory productivity of the mining, non-mining, agricultural and external sectors, to (permanent) global productivity, the country risk, to the interest rate parity equation, fiscal spending on consumption, investment and transfers, labor disutility, the exogenous destruction of jobs, the domestic fuel price, the domestic and external interest rate, the global price factor, the prices of oil, copper and imported goods, external inflation, and the size of the labor force.

The transmission mechanisms of the monetary policy (i.e. the response of the different agents to interest rate shocks) are described schematically in Figure 3.6 and are mainly manifested through demand-side channels. First, by altering the trajectory of the MPR, the central bank affects the contemporary and expected interest rates of peso-denominated debt instruments. In the context of financial integration with international markets, the exchange rate responds to differences between interest rates in pesos and other currencies, so that expectations of exchange rate appreciation or depreciation compensate for these interest rate differences. Thus, when affecting peso-denominated interest rates, the central bank affects the contemporary value and future expectations of the exchange rate. MPR increases tend to appreciate the exchange rate. Lower rates cause depreciation. The exchange rate effect influences inflation both directly, through the prices of imported goods, and indirectly, by modifying relative prices and, consequently, consumption and investment decisions.

Figure 3.6

Monetary policy transmission mechanisms in the XMAS model



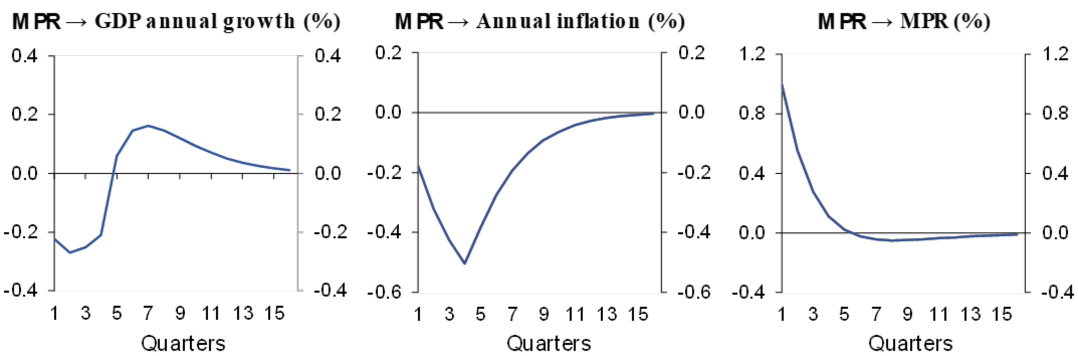
Source: Based on García *et al.* (2019).

In addition, interest rates affect savings, spending and investment decisions. Higher interest rates make it more attractive for unconstrained households to postpone spending decisions, and more difficult to find projects with positive net pres ent value, thus reducing spending on investment projects. Likewise, lower rates encourage greater consumption and investment.

The effect that the different channels have on financial conditions and the economic agents' decisions on spending, production and employment directly impacts the cost structure and the determination of firms' margins, and with it the setting of prices. For the export sector, its costs measured in foreign currency are also altered by the effect on the exchange rate, affecting the sector's competitiveness and export growth. A rise in rates depresses demand, reducing marginal costs and inflation. A drop in the MPR stimulates production, costs, and inflation. Figure 3.7 shows the XMAS model's prediction of the dynamic general equilibrium effects of a sudden 1% increase in the interest rate, considering all the channels described above. The maximum effect on inflation is attained in four quarters, while for the GDP, this occurs between two and three quarters after the change in the MPR.

Figure 3.7

Effects on GDP and prices of a sudden interest rate hike in the XMAS model(1)



(1) A one-period monetary shock is simulated, without persistence. Its size is calibrated to generate a de 1% MPR increase on impact.

Source: Based on García *et al.* (2019).

Data and estimation

The parameters governing the intensity with which the different shocks spread across the economy are estimated using Bayesian techniques (Herbst and Schorfheide, 2015) using quarterly data from 24 series for the Chilean econo my and the rest of the world in the period from 2001 to 2017. The starting point of the sample coincides with the moment when the Central Bank of Chile officially adopted the inflation targeting regime.

The 24 series chosen[72]/ consider, among other variables, local indicators of activity, foreign trade, prices, wages, employment, labor force composition, government expenditure, interest rates and

[72]/ The XMAS is estimated using data on mining, non-mining and trading partners' GDP, private consumption and government consumption, aggregate gross fixed capital formation, mining and public, government transfers, employment, average hours worked per employee, nominal wages, food, energy and other products' inflation, external inflation, prices of copper and oil and imported goods, the MPR, the Libo rate, the real exchange rate, country risk (EMBIG) and the trade balance as a percentage of GDP.

exchange rates. They also include world economic indicators such as commodity prices, interest rates and trading partners' activity.

In this way, the model is built and estimated to enable an accurate replication of the historical interrelations among the variables considered, and thus be able to infer the most likely future behavior of the economy.

Box 3.3: **Using the XMAS model to analyze the spread of shocks to the volatile components of inflation and the role of expectations**

In Box IV.1 of the December 2017 MP Report, the XMAS model was used to analyze the monetary policy implications of persistently high inflation, but with a focus on the volatile components of inflation. At that time, the effect of different types of shocks was analyzed, in terms of both inflation and policy prescription. The implications of an eventual de-anchoring of expectations[73]/ on inflationary and interest rate dynamics were also analyzed

Given that the operational objective of the CBC is defined in terms of projected inflation over two years[74]/, the appropriate monetary policy response to changes in contemporary inflation will crucially depend on the specific causes of the change in prices. In this way, shocks of low persistence and/or spread to the rest of the economy will generate a less intense monetary policy prescription, even with similar short-term inflationary effects. However, if a sequence of shocks to the volatile components generates a de-anchoring of the inflation expectations in the medium term, the response of the monetary policy should be different to avoid the change of expectations being validated later.

The model allows distinguishing the potential consequences of falls in prices depending on their cause. The effects will be different if the origin of the fall in inflation comes from shocks to food prices, energy prices or other types of exogenous factors.

Simulations of the model show that shocks to food prices explain a significant part of the fluctuations of inflation in the short term —the actual and forecasted inflation for horizons of less than one year—, but their impact on medium-term inflation is shorter. Shocks to fuel prices, on the other hand, have somewhat greater effects in the medium term, although significantly less than those of the rest of shocks facing the economy, whose relative importance is increasing over time. A summary of these results is presented in Table 3.7.

These results suggest that, as previously mentioned, in the face of shocks to food or energy prices, of relatively low persistence and spread, the monetary policy response should be limited. However, if said shocks generate a de-anchoring of expectations, the appropriate response

[73]/ A de-anchoring of expectations occurs when the agents of the economy expect inflation to be different from the inflation target of the CBC.
[74]/ The objectives and instruments of the CBC are detailed in the document "La Política Monetaria del Banco Central de Chile en el Marco de Metas de Inflación (2020)".

Table 3.7

Variance decomposition of current and expected inflation (1) (2)

	Food	Energy	Other
Quarterly change	12.2	14.6	73.2
Annual change	6.0	15.6	78.4
Expected annual change,3 month ahead	5.1	15.8	79.2
Expected annual change,6 month ahead	4.0	15.8	80.2
Expected annual change,1 year ahead	0.3	15.1	84.6
Expected annual change,2 years ahead	0.7	10.0	89.3

(1) Each entry is the variance proportion of the quarterly or annual inflation of actual CPI (second and third row) and the annual inflation forecasted on the respective horizon (fourth to last row), explained by the different shocks (columns). Simulations made for the December 2017 Monetary Policy Report.

(2) The "food" column shows the proportion of the variance attributable to shocks to productivity of the agricultural sector, the "energy" column includes the effects of shocks to fuel prices, while the "others" column considers the effects of the rest of the shocks in the model.

Source: García *et al.* (2017).

from monetary policy could be greater. To incorporate the possibility of de-anchoring of expectations, the XMAS is extended in a similar way to Erceg and Levin (2003). This allows simulating the de-anchoring effects, where households and firms of the model assume that the central bank has modified its inflation target and expect it to act accordingly (even if this has not happened within the same model).

This extension allows simulating a scenario where, concurrent with a fall in food prices, expectations about the CBC's inflation target fall. As agents observe that the Bank behaves consistently with an inflation target that has not changed, they slowly correct their expectations to their original values. In the transition, however, the de-anchoring effects are important. To combat deflationary pressures and avoid validating expectations for a reduced inflation target, the Central Bank must reduce rates at a faster pace, even in the face of a shock of reduced persistence and economic spread.

This exercise illustrates the usefulness of structural models such as the XMAS beyond the generation of a central forecast scenario. Given their ability to simulate alternative scenarios, the use of these models allows appropriate policies to be proposed if different alternative scenarios materialize.

Box 3.4: **Differences between models and the importance of judgment**

Figures 3.5 and 3.7 show that the effects of shocks to the MPR on GDP are of similar magnitude in the MSEP and XMAS, respectively. Despite the above, there is a significant difference in the inflationary effects. These differences highlight the importance of understanding the strengths and weaknesses of the different models for evaluating the state of the economy and for a correct calibration of monetary policy. Although both models are based on the neo-Keynesian theory, as it appears from what is described in Sections 3.3.1 and 3.3.2, their structure has important differences in terms of the transmission channels present, as observed when comparing Figures 3.4 and 3.6, and the strength with which the theoretical constraints are imposed.

In general equilibrium models such as the XMAS and MSEP, the differences in the responses to monetary shocks are due to the interaction of each of the different aspects of both models, so it is difficult to isolate a single determinant. However, an important difference between the MSEP and XMAS models has to do with the inflation expectations channel. The importance of this difference can be illustrated precisely through the effect of monetary policy on inflation in both models, remembering that, in the derivation of the canonical version of neo-Keynesian models, monetary policy affects inflation mainly through its impact on aggregate demand and costs of firms[75]/. The Phillips curve, which relates these variables, is usually represented as follows:

$$\pi_t = b_1 E_t(\pi_{t+1}) + \phi_t$$

where π_t denotes contemporary inflation, while $E_t(\pi_{t+1})$ denotes inflation expectations for the following period. Parameter b1, that accompanies expectations, corresponds to the household discount factor, closely linked to the inverse of equilibrium interest rates, and that in quarterly frequency models considers values around 0.99. The direct effect of contemporary marginal costs on inflation is summarized in ϕ_t. By making recursive replacements of inflation expectations, we can rewrite the Phillips curve as:

$$\pi_t = \phi_t + \sum b_1^i E_t(\phi_{t+i})$$

In this alternative representation it can be seen that, in neo-Keynesian models, contemporary inflation is equal to future cost expectations. It is also evident that the discount factor b_1 directly controls the weight given to cost expectations. The lower this parameter, firms will give less importance (greater discount) to cost expectations in the decision-making process. If monetary policy has persistent effects on activity and costs faced by firms, low values for b_1 will reduce the effect of monetary shocks on inflation

In the XMAS structural model, the parameter that accompanies expectations, which are assumed to be rational, is determined by the theoretical constraint that it must be equal to

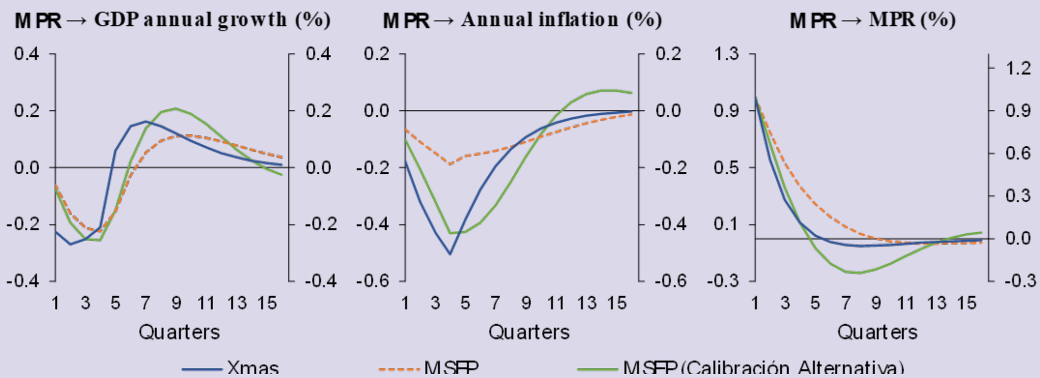
[75]/ Although the focus of this analysis is the demand channel for monetary policy, as described in Sections 3.3.1 and 3.3.2, in more complex models there are additional transmission channels that can help explain the discrepancy among the effects of monetary shocks on inflation.

the discount rate of households, which ultimately own the firms. As explained before, semi-structural models such as MSEP, although based on the same theory as DSGE models such as XMAS, allow for the relaxation of certain assumptions in order to improve their adjustment to the data. In particular, in the MSEP the canonical specification of the Phillips curve is modified to allow the explicit inclusion of lagged inflation values. Additionally, the parameter that accompanies the expected inflation, instead of restricting itself to values consistent with the discount factor, is estimated using statistical techniques, obtaining a value of 0.16 for the non-tradable sector[76]/[77]/. Coibion, Gorodnichenko and Kamdar (2018) argue that parameter b1 may have values lower than β, the household discount rate, due to the existence of expectation formation mechanisms different from rational expectations with complete information, as the XMAS assumes. In particular, the cases of optimizing firms with incomplete information and simple rules (Galí and Gertler, 1999), informational rigidities (Mankiw and Reis, 2002), adaptive learning (Milani, 2007) and rational inattention (Afrouzi and Yang, 2019) are analyzed.

To illustrate the important role that the expectations component plays in the effect of monetary shocks on inflation, Figure 3.8 presents the results of an exercise where the coefficient associated

Figure 3.8

Role of the Phillips curve expectation coefficient of the MSEP model (1) (2)



(1) For each model, a one-period monetary shock is simulated, without persistence, and whose size is calibrated to generate a 1% increase in impact on the MPR.

(2) In the alternative calibration of the MSEP model, the parameter associated with inflation expectations is increased so that the sum of said parameter with the one associated to the lag of the same adds up to 0.99. The rest of the parameters of the model remain constant at their original values.

Sources: Based on Arroyo *et al.* (2020) and García *et al.* (2019).

[76]/ It should be noted that a low estimate for the coefficients associated with expectations may reflect a genuine absence of future expectations in pricing, a low correlation between contemporary price movements and the internal expectations of the model, or a combination of both effects.

[77]/ As described in Section 3.3.1, the MSEP models core inflation, food inflation, energy inflation, and other volatile components separately, with the first difference between tradable and non-tradable sectors. Of these equations, only the non-tradable sector considers a Philips curve with future expectations.

to the expectations on the Phillips curve of the MSEP model is increased and compared with the one obtained in the base calibration and in the XMAS model. In particular, it can be seen how values of b_1 lower than that associated with the discount rate are able to generate effects of similar MPR movements on activity, but different on inflation.

This type of analysis, adequately incorporated in the judgment of the economic staff, validates the search for robustness by means of a strategy of multiple sources of information, maintaining a balance between semi-structural and structural models, where the former are motivated by theory but flexible in their parameterization, with assumptions not necessarily consistent between equations with the aim of adjusting in the best way to the historical relations between the variables in the sample; while the latter are more theoretically coherent and more robust to Lucas' criticism, although having greater restrictions between equations. In this sense, in the analysis carried out in the CBC, the results of each model are analyzed in the light of their own characteristics, considering their strengths and weaknesses, and the final vision on the state of the economy judiciously weighs the results of each one of them.

The effects of immigration

The XMAS structure can be extended to analyze shocks other than those discussed above, but which are relevant to the CBC's analysis. For example, Garcia and Guerra-Salas (2020) describe an extension to the model that makes it possible to analyze the effects of an exogenous shock on the size of the labor force, like the one experienced by Chile from 2015 onwards as a result of increased immigration flows to the country.

This specification allows for a varying fraction of each household to be immigrant. This fraction is assumed to evolve exogenously by replicating the migratory dynamics observed in the data fed into the model. For modeling purposes, immigrants are identical to the local population in all dimensions except in their interaction with the labor market and in their propensity to send home part of their labor income in the form of remittances.

Immigrants are assumed to arrive in the country unemployed, and to take some time to find a job. They are also assumed to be potentially as productive as their local peers[78]/, but when recently arrived they are temporarily less productive as they adapt to the labor market. In addition, work disutility is allowed to be temporarily lower for the newly arrived immigrants.

In the model, immigration affects the economy through both supply and demand channels. On the household side, the arrival of immigrants creates greater demand for goods and services, but this is partly mitigated by the remittances they send home. This increase in demand puts pressure on firms' costs with consequent inflationary effects. In the labor market there is, on the one hand, an increase in labor supply because more people are seeking employment, and on the other hand, a increase in demand for labor, as firms need to scale up production to meet the higher aggregate demand. On the companies' side, the greater number of people seeking employment facilitates

[78]/ Aldunate et al. (2018) document that immigrants arriving in the country have on average a similar level of education as the natives.

an increase in hiring, thus expanding the productive capacity of the firms. This increase in the productive supply is to some extent offset by the lower transitory productivity of immigrants as they enter the labor force and slowly find better quality jobs matching their skills, climbing the labor ladder as described in the literature. Furthermore, the increased labor supply lowers the level of capital per worker, boosting the marginal productivity of capital and stimulating investment.

In general, it is not clear whether supply or demand channels will predominate with respect to inflation. The combination of higher consumption and investment with an expanding labor force can, in principle, generate inflationary or deflationary pressures. The aggregate effect will depend on the assumptions made about different factors, such as the incentives to recover optimal levels of capital, the speed at which immigrants are integrated into the labor force, or the way in which their productivity, labor supply or propensity to send remittances evolves. In this sense, the expected effect on inflation, and the policy prescription that is derived from it, will depend fundamentally on the judgment of the economic staff and on the form in which said judgments incorporate external information.

3.4 Unobserved variables and parameters

An important part of monetary policy decisions is based on gaps between observable variables, like the interest rate or the GDP, and some unobservable ones, like the neutral interest rate or potential and/or trend GDP. Thus, for example, the interest rate will be contractionary, helping to contain inflation, if it is above its neutral level. Similarly, activity will be in an expansionary cycle, putting pressure on inflation, if actual GDP is above its potential.

As noted by Schmidt-Hebbel and Walsh (2009), the fact that gaps are defined in terms of unobservable variables poses significant challenges for implementing an effective monetary policy. In particular, the monetary authority must determine which is the most appropriate theoretical definition of said unobservable, in terms of its relevance for monetary policy, and which is the best estimation methodology. The use of models, together with Board and staff judgment, appears then as a fundamental tool for obtaining estimators on the current and expected state of these variables. In particular, at the CBC, models have been developed that allow making periodical estimations for three unobservable variables that work as an anchor for the medium term projections, as a guide for the evaluation of the current state and future outlook of the economy, and for monetary policy calibration. Two of these variables, namely trend and potential GDP growth, refer to the productive capacity. The first is defined as a country's productive capacity in the absence of transitory shocks and when productive inputs are used at normal capacity. The second relates to the current level of productive capacity, including cyclical fluctuations in productivity and resource allocation. The neutral interest rate is also estimated, defined as the rate that is consistent with GDP at its equilibrium --trend-- level and an inflation rate that stands at the 3% target.

The correct estimation of these variables is of utmost importance to correctly evaluate monetary policy. These variables cannot be directly observed, and must be inferred through a combination of statistical methods and economic theory. This inference certainly has an important degree of uncertainty, since it is based on the estimates of multiple models, each with their own degrees of uncertainty. The judgment of the staff and the Board determines, through a critical analysis of the different estimates, the values that will be used to calibrate monetary policy. The estimates are updated annually, and the results are made public in the Monetary Policy Reports. The methodological details of the last estimation, whose results are summarized in boxes 3.5 and 3.6, can be found in Aldunate et al. (2019).

3.4.1 Trend and potential GDP growth

The productive capacity of the economy is a key element in the set of tools used in economic projections and analysis. The CBC regularly publishes its evaluation of two measures of the country's productive capacity: trend GDP and potential GDP.

Trend GDP is a relevant concept in studying the economy over a long period of time, e.g. ten years. The focus on the long term allows for the assumption that the accumulation of positive and negative transitory shocks counteract each other and can therefore be omitted from the analysis. On the other hand, potential GDP is a relevant concept to measure the pressures that could divert inflation away from its 3% target, because the capacity gap (the difference between the level of actual and potential product) is an important determinant of inflation over shorter terms. Thus, in the short term, potential GDP will fluctuate around its trend, temporarily deviating as a response to shocks that affect the productive capacity in the short term, while in the long term both notions will tend to coincide.

Trend and potential GDP levels are not visible in the data, so they have to be estimated. These estimates are complex because they require identifying which part of the observed fluctuations in GDP are due to demand shocks and which to supply shocks, and for the latter to differentiate between transitory and permanent ones. Proper estimations of potential and trend GDP are also important because of the role they play in the process of medium-term forecasting. On the one hand, potential GDP allows identifying the gaps in the economy, one of the main factors in explaining inflation in the MSEP model[79]/. Trend GDP growth, meanwhile, operates as an anchor for the long-term growth in both MSEP and XMAS. Below is a description of the methodologies used at the CBC to estimate these two measures.

Trend GDP

The methodology used at the CBC to forecast trend GDP is based on the so-called production function approach, which is based on the neoclassical theory of growth[80]/. This method assumes that the generation of aggregate activity in the economy can be described as a production function that depends on two productive factors: aggregate capital stock and total labor force. How efficiently the economy is able to combine these factors is captured in the production function by total factor productivity (TFP), which implicitly captures aspects such as technology, the quality of the institutional framework, and how well the economy can allocate factors to the sectors and firms where their productivity is highest.

[79]/ In the XMAS structural model, the relevant potential GDP is determined endogenously as that which is consistent with a flexible price equilibrium.
[80]/ For a more detailed description of the methodology, see "Crecimiento tendencial: proyección de mediano plazo y análisis de sus determinantes" (Central Bank of Chile, 2017)

Specifically, it is assumed that the level of non-mining GDP[81]/ follows a Cobb-Douglas-type production function, where the country's output depends on the level of capital, the labor factor, and TFP. The labor factor is subdivided into three components: the effective labor force, considering the evolution of the number of working-age persons and their participation within the labor force; the effective hours worked; and the quality of the labor force, meaning the level of human capital. In this context, GDP growth can be expressed as the growth of the various production factors weighted by their share in total production.

Since trend GDP growth is intended to capture long-term productive conditions, it is important to reiterate that its projected values do not correspond to estimates of actual GDP. Thus, to the extent that transitory shocks exist, effective GDP will deviate from its long-term trend for some time. For this reason, the CBC makes 30-year trend GDP forecasts, where the analysis does not focus on any one year, but on average values over longer horizons, typically one decade.

Because the exercise of forecasting growth over 30 years carries a high degree of uncertainty, it is necessary to apply some discipline to those variables that are most difficult to predict and which at the same time can be reasonably quantified. In general, forecasting these variables is done based on their historical trends. Where relevant, this information is supplemented by using trends from other groups of countries that provide an important reference in the medium term, typically the mid-sized OECD member country. For example, the hours worked in Chile show a steady decline over the past 20 years. Clearly, the working hours forecast cannot assume that these will remain constant, but must consider a declining trend. Therefore, the experience of other countries that have experienced similar patterns in the past is informative. This is also true for other variables, such as the share of different demographic groups in the labor market, or the evolution of human capital quality. For immigration, the information is built based on the INE's immigration flows forecasts. As described in box 3.5, the immigration phenomenon in Chile of recent years prompted a major revision of trend GDP in June 2019, that incorporated updated INE information on the recent immigration flows and their future projections.

On the other hand, the historical analysis of capital accumulation and TFP in the non-mining sector does not reveal clear trends that would allow for an upward or downward pattern. For example, the capital/output ratio has fluctuated without a marked trend in the last 20 years, so it would be risky to project scenarios where this ratio deviates systematically from its historical average. Something similar occurs with TFP growth, which shows a high degree of volatility --which is to be expected, given that it is measured as a residual between GDP and factor utilization--, without revealing systematic movements that could inform a long-term forecast different from its historical trend. In these cases, the central projection is based on historical averages, incorporating, where necessary, information from complementary models, as was done in 2019[82]/ to analyze the immigration phenomenon and its possible medium-term consequences on capital accumulation and productivity.

[81]/ Mining GDP is excluded because it has a different production function, as it depends very largely on an associated non renewable factor associated to mineral deposits.
[82]/ See box V.1 in the Monetary Policy Report of June, 2019.

Potential GDP and production capacity

As mentioned above, on a long-term horizon, i.e. three or more years, the transitory shocks are expected to have dissipated and the economy to be close to its trend level, while, in the short term, the dynamics of potential and trend GDP may differ because the former is affected by shocks that alter the economy's productive capacity. Thus, potential GDP measures the economy's current productive capacity

In general, potential GDP does not coincide with actual GDP, because the latter, besides including transitory shocks, does not exclude the possibility of factors being under- or over-utilized. Indeed, the difference between the levels of potential and actual GDP is one of the main factors determining inflationary pressures. This difference is known as the output gap.

To estimate potential GDP and to obtain an assessment of the gaps in the economy, the CBC uses various statistical filters, as well as measures of directly observable capacity utilization. The statistical filters used are simple models that, by taking one or more time series as input (e.g. GDP) provide a breakdown between cycle and trend. The first component is characterized by recurrent oscillations that are quickly reversed. To identify this component, the average of the cyclical component in the long term must be zero. The trend component, on the other hand, is characterized by infrequent, minor oscillations.

To estimate potential GDP, the CBC uses multivariate versions of these filters, which include information from several sources and semi-structural equations that constrain the relationships among the different variables based on economic theory.

The first of these filters is the tri-variate filter, which is fed data on non-mining GDP, interest rates and inflation. Its structure has several equations, of which we detail three critical ones. The first is an IS curve that relates the output gap to the differential between the real effective interest rate and the neutral interest rate, plus lags of the same gap. Additionally, the structure of the model imposes that the potential GDP growth follow a stochastic non-stationary random walk process. The second corresponds to an Euler equation in trends, that relates the real neutral interest rate with the potential growth. Finally, a Phillips curve relates inflation, as deviation from the target, with the output gap and the exchange rate fluctuations.

A second filter, i.e. the extended multivariate filter (FMV-X)[83]/, includes an Okun's law[84]/, a Phillips curve and market expectations for both GDP growth and inflation. In the long run, the filter assumes that inflation is equal to the target, actual GDP growth is equal to potential, and the unemployment rate returns to its equilibrium level. This modeling allows the filter to infer a potential GDP that is consistent with the set of variables observed and the structure imposed on the model's equations. If activity is growing very rapidly, and so is inflation, the multivariate filter will deliver a positive cyclical estimate consistent with GDP growing faster than potential. In contrast, if an acceleration of inflation is observed due to an increase in the exchange rate, rather than an acceleration of activity, then the filter will suggest that the gap is not so positive. This is so because the filter is

[83]/ Both models, together with some alternative models used as benchmark are described in detail in Fornero and Zúñiga (2017), Bullano et al. (2018), and Aldunate et al. (2019).

[84]/ Okun's law refers to the empirical relationship, first observed by Arthur M. Okun in 1962, between GDP growth and the evolution of unemployment.

controlling for the increase in the exchange rate. In this case, the signal of the exchange rate is crucial to identify that the origin of inflation is not the gap, and, therefore, it is decisive for the GDP decomposition between potential and cyclical that is obtained from the filter.

The potential GDP used by the CBC to estimate the GDP gap, both past and present, arises from averaging the estimates of the tri-variate and FMV-X filters just described. To forecast the future evolution of potential growth, the FMV-X filter is used, additionally incorporating information from trend growth estimates to ensure long-term consistency between the estimates for potential and trend GDP growth.

Box 3.5: **Estimation of trend and potential GDP**

An update of potential and trend GDP estimations was included in the June 2019 MP Report. It used the methodologies described above, including as the main change the significant immigration phenomenon observed since 2015. Its intensity was not incorporated in the previous population forecasts, generating, as can be seen in Figure 3.9, important changes in the assumptions about the labor factor forecast and, through this, in the economy's growth capacity. The rest of the forecast assumptions did not undergo major changes with respect to the previous estimation, except that explicit modeling was incorporated for the way in which capital and the TFP respond to the increase in the labor factor associated with immigration.

The forecast of trend GDP, as described in Section 3.4.1, requires assumptions for growth of employment, capital and TFP. The contribution of labor to trend growth rose by 0.2%, mainly due to the updating of the assumptions on immigration flows, particularly for 2019 and 2020. Forecasts of participation, hours worked, factor quality, and the secular demographic trend towards greater ageing and lower birth rates maintained their assumptions. Regarding capital growth, a contribution to trend growth similar to that previously obtained was estimated. The response of investment to higher growth of the labor factor associated with immigration, which makes capital more profitable, contributes one tenth to that growth. Finally, the trend growth of the TFP of non-mining GDP was estimated at around 1%, in line with the latest update of the National Accounts and the modeling of the effects of immigration on the productivity path[85]/.

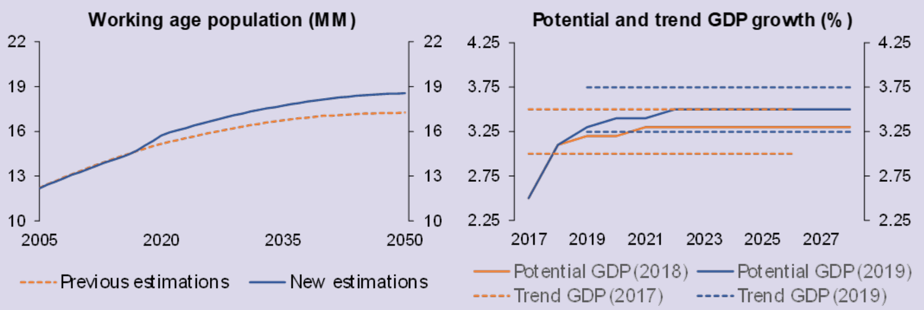
For potential GDP, the models used suggested faster growth than actual GDP, thereby widening the estimated activity gap; which is consistent with low inflationary pressures of the period. The different models attributed a significant part of the higher potential GDP to the surprise associated with the evolution of labor force resulting from immigration.

Considering the results of the models, the associated level of uncertainty, and the judgment of the staff and the Board, trend growth in GDP for the 2019-2028 decade was estimated at between 3.25 and 3.75%, 0.25 percentage points above the estimation made two years earlier.

Additionally, potential GDP growth was estimated to be around 3.4% in the 2019-2021 period. These levels were higher than previously estimated, due to the incidence of new data, the revision of some of the previous data, the effect of filters and, especially, the surprise associated with the evolution of the labor force derived from immigration.

Figure 3.9

Estimations for population, potential, and trend GDP (1)



(1) Estimations made for the September 2017, September 2018, and June 2019 MP Report.

Sources: Central Bank of Chile and Instituto Nacional de Estadísticas.

3.4.2 The natural interest rate

The natural monetary policy interest rate (NMPR) is one of the key variables used at the CBC to evaluate the current state of the economy, the economic outlook and the monetary policy calibration. This last variable is thought to be expansionary (contractionary) when the effective MPR is below (above) the NMPR. Accordingly, keeping an updated estimate of the neutral rate is important for monetary policy making and for communicating its future orientation. In addition, the neutral rate estimates operate as an anchor to inform the interest rate gap in the MSEP model and the long-term rate level in the XMAS and MSEP models.

For estimation purposes, the NMPR is defined as the rate that is consistent with GDP at its trend equilibrium level, inflation near its 3% target and the effects of transitory shocks to the economy having dissipated. For this reason, the neutral monetary policy rate is associated with the long term, to which the effective monetary policy rate is expected to converge gradually, absent further disturbances that drive the economy away from its trend level. Hence the NMPR referred to herein

[85]/ The international literature suggests that immigrants are initially employed in jobs that are not commensurate with their skills, implying a loss in productivity. Over time, they move into jobs that are more in line with their skills, leading to improvements in total productivity. For details on modeling and calibration assumptions, see Aldunate et al. (2019).

is understood as a trend neutral interest rate[86]/.

Since the NMPR cannot be directly observed, it must be inferred from variables that can. This inference can be made using different methodologies, with results that may vary between approaches. In the case of the neutral rate, the practice of central banks has been to choose a range of models, given that the estimators are subject to significant uncertainty.

The choice of methodologies for calculating the NMPR by the CBC considers several aspects: (i) earlier use of such methodologies, in order to maintain consistency over time; (ii) their use by other central banks; (iii) the applicability of each method to the Chilean economy; and (iv) the degree of certainty in inferring the level of the neutral rate. With these criteria, three approaches are used. The first approach uses the expected long-term interest rate implicit in financial assets. The second approach consists of the statistical inference of the NMPR based on inflation and activity data. The third infers the NMPR from actual and expected inflation data, as well as the prices of financial assets.

Inference based on asset prices and market expectations:

In principle, it is possible to measure the neutral real interest rate (NRIR)[87]/ directly by using the rates implicit in the prices of financial assets, particularly central bank bonds and swap instruments[88]/. The method consists in approximating the long-term NRIR by the forward 5-in-5 rate (five year expected rate starting five years from now). The 3-in-2 forward rate (three year rate after two years) can also be used to estimate a contemporary measure of the NRIR. These estimates reflect the interest rate level that the markets expect to prevail in the medium term, once the transitory shocks have dissipated.

This measurement is correct if the long-maturity market interest rates are equivalent to the average expected rate of a short-maturity bond, which should be similar to the MPR. However, term premiums (in level and variability) are known to help explain the interest rates on long-term bonds. For the Chilean case, Ceballos, Naudón and Romero (2016) provide evidence that central bank bond rates contain important term premiums, so movements in these rates do not necessarily represent movements in the expected MPR trajectory.

To isolate the effect of premiums on long rates it is assumed that they can be decomposed into the sum of two amounts: (i) the average expected short rate, which is associated with the expected MPR path; and (ii) the term premiums. Since the premium is simply the difference between the market's long rate and the average expected rate, the key question is how to construct the short rate expectations.

Following Ceballos, Naudon and Romero (2016), an affine model is utilized to estimate the expected short rates. These are derived from a set of factors representing the three main components of the interest rate structure, which are complemented with real macroeconomic variables such as a non-

[86]/ There is also the concept of a short-term neutral rate in the academic literature, characterized by the absence of price rigidities, which can fluctuate substantially over the business cycle. However, the Board associates its NMPR estimates with the concept of a long-term or trend neutral rate.

[87]/ Real and nominal neutral rates are related through the Fischer equation, which imposes that the real natural interest rate plus the inflation target corresponds with the NMPR.

[88]/ The swaps are contracts between two parties to exchange cash flows at a future date. The prices of these contracts provide information on the markets' expectations about the evolution of various economic variables.

mining monthly GDP index, a measure of core inflation, and the VIX.

Inference based on inflation and GDP

Following the methodology of Holston, Laubach and Williams (HLW) (2017), the inference is made using statistical methods to find a neutral rate that is consistent, on one hand, with a neo-Keynesian structure model, and, on the other, with the empirically observed GDP, interest rate and inflation.

The model's structure is based on a simple neo-Keynesian model (see Galí, 2015), modified to allow for a relaxation of the lag structure, thus giving it greater parametric flexibility.

The first two equations represent an IS curve and a Phillips curve, where the first relates the GDP gap (the difference between effective and potential GDP) with its lags and with the interest rate gap (the difference between the effective and the neutral rate); and the second relates inflation with the GDP gap:

$$\tilde{y}_t = a_1\tilde{y}_{t-1} + a_2\tilde{y}_{t-2} + a_3(r_{t-1} + r_{t-2} - r^*_{t-1} - r^*_{t-2})/2 + \varepsilon_{\tilde{y},t}$$

$$\pi_t = b_1\pi_{t-1} + (1 - b_1)(\pi_{t-2} + \pi_{t-3} + \pi_{t-4})/3 + b_2\tilde{y}_{t-1} + \varepsilon_{\pi,t}$$

where $\tilde{y}_t$ is the GDP gap (i.e. the difference between the logarithm of GDP (y_t) and potential GDP (y^*_t); π_t is the inflation rate; r_t is the real interest rate, and r_t is the real natural rate; $\varepsilon_{\tilde{y},t}$ and $\varepsilon_{\pi,t}$ are stochastic disturbances. In addition, based on the Euler equation of a neoclassical growth model like that of Ramsey (1928), the neutral real interest rate is models as the sum of the trend of the rate of potential GDP growth (g_t) plus a random variable (z_t) that captures all the unobserved elements that could affect the rate, such as the discount rate or the households' risk aversion:

$$r^*_t = g_t + z_t$$

Finally the evolution of potential GDP is defined as a random walk process with a growth trend g_t, which in turn is specified as a random walk, as is the stochastic process z_t:

$$y^*_t = y^*_{t-1} + g_{t-1} + \varepsilon_{y^*,t}$$

$$g_t = g_{t-1} + \varepsilon_{g,t}$$

$$z_t = z_{t-1} + \varepsilon_{z,t}$$

where $\varepsilon_{y^*,t}$, $\varepsilon_{g,t}$ and $\varepsilon_{z,t}$ are random variables which, the same as $\varepsilon_{\tilde{y},t}$ and $\varepsilon_{\pi,t}$, are assumed to be independent, identically distributed processes.

Inference based on inflation and asset prices

Following the methodology described by Del Negro et al. (2017), the trend natural rate is estimated based on the observation of a set of financial asset prices, inflation, and market expectations[89]/, considering theoretical constraints and common trends[90]/. Furthermore, the estimation also input small, open economy considerations that are relevant to Chile.

In its baseline version, the specification considers a multivariate model that decomposes into trend and cycle. The model variables can thus be denoted, generically, as:

$$y_t = \Lambda \bar{y}_t + \tilde{y}_t$$

where y_t is a vector containing the model's observable variables, while $\bar{y}_t$ and $\tilde{y}_t$ contain, respectively, the trends and cycles of said variables. Λ is a matrix of weights containing the relationships between the different trends, either trends shared by variables, or co-integration relationships. Both $\bar{y}_t$ and $\tilde{y}_t$ are latent unobserved variables that are modeled as random walk processes and autoregressive VAR, respectively: $\bar{y}_t = \bar{y}_{t-1} + \varepsilon_{\bar{y},t}$,

$$\tilde{y}_t = A_1\tilde{y}_{t-1} + A_2\tilde{y}_{t-2} + \ldots + A_p\tilde{y}_{t-p} + \varepsilon_{\tilde{y},t}$$

Therefore, given the observations for y_t and the constraints imposed by the matrices Λ and A, the model allows inferring the most likely trajectories for $\bar{y}_t$ and $\tilde{y}_t$, where the neutral rate would be part of the trend vector $\bar{y}_t$. The matrices Λ and A are estimated using Bayesian methods.

The variables considered for the estimation are effective values and expectations for inflation and interest rates, both short and long term. Inflation, real and nominal interest rates become related when compliance with the Fisher equation in trend is imposed, meaning that the trend of the nominal rate equals the trend of the real rate added to the inflation trend. On the other hand, common trends are assumed for both short and long rates, adding to the latter an additional term given by trend term premiums.

The estimates for Chile consider this specification as a base sensitized to the use of different maturities for long rates (five- and ten-year CBC bonds). In addition, open economy considerations are incorporated, allowing the model to observe external rates and exchange rates (effective and expected), which are related to local variables and imposing that, in trend, the assumption of uncovered interest rate parity must hold.

The main differences between this extension and the one in Del Negro et al. (2019) is that in the extension developed for Chile, considerations of small, emerging economy are imposed. This implies restricting the influence of local developments in the determination of external rates and allowing for a non-zero trend for the real exchange rate depreciation rate.

[89]/ Expectations are considered for inflation, interest rates and the exchange rate.
[90]/ For a detailed description of the assumptions used, see Aldunate et al. (2019).

Box 3.6: **Estimation of the natural monetary policy rate**

Box V.2 of the June 2019 MP Report presented estimations for the neutral real interest rate (NRIR) derived from the models described above. The NRIR estimations in 2019 were found to be between 0.6 and 1.4%, depending on the measurement methodology. The estimation of the Holston, Laubach and Williams (2017) model for Chile showed a NRIR that has followed a decreasing trend over time. By the end of the 1980s, the NRIR was between 6% and 7%; then fell to levels between 2% and 3% in the 2000s; and, at the end of the sample, in the first quarter of 2019, the point estimation was 0.6%. This downward trend in the NRIR is consistent with that reported for other economies such as the United States, Canada, the United Kingdom, and the Eurozone.

Table 3.8 and the left panel of Figure 3.10 summarize the results of the different methodologies. The simple average and median of these models is 1%. Considering the point results and the ranges of uncertainty of these estimations, a reasonable range for the natural rate of between 0.75 and 1.25% was estimated in real terms. Adding the 3% inflation target, the Board considered that in nominal terms the NMPR would be between 3.75 and 4.25%.

Additionally, the XMAS model was used to determine what fraction of the changes in the estimation could be attributed to two highly persistent phenomena faced by the economy. On the one hand, the sustained drop in external rates and their medium- and long-term expectations; and, on the other, the migratory phenomenon that, by increasing labor force, generated a relative shortage of the per capita capital level. To analyze the first phenomenon, the migration extension of the XMAS model described in section 3.3.2 is used. To capture the effect of external rates, the long-term external rate is allowed to move stochastically, with shocks chosen to replicate the neutral rate estimations for the US.

As shown in the right panel of Figure 3.10, it was estimated that the migratory shock would generate an increase in the r ate above its trend, as a result of the initial drop in capital per worker associated with the increase in the labor factor, and which increases the marginal return on capital. However, this effect would be of moderate magnitude —6 basis points (bp) —and would be concentrated, for the most part, from 2015 onwards. This effect is more than offset by the fall in external rates, particularly since the 2008-09 global financial crisis (15bp). The sum of these forces provides an estimated net contribution of -10bp in 2019..

Table 3.8

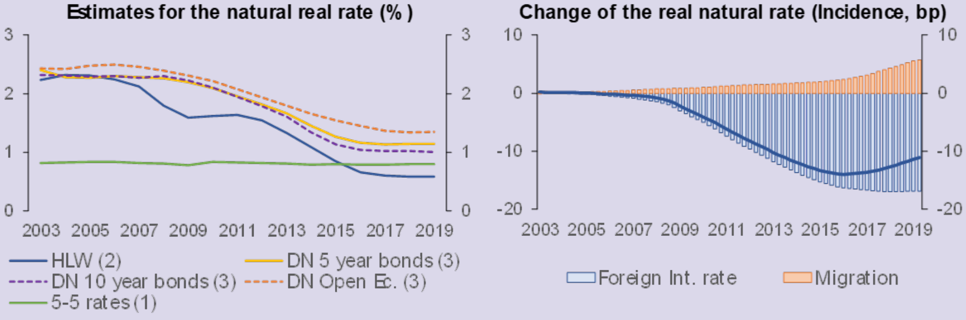
Estimates for the natural real interest rate

Methodology	2019 Estimation	Standard Deviation	68% Conf. Interval	95% Conf. Interval
Bonds 5-5	0.80	0.14	[0.7 0.9]	[0.5 1.1]
HLW	0.59	7.48	[-6.9 8.1]	[-14.1 15.2]
Del Negro et al. (BCP5)	1.14	0.38	[0.8 1.5]	[0.6 2.1]
Del Negro et al. (BCP10)	1.00	0.29	[0.8 1.3]	[0.5 1.7]
Del Negro et al. in SOE	1.35	0.39	[1.0 1.8]	[0.8 2.3]

Source: Aldunate *et al.* (2019).

Figure 3.10

Estimates for the natural interest rate (1)



(1) 2019 MP report
(2) 5 in 5 rate derived from financial asset prices corrected for term prizes.
(3) Based on Holston, Laubach and Williams (2017).
(4) Based on Del Negro et al. (2017), using data from 5-year BCP rates, 10-year BCP rates and open economy considerations.

Source: Aldunate *et al.* (2019).

4. SATELLITE MODELS FOR COMPLEMENTARY USE

In addition to the main or frequently used models described in the previous section, the CBC's toolkit considers a set of complementary models for economic analysis.

All models, even the most complex ones, are simplifications of reality. In this sense, none of them provides by itself a complete analysis of the economy. By simplifying some dimensions and extending the analysis of others, the use of complementary models, together with the main models and the judgment of CBC economists and Board members, helps to generate a broad view of current and expected developments in the economy.

This section describes these complementary models, which, in different dimensions, help to expand the vision provided by those frequently used, by incorporating, e.g., alternative sources of information, additional sectors to the production chain, alternative ways of generating expectations, or life-cycle considerations in the modeling of agents.

4.1 ECONOMETRIC MODELS

4.1.1 Alternative models for mining GDP

Complementing the approach described in sub-section 3.2.1, two additional approaches are used to forecast mining activity. For the medium term, copper production, which accounts for 88% of the mining sector's added value at a national level, is modeled separately from other mining activities. On the other hand, for the contemporary inference a nowcasting model with exogenous macroeconomic variables is used, which allows to deduce the mining activity of the period. These forecasts are used to contrast the results of the methods described in sub-section 3.3.2 and thus obtain a definitive forecast for mining activity that is consistent with all the available information.

A. Medium-term mining GDP

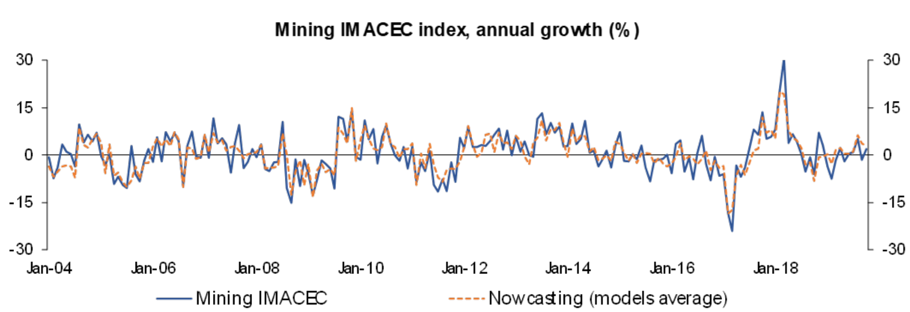
Copper production is estimated at monthly horizons of up to two years, using time series models. In this process, the production of the various mining firms is calculated separately, using ARIMA methods like those described in section 3.2. Individual estimates are made for the production of the larger firms, whereas the medium-sized and small mining firms are grouped into a single forecast. This separation by firms allows to identify differences in seasonal production processes and, therefore, to define particular profiles for each one.

The vision given by these models is complemented by public information reported by the firms themselves at the beginning of each year. These provide a forecast range for annual production, which is updated and revised throughout the year. Additionally, public information is considered regarding increases in the productive capacity associated with new investment projects, along with other relevant news, such as transitory changes in productive capacity, changes in ore grade, weather events, strikes, unexpected maintenance, and so on.

B. Nowcasting model for mining GDP

A nowcasting model is used to infer the current state of mining production, making use of leading indicators. Given the high volatility of the monthly dynamics of mining activity, making accurate forecasts is no easy task. Considering this, ARIMA processes with exogenous variables, correction for outliers and seasonality are incorporated. Low relative volatility series are used as exogenous variables, but which are highly correlated with mining activity. This helps to dissipate some of the volatility in the current month's inference. The set of exogenous variables chosen consider: electricity generation informed by the national electricity system (SEN); nominal mining exports of the current month; and expectations of the monthly index of entrepreneurial confidence (IMCE), with relevant information on production and productive capacity of the sector. As shown in Figure 4.1, this procedure enables an accurate inference of the contemporary mining production level.

Figure 4.1
Mining GDP inference using a nowcasting model (1)



(1) Projection within sample is shown.
Source: Central Bank of Chile.

C. Trend models for mining GDP

Other measures of contrast are related to the long-term evaluation of mining production, an analysis carried out on the basis of statistical filters that separate the cycle's dynamics from long-term trends. The trend extracted with these filters allows to obtain an idea about the long-term growth that could be expected in the future, and to which it should converge in the absence of additional disturbances that could affect production in longer terms. The latter include changes in productive capacity, ore grade, capital or labor productivity, etcetera.

4.1.2 Forecasts for the fiscal sector

The CBC carries out short and medium-term forecasts of central government revenues and expenditures, its balance sheet and savings. Disaggregated data from the Chilean Government's Budget Directorate (Diprés) are used as input. The different items are forecasted based on an adaptation for Chile of the Government Finance Statistics Manual (2014) of the International Monetary Fund.

Since 2001, the Chilean fiscal policy has been based on a structural balance rule. Under this methodology, based on estimations of expert committees of the trend GDP and the benchmark copper price[91]/, the government defines the parameters to estimate the structural revenues, which, combined with the structural target, determines the limit for the effective expenditure. Actual revenues, in turn, are estimated by the Dipres. This is the basis for the budget proposal that is sent to Congress for approval as the Budget Law for the following year. Annual structural balance targets are set for each government period through a procedure defined in the Fiscal Responsibility Law. The methodology has been disseminated in various documents, including Marcel et al. (2001), Rodríguez et al. (2006), Velasco et al. (2010), Corbo et al. (2011), Larraín et al. (2011) and Marcel, Cabezas and Piedrabuena (2012).

For the fiscal scenario, the CBC assumes that the government adheres to the Budget Law and that actual revenues behave according to CBC's inferred expected macroeconomic scenario, which is updated in each Monetary Policy Report (MP Report). Once the forecast of actual revenues is obtained, it is adjusted cyclically according to the methodology published by the Diprés. These cyclically adjusted revenues are also referred to as structural revenues. Given the forecast for structural revenues and the expenditure committed in the Budget Law, the Cyclically Adjusted Balance (BCA) is estimated. Its difference with the authority's target allows estimating the budget gap for future years.

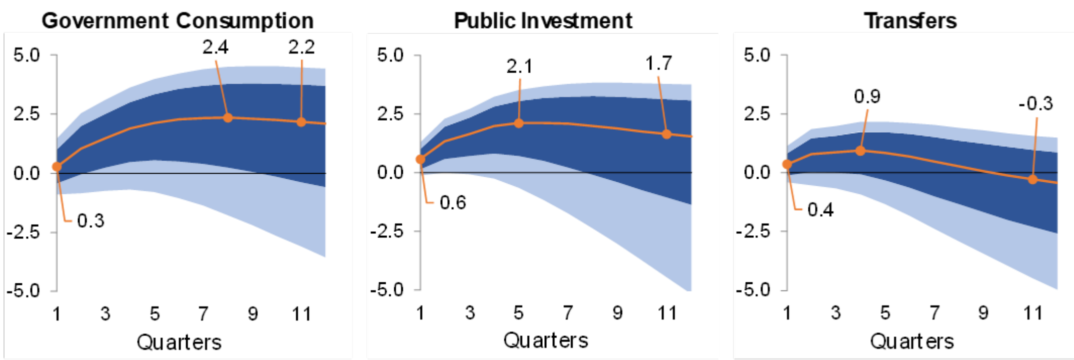
In addition, the CBC has different models to analyze in depth the fiscal policy transmission mechanisms. In addition to the fiscal block contained in the XMAS forecast model[92]/, it uses the methodology proposed by Fornero, Guerra-Salas and Pérez (2019), who, using structural VARs, estimate the fiscal multipliers of total expenditure and three components (public investment, government consumption, and transfers). Figure 4.2 shows the results of this work. A differentiated

[91]/ Prior to the drafting of each public sector budget bill, the Ministry of Finance convenes two committees of independent experts. One estimates the benchmark copper price, or long-term price, and the other estimates the inputs —capital, labor and productivity— for the trend GDP estimation.

[92]/ See García et al. (2019). Also see sub-section 3.3.2 of this volume for further detail on the implementation of the fiscal sector in the XMAS model..

impact is observed for the different expenditure components. This highlights the importance of a detailed analysis of the expected expenditure trajectory, beyond its aggregate level. Changes in its composition, while keeping aggregate levels constant, could have non-trivial effects on the economy.

Figure 4.2
Fiscal multiplier by spending component (1)(2)



(1) The fiscal multiplier for period T is defined as the present value of the cumulative GDP change per additional present value cumulative fiscal spending, since the beginning of the shock, up until period T.
(2) Each panel shows the fiscal multiplier associated with the corresponding spending component. Highlighted are the multipliers at impact, at their peak, and 10 quarters after impact.
Source: Fornero, Guerra-Salas y Perez (2019).

4.1.3 Models for high-frequency analysis of the nominal exchange rate

For daily monitoring of the nominal exchange rate, a reference model based on Cowan et al. (2007) is used, where the determinants of the daily variation of the nominal exchange rate are estimated in an error-correction model, following the approach of Engle and Granger (1987). In particular, the following specification is estimated:

$$\Delta ltcn_t = \alpha_0 + \alpha_1(ltcn_t - \beta X_{t-1}) + \sum_{i=0}^{p} \delta_j \Delta X_{t-j} + \sum_{i=0}^{p} \eta_j \Delta Z_{t-j} + \epsilon_t \,,$$

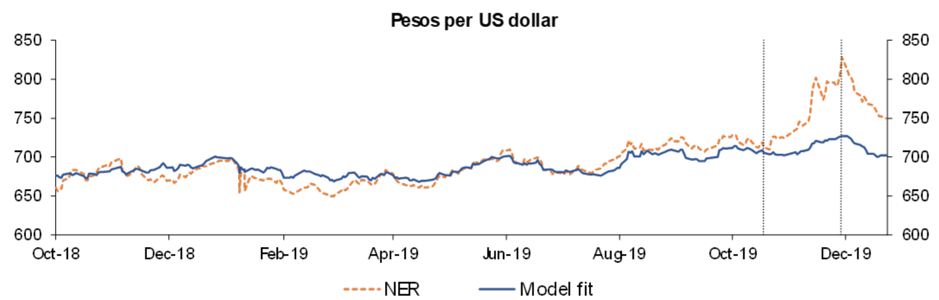
where Δ is the difference operator, $ltcn_t$ corresponds to the natural logarithm of the nominal exchange rate, X_t and Z_t are vectors that include, respectively, the fundamental and short-term determinants for the exchange rate, and ϵ_t is a stochastic process.

Two alternative specifications are estimated. Both input into vector X the copper and oil prices, the domestic and U.S. price levels, the spread of credit default swaps on Chilean sovereign bonds, and the one-year interest rate differential between Chile and the United States. In addition, they contain information on international currency parities. One specification includes the parity between the U.S. dollar and a basket of Latin American countries and commodity exporters, while the other incorporates the broad dollar index developed by the Saint Louis Federal Reserve, which reflects the parity between the U.S. dollar and its trading partners' currencies, while vector Z includes the Dow Jones stock index.

Given its nature and the frequency of its data (daily), this model is useful for determining whether or not the observed exchange rate movements can be explained by the dynamics of its fundamentals. For example, as presented in Figure 4.3, in the analysis following the social crisis that broke out on 18 October, 2019, the model suggests that the sharp depreciation observed deviates significantly from the trajectory predicted by its long-term determinants. Moreover, the model shows how this gap begins to close after November 28, the day the CBC announced its exchange-rate intervention program[93]/.

Figure 4.3

Nominal Exchange rate and its fundamentals (1)(2)



(1) Daily frequency model estimated between July 2019 and December 2019.
(2) Vertical lines denote the beginning of the protests and the exchange rate intervention announcement by the CBC.
Source: Central Bank of Chile

4.1.4 VAR models for analyzing the exchange rate pass-through to inflation

The use of VARs is useful to analyze the exchange rate pass-through to domestic prices. These allow to model the expected responses of the economy to innovations or unexpected changes in variables of interest, in this case the effect of exchange rate fluctuations on inflation. In the analysis carried out by the CBC of the exchange rate pass-through to prices based on VAR models, the implementations documented in Justel and Sansone (2016) and Contreras and Pinto (2016) stand out. In these, the degree of the exchange rate pass-through to inflation is defined as the ratio, after an exchange rate shock, between the cumulative responses of inflation and the response of the exchange rate.

[93]/ Details of the program can be found at https://www.bcentral.cl/documents/33528/133208/np28112019.pdf

In the implementation of Justel and Sansone (2016), the VAR model incorporates monthly inflation, the MPR, the Imacec and the monthly variation of the nominal exchange rate (NER) as endogenous variables. Exogenous variables include the price of oil, the international food price index, external prices, the U.S. federal funds interest rate and an industrial production index of commercial partners. In alternative specifications, the model is estimated by disaggregating the consumer price index into its energy, food and underlying components, in order to study the differentiated responses of each of these to exchange rate shocks. Identification of the shocks is achieved by assuming the following Cholesky ordering[94]/ for the endogenous block of variables: Δlog(IMACEC) → ΔMPR → Δlog(NER) → Δlog(CPI). This ordering allows shocks on the exchange rate to be passed-through to prices within the same period.

A second implementation of the methodology is that documented in Contreras and Pinto (2016). In it, VAR models are estimated separately for 131 different CPI subclasses[95]/. For each of these, a VAR with the following order of variables is estimated[96]/:Δlog(IMACEC) → Δlog(salario sectorial) → ΔMPR → Δlog(NER) → Δlog(CPI subclass)[97]/ → Δlog(CPI). In the first instance, this implementation provides a complementary estimate, with a BU approach, of the exchange rate pass-through coefficient on different price groups. Additionally, it allows for the identification of the categories that present greater pass-through coefficients, permitting a better follow up of them in the monitoring of inflation in the face of episodes of nominal exchange rate volatility.

4.2 STRUCTURAL MODELS

4.2.1 Learning, expectations and de-anchoring

A recurring concern among central banks —and in the CBC in particular— is the anchoring of inflation expectations, "as it" ensures that temporary movements in inflation do not feed into wages and prices and hence become permanent" (Draghi, 2014). However, standard monetary models derived under rational expectations assumptions, such as those usually used in central banks, do not allow for an adequate analysis of this anchorage of expectations. This, because under this framework agents have perfect knowledge of the economy, including the target function of the central bank, so they trust that the long-term inflation rate corresponds to the inflation target of the central bank. However, inflation expectations, in general, are not perfectly anchored in reality, and the degree of anchorage can vary according to the economic evolution or the monetary policy conduct.

Although the de-anchoring phenomenon cannot be easily addressed in the context of rational expectations, it does fit naturally into a scenario of adaptive learning. Motivated by this, the CBC has developed a general equilibrium monetary model[98]/, where de-anchoring of inflation expectations

[94]/ Cholesky's decomposition allows identifying shocks from a recursive ordering where the "most independent" variables contemporaneously affect the "least independent", but not in the opposite direction.

[95]/ Of the 137 CPI subclasses with base 2013, five subclasses whose price records start in 2008 (Other services related to Housing, Motorcycle, Bicycle, Stationery, and Teaching services not attributable to any level) and a subclass with information available from 2013 (Co- ownership expenses) are excluded. The excluded subclasses have a weight of 1.4% in the total basket.

[96]/ The choice of this ordering is based on the work of Choudhri et al. (2005), Ca' Zorzi et al. (2007) and McCarthy (2007).

[97]/ Sector wages result from assigning each of the 131 subclasses to a sector within the 9 sectors whose wage index is measured by the INE.

[98]/ Arias and Kirchner (2019) present a detailed description of the model and its implications.

is conceptualized from the assumption of an adaptive learning mechanism that varies in time and where the agents' sensitivity to incoming data depends on cumulative inflation errors.

Theoretically, anchoring of inflation expectations can be defined as a situation in which long term inflation expectations do not respond significantly to new information or, in other words, when these are rather insensitive to short-term surprises. The adaptive learning framework enables a natural conceptualization of this idea. Under this approach, agents use reduced-form models to form their expectations and re-estimate these models each period as new information becomes available.

Model structure

The model is framed within the literature of small open economy neo-Keynesian models. An economy composed of five sectors is modeled: households, firms, government, central bank and an external sector.

In the first sector, agents with infinite lives, identical endowment of assets and same preferences, seek to maximize their utility throughout their lives subject to a budgetary constraint. They face decisions on how much to consume of a final good (relative to a habit component) and how many hours to work. In addition, in each period they decide how much to invest in capital, taking into account adjustment costs and how much to save from buying and selling domestic and foreign currency bonds.

The second sector is composed of different types of firms that are all owned by households. These firms in monopolistic competition produce different varieties of a domestic good, choosing the amount of labor and capital to be used as inputs, and determining prices with Calvo-style rigidities and indexation. In addition, a group of firms importing a homogeneous good transform it into different varieties, which allows them to set the price, also subject to Calvo-style rigidities and indexation. Finally, there are three perfectly competitive firms that aggregate products: one combines the different varieties of domestic goods to produce a composite domestic good, a second combines the different varieties of imported goods into a composite foreign good, and a third combines the composite domestic good with the composite foreign good to produce the final good of this economy. The latter is purchased by households, for both consumption and investment, and by the government. In turn, there is a competitive firm that produces a homogeneous good (commodity) that is exported and follows an exogenous process. This good mainly captures the importance of copper for Chile.

The third sector represents the government, which follows a Ricardian fiscal policy. The fourth sector is made up of a central bank that determines the short-term nominal interest rate according to a Taylor rule.

The fifth sector (rest of the world), demands the domestic composite good and buys the domestically produced commodity. It is worth mentioning that there are no transaction costs or other barriers to international trade in this economy. The external economy's structure is assumed to be identical to the domestic one, but the latter is assumed to be small in relative terms, meaning that the external price level and interest rate are taken as given. However, the relevant external nominal rate depends on the country risk, which increases with the level of net external debt. Additionally, a standard set of exogenous shocks is assumed and the external sector is modeled based on exogenous processes.

Finally, as mentioned in previous paragraphs, the assumption of rational expectations is relaxed and instead a mechanism of expectations formation is assumed in which agents learn about the parameters of their forecasted models, in the spirit of adaptive learning models. In particular, agents are supposed to shape their expectations using linear models of the form:

$$x_t^f = \beta'_{t-1} x_{t-1}^s + \epsilon_t \ ,$$

where x_t^f corresponds to the vector of variables to be projected, which is assumed to depend linearly on the information available at the beginning of period t, which is summarized in the vector of states x_{t-1}^s, and on beliefs about how this information correlates with the variables to be forecasted. The updating of these beliefs, expressed in the coefficient matrix β_t, depends on the last forecast error made, ϵ_t:

$$\beta_t = \beta_{t-1} + K(g_t)\epsilon_t,$$

The weight assigned to the forecast error ϵ_t in turn depends on the variable g_t, which is interpreted as the degree of sensitivity or anchorage of said expectations[99]. Intuitively, the greater the degree of anchorage, the less importance will be given to the last forecast error and the lesser the updating of forecast models. In this way, the more anchored the expectations, the inference on the long-term level of the variables, including inflation, will be more stable over time.

In the case of inflation expectations, g_t is allowed to vary over time. Based on international experience and a series of empirical exercises for the Chilean economy, this variable is modeled as dependent on the accumulation of past forecast errors. It is assumed that in face of a succession of forecast errors, the degree of the agents' confidence in their forecast models decreases, so they begin to adjust them more, thus increasing g_t as they avoid repeating recent forecast errors.

Main results

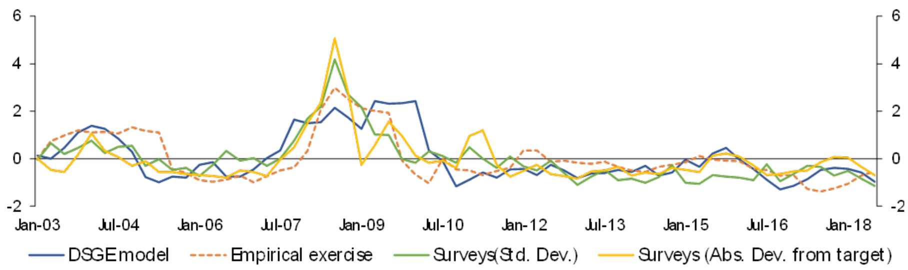
This expectations formation mechanism, which allows de-anchoring, improves the fit of the model to the data, compared to the fit achieved with the same model, but assuming rational expectations as usual. As shown in Figure 4.4, the model can correctly capture episodes of inflation expectations de-anchoring and anchoring, identified through other strategies.

An advantage of the de-anchoring indicator of the structural model over other empirical indicators lies in the possibility of performing counterfactual simulations. For example, the model can be used to evaluate the monetary policy role in anchoring inflation expectations. The results of this exercise show that a monetary policy that systematically behaves more aggressively during episodes of high degree of de-anchoring can reduce both the frequency and the intensity of these episodes. Also, contrary to the results that arise under rational expectations, the model shows that in a learning environment there is additional information in the expectations of agents that makes it

[99]/ In particular, $K(g_t) \equiv g_t R_t^{-1} \chi_{t-1}^s$ is expressed in a recursive way, where $R_t = R_{t-1} + g_t (\chi_{t-1}^s \chi_{t-1}^{s}{}' - R_{t-1})$.

Figure 4.4

Alternative measures for expectations de-anchoring (1) (2) (3)



(1) All measures are standardized with respect to their respective means and standard deviations.
(2) "Empirical exercise" refers to an econometric estimation of the role of past forecast error in the formation of expectations for two years ahead. Reported is a rolling estimator for a_i from the regression $E_{t-1}(\pi_{t+23}) = a_i(\pi_{t-1} - E_{t-2}(\pi_{t-1})) + \epsilon_t$, where $E_\chi(\pi_y)$ c is the median of the survey "Encuesta de Expectativas Económicas" at period χ for period's y inflation.
(3) "Surveys" are constructed based on the answers regarding the two years ahead inflation expectation from the survey "Encuesta de Expectativas Económicas", and are, respectively, the standard deviation of the answers, and the absolute difference between the answers and the CBC's inflation target.
Source: Based on Arias and Kirchner (2019)

convenient for monetary policy to respond to them. At the same time, the model predicts that the effectiveness of monetary policy on inflation improves when agents become more sensitive to short-term information. The model also suggests that an optimal monetary policy derived under assumptions of rational expectations may perform poorly in the context of a de-anchored model where a greater response to inflation is required.

4.2.2 A model of tradable and non-tradable goods and the exchange rate pass-through

The study of the exchange rate pass-through (also known as ERPT) coefficient has implications not only for various topics related to the global economy, but also for those more closely related to the conduct of monetary policy, thus becoming, as highlighted in box 4.1, a topic of special interest to central banks, including the CBC. This is due to the fact that, from the standpoint of a small, open economy like Chile, fluctuations in the nominal exchange rate can have a major inflationary impact by affecting the prices of goods. Indeed, Bernanke (2007) emphasizes that changes in the relative prices of imports could affect, at least for a period of time (in the short or medium term), domestic inflation levels.

The coefficient of ERPT to prices is defined as the ratio between the variation of a price or price index and the variation of the exchange rate. A high coefficient means that a large part of the exchange rate movements will be transmitted to the domestic prices of the economy and, therefore, to inflation. This can be calculated either conditionally on a particular shock or unconditionally. The work described below analyzes the differences between these forms of calculation and the advantages that a conditional pass-through analysis can have for better understanding the inflationary effects of exchange rate movements.

The model[100]/ presented in this case is of the large-scale DSGE type, similar, although somewhat smaller in size, to the CBC's main model of this type, the XMAS. It was built aiming to analyze the inflationary dynamics generated by external shocks that have a major impact on the exchange rate. With that objective in mind, the model design includes a more detailed characterization of productive sectors that present heterogeneous responses to exchange rate movements. Specifically, this model differentiates between the tradable and non-tradable sectors and includes imported goods as inputs in the production of both, but with different intensity of use in each sector. The differentiation between tradables and non-tradables refers to the participation of different sectors in international trade. Tradable goods compete in international markets, while non-tradable goods can only be consumed in the country where they are produced, which implies that consumption will be equal to the domestic production.

These differentiations are important for two reasons. First, non-tradable goods have a different dynamic from those traded internationally, because their market must be balanced domestically. In these goods, when production exceeds the quantity demanded, for example, the price must decrease so that the quantity is balanced out. On the contrary, when goods are traded internationally, if there is a greater quantity produced, the difference is simply exported and the price determined (or significantly influenced) by the external price. The second reason is that there are important differences in dynamics, because each sector uses inputs with different intensity and also has different degrees of flexibility in pricing. For example, the greater the quantity of imported inputs used by the sector, the greater the effect on their marginal cost of a change in the exchange rate, and therefore the greater the changes in the prices of that sector. In addition, the speed with which cost changes are factored in will depend on the flexibility with which firms in each sector change their prices.

Because of these characteristics, the model allows a detailed analysis of how and for how long changes in international prices of goods (e.g. the price of copper or oil) or external rates affect different sectors of the local economy, and understanding the means by which the effects will occur. In particular, it allows analyzing to what extent different domestic prices are affected by events that cause strong exchange rate movements.

Model Structure

The model has four types of agents: households, firms, government (including the central bank) and the external sector. Households consume, provide jobs, invest, rent their capital and have access to bonds from the government or from abroad. There are four types of goods offered in the economy: the mining good, intermediate goods of imported origin, exportable goods, and non-tradable goods. The mining good is given stochastically, different varieties of intermediate goods are made from a homogeneous imported good and the last two, exportables and non-tradables, are produced using a combination of labor, capital and intermediate goods. Both wages and

[100]/ A detailed version of the model and its main results can be seen in García and García-Cicco (2020).

prices of intermediate goods, exportables and non-tradables, have rigidities. In each period, only a fraction of these are optimally set, while the rest are indexed to a combination of the inflation target and past inflation. For its part, monetary policy follows a Taylor rule and fiscal policy presents exogenous expenditure.

The relationship of this economy with the external sector is diverse. First, as mentioned, households can buy external bonds at an exogenously given interest rate (which depends on an external interest rate, the level of the country's external debt as a fraction of GDP and exogenous factors). Moreover, the local economy imports homogeneous goods that are used to produce different varieties of intermediate goods and exports both the mining good (at an exogenously given dollar price) and the exportable good.

The model contains 24 shocks, among which there are local sources (such as government expenditure, preferences and productivity) and external sources (such as prices of foreign goods in dollars, external demand, interest rate). The model parameters are chosen based on a combination of calibration and estimation. Quarterly data are used for the Chilean economy between the third quarter of 2001 and the third quarter of 2016.

Main results

The results of the estimation of the model parameters, in particular those defining the degree of indexation and the rigidity of pricing, show significant differences across sectors in the way prices are determined. Firms in the non-tradable sector have the most sticky and indexed pricing, while those in the exportable sector have the least rigidity.

The model generates ERPT coefficients at substantially different prices depending on the shock faced by the economy. While the coefficient is large and persistent in the case of shocks to the uncovered parity rate equation, it is small and transitory in the case of shocks to external prices.

This can be intuitively understood if we consider that the main channel through which the exchange rate affects inflation is import prices. In the model this occurs directly through the share of imported goods in the consumer basket, and indirectly through the use of imported intermediate goods for the production of exportable and non-tradable goods. If the shock that causes an exchange rate depreciation simultaneously reduces import prices, the final effect on domestic prices will be, all other things constant, smaller than if the shock keeps international prices unchanged.

Another way of looking at it is through the real exchange rate equation: $rer_t = s_t p_t^* / p_t$, where rer_t is the real exchange rate, s_t is the nominal exchange rate, p_t^* is the external price level, and p_t is the domestic price level. A shock that affects the nominal exchange rate but spares external prices will require an equivalent movement in domestic prices to balance out the real exchange rate. On the other hand, if the shock caused by the foreign exchange movement affects external pricing, balancing the real exchange rate will require only a partial adjustment via domestic prices. Part of the adjustment will be achieved through changes in external prices.

The speed of the inflationary adjustment, in turn, will depend crucially on the rigidity and the indexation degree in the pricing of different sectors.

The above analysis shows the importance of correctly identifying the shock behind exchange rate movements. If it is an external price shock, no major inflationary effect should be expected and also it should occur in the short term; however, if the origin of the exchange rate movement is a domestic shock that does not affect external prices, e.g. a shock to the interest rate parity, then its influence should be significant and long lasting.

Due to the pricing dynamics and the nature of the different markets, the pass-through coefficient for tradable (exportable and imported) prices is higher than for non-tradable prices over the same time span. This happens because tradable sectors use a greater amount of imported goods in their production and also because non-tradable prices show greater inertia, through indexation with respect to their past inflation rate. Then, changes in tradable prices are bigger and more immediate, while for non-tradable prices, changes happen gradually over longer periods.

The model can also be used to compare conditional pass-through measures to unconditional ones, which are the best known and are generally measured in the empirical literature[101]/. The results show that empirical measures are comparable weighted average of the conditional coefficients, using as weights the importance of the respective shock in explaining exchange rate variations.

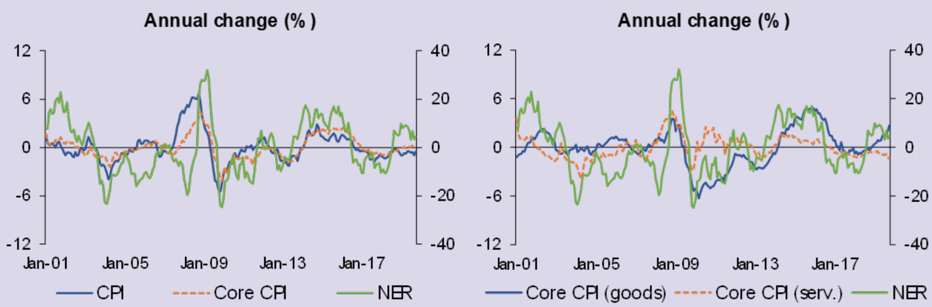
[101]/ See, for example, Justel and Sansone (2016), Contreras and Pinto (2016), and Albagli et al. (2015).

Box 4.1: **Assessing the inflationary effect of movements of the exchange rate**

The exchange rate is one of the main determinants of inflation. Figure 4.5 shows the evolution of the exchange rate in Chile, and how it compares with different measures of inflation. There is a significant correlation between domestic prices and the exchange rate. However, this correlation differs significantly depending on the price subdivision analyzed. Exchange rate movements seem to affect the goods sector more than the services sector. The high correlation observed motivates the recurrent study —in thematic boxes of MP Reports— of the effects of exchange rate movements on the different components of inflation.

The last three associated boxes were presented in the March 2014, 2016 and 2018 reports. In

Figure 4.5
Inflation and exchange rate (1)



(1) All series in deviation from sample mean. Core inflation measure refers to CPI without food or fuels.
Source: Central Bank of Chile and Instituto Nacional de Estadísticas.

these studies, the statistic that summarizes the relationship between prices and the exchange rate is called pass-through coefficient and is defined as the ratio between the cumulative variation of a price (or price index) during a given period, and the cumulative variation of the exchange rate during the same period.

In the international literature, the main methodology for estimating the pass-through coefficient is based on autoregressive vector models (VARs). Along these lines, in March 2014, using the model documented in Justel and Sansone (2016) and described in section 4.1.4, a pass-through coefficient from the nominal exchange rate to the consumer price index (CPI) was estimated at between 0.1 and 0.2 for a horizon of between one and two years. For core inflation, considering the same horizon, the coefficient was estimated at around 0.1. This means that, in the face of exchange rate movements where the peso depreciates by 1%, CPI inflation will increase on average between 0.1% and 0.2%.

Subsequent analyses were carried out in 2016 and 2018 to further study the connection between the exchange rate and local prices. In 2016, the analysis focused on studying whether the pass-through coefficient is different for different price subclasses, while in 2018, the analysis focused on the pass-through coefficients differentiated according to the different shocks that hit the economy.

For the 2016 box, the analysis was mainly based on the study by Contreras and Pinto (2016), described in sub-section 4.1.4. The first row of table 4.1 reproduces the results obtained in this study. The pass-through to the goods component of core inflation is estimated at 0.15, much higher than that of services, which is estimated at 0.08. This implies that, for a given variation in the exchange rate, goods prices are expected to be more affected than services prices. The reason for this discrepancy is attributed to the greater share of the imported component in the goods sector than in the services sector.

Table 4.1

Conditional and unconditional one year exchange rate pass-through by subclass (1)

	Total CPI	Core CPI (Goods)	Core CPI (Services)
Unconditional	0.15	0.15	0.08
Conditional to			
Foreign prices shocks	0.05	0.07	0.02
Uncovered interest rate parity shock	0.26	0.4	0.09

(1) Cumulative change in prices per cumulative change in exchange rate.

Sources: Garcia et al (2018) and Contreras and Pinto (2016).

For its part, the analysis of March 2018 was based on the structural model described in García and García-Cicco (2020) and in sub-section 4.2.2 of this book. This model, unlike VARs, allows identifying specific shocks behind exchange rate movements and calculating the pass-through coefficients associated with each of them.

With the help of this model, in a first stage, the shocks that explain most of the exchange rate variations are identified, finding that international price and interest rate parity shocks are the most important ones: they explain 69% and 18%, respectively, of the exchange rate variations. In a second stage, the pass-through coefficient is calculated for each of these shocks, both for total CPI and for the goods and services components of core inflation. As shown in the lower part of table 4.1, the estimated pass-through coefficients are substantially different depending on the shock and the component of inflation analyzed.

The one-year coefficient for the total CPI in response to an international price shock is estimated at 0.05, while the coefficient estimated for an interest rate parity shock is estimated at 0.26. This implies that, given the same variation in the exchange rate, if it comes from a shock to the rate parity, the effects on the local economy will be significantly greater than if it comes from changes in international prices. As is to be expected, the same as for the unconditional case, the pass-through coefficients of both shocks are higher for the goods component of core inflation and lower for services.

4.2.3 Overlapping generations models for long-term analysis

The CBC has overlapping generation models (OLGs) to address the analysis of certain phenomena, as well as to complement the study of others. In OLG models, individuals live a finite number periods, leading to a population structure where different generations (or ages) coexist in each period, and where it is possible to distinguish between different stages of an individual's life cycle. This characteristic is the main difference between these models and those that, like the XMAS, consider households that make decisions with an infinite time horizon, ignoring the importance of the age structure. Thus, OLG models enable, for example, to study pension systems, for which it is critical to model both work, savings and consumption decisions of active individuals and savings and consumption decisions of passive individuals (retirees). Furthermore, in the CBC these models have been used to analyze the impact of the migratory influx Chile has received in recent years, capturing the age distribution of migrants, which is characterized by individuals who are mostly young adults.

Overlapping generations models

Although OLGs have a long tradition in economic analysis, since their appearance with the works of Allais (1947), Samuelson (1958) and Diamond (1965), their use is not common in central banks. The reason is that OLG models are mostly used to analyze long-term phenomena that are outside the scope of monetary policy. Precisely, given the nature of the economic policy carried out by central banks, they focus mainly on the evolution of the economy throughout the business cycle, under the assumption that monetary policy has little or no effect on the long-term. Nevertheless, OLGs are useful to complement the analysis of issues of interest to the CBC.

Macroeconomic effects of changing the pension system

At the request of the Ministry of Finance, during the second administration of President Michelle Bachelet, the CBC developed an economic and financial assessment of the effects that a reform to the pension system could produce in Chile[102]/. Part of the conclusions of the resulting report were based on simulations made with an OLG model with three generations coexist, where at each moment two generations are working-age individuals, young and adult, and a third one are older individuals who are assumed to be retired. Working-age individuals, in addition to considering their consumption needs throughout their work cycle, save part of their income to finance their consumption during retirement. This OLG model incorporates an informal work sector, which has been stylistically modeled, with the aim of capturing this significant extensive margin typical of emerging economies such as Chile[103]/,[104]/. Individuals decide how long they will work in the formal sector, where firms produce goods that are traded on the market, and how long they will work in the informal sector, which is modeled as production in a household that generates goods that are consumed only by the very individuals who produce them. It is also assumed that there are individuals with different levels of ability and inter-temporal preferences, which makes it possible to approach the distribution of income and the differences in the savings rate observed in Chile. Finally, the model incorporates, in a reduced form, information frictions that limit the agents' capacity to internalize future benefits derived from contributions to a pension system.

A more recent version of the model, documented in Albagli et al. (2020), incorporates a series of improvements compared to that on which the report presented in 2017 was based[105]/. Among the amendments introduced into this new version of the model a tax on formal work income stands out, to generate a difference between gross and net income, decreasing returns on informality, and a new calibration of the elasticity of informal work in line with Joubert (2019). These changes, which make it possible to better model the dynamics of the informal sector, do not alter the qualitative results produced by the previous version: individual capitalization and conditional intra-generational savings systems continue to produce similar effects that dominate the non-conditional intra-generational savings scheme, and the pay-as-you-go scheme remains the option that most affects the GDP. With the richer analysis of labor dynamics that the new version of the model allows, it is found that the conditional intra-generational savings system is capable of reducing informality more significantly than can the individual capitalization scheme.

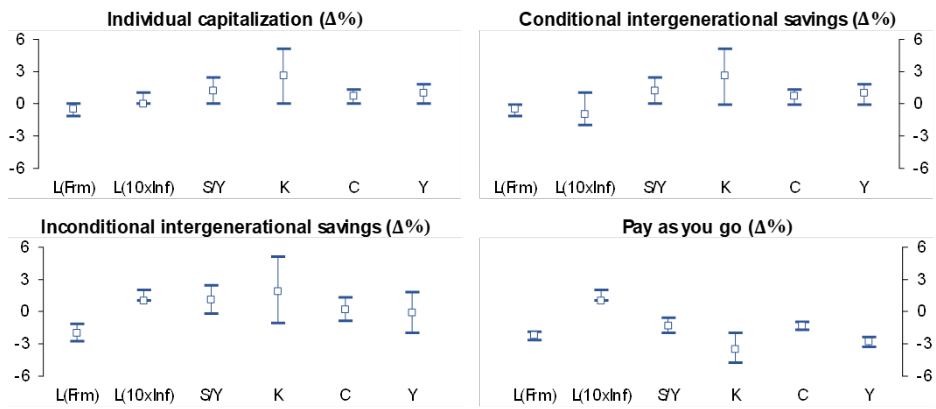
The model allows analyzing the macroeconomic impact of a 5% increase in pension contributions, payable by the employer, under different schemes: (i) individual capitalization, where the additional contribution goes to a fund that belongs to each worker and can only be withdrawn during their retirement period; (ii) intra-generational savings, where the additional contribution goes to a fund that belongs to the generation of the worker for whom the firm makes the contribution, and is distributed among the members of that generation when he retires according to two rules: one, conditional on the amount of contributions and another, progressive but unconditional on the historical record of contributions of each worker; and (iii) pay-as-you-go, where the additional contribution is used immediately to finance the existing pensioners.

[102]/ The report Evaluación de Impactos Macroeconómicos de Largo Plazo de Modificaciones al Sistema de Pensiones (Assessment of the Long-Term Macroeconomic Impacts of Amendments to the Pension System), Central Bank of Chile (2017b), summarizes the results of the evaluation.
[103]/ Although there is more than one way to define informality, the literature finds that most self-employed workers meet various characteristics associated with informality. See, for example, Fernández and Meza (2015).
[104]/ The structure of the informal sector in the model follows Orsi et al. (2014).
[105]/ The most recent version allows for replication of the 2017 results by adjusting calibration and closing channels not present in the original version.

The results, summarized in figure 4.6, show that reforms involving an individual capitalization scheme and a conditional intra-generational savings scheme would have similar macroeconomic impacts: moderate negative effects on the labor market, offset by an increase in the capital stock resulting from forced savings, which would generate an expansion of output in both scenarios. The unconditional intra-generational savings scenario would have more negative effects on the labor market, aggregate savings, capital stock and output, which would be marginally lower than before the reform. Finally, the pay-as-you-go scheme would be the most negative scenario in terms of macroeconomic variables, with a significant drop in capital stock and demand for labor, beyond the deterrent effect that the latter has on the contribution charged to the employer. With regard to the long-term impact on aggregate pensions, these would increase significantly under individual capitalization and conditional intra-generational savings, and to a lesser extent under unconditional intra-generational savings, while the system that would grow least would be the pay-as-you-go scheme.

Figure 4.6

Simulated macroeconomic effects of a change in the pension regime (1)(2)(3)



(1) Results published at "Evaluación de Impactos Macroeconómicos de Lago Plazo de Modificaciones al Sistema de Pensiones", Banco Central de Chile (2017). Results from Albagli et al. (2020) are qualitatively equivalent.

(2) L(Frm) is formal employment, L (Inf) is informal employment, S/Y is savings over PIB, K is capital, C is consumption, and Y is GDP.

(3) Results show percent change in long term levels based on model simulations. The figure shows the results from the baseline calibration, and also the maximum and minimum from alternative calibrations.Fuente: Banco Central de Chile (2017).

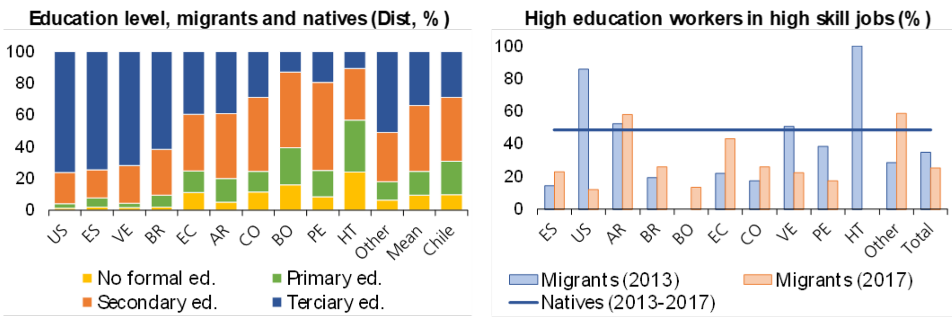
Macroeconomic implications of migration

The CBC has also used an OLG model to analyze the macroeconomic effects of the flow of immigrants that Chile has received in recent years[106]/. In this case, unlike the previous one that studied pension systems, both medium- and long-term effects were considered on the basis of a model with 24 generations, i.e. one in which 24 generations coexist in each period; each individual lives 24 periods. Individuals belonging to the first 16 generations are assumed to be of working age, while individuals belonging to the next eight (17 to 24) are assumed to be retired. The model is calibrated so that each period covers 10 quarters, meaning that individuals work for 40 years (a working life roughtly between 20 and 60 years of age), and that they are retired during the last 20 years of their life (from 60 to 80 years old)[107]/.

The way in which migrants blend into the local labor market is a key determinant of the effect of the immigration flow. The evidence, as illustrated in Figure 4.7, indicates that although immigrants have an educational level similar to that of Chileans, they may undergo a transitional period of underemployment[108]/. The design of the OLG model used in this analysis allows incorporating this transitory underemployment, since it considers individuals of different skill levels. Thus, it is possible to simulate an immigration flow characterized by migrants whose skill level is temporarily lower.

Figure 4.7

Employment and educational characterization of immigrants (1)



(1) Countries: United States (US), Spain (ES), Venezuela (VE), Brazil (BR), Ecuador (EC), Argentina (AR), Colombia (CO), Bolivia (BO), Perú (PE), and Haití (HT).

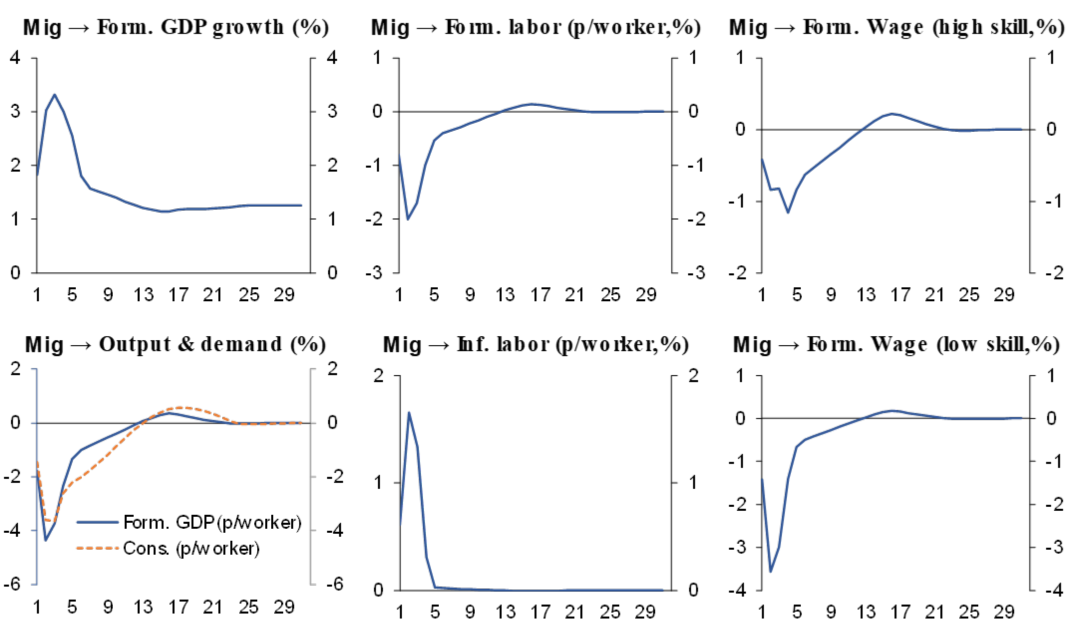
Source: Aldunate *et al.* (2018).

[106]/ A detailed version of the model and its results can be seen in Arias and Guerra-Salas (2019).
[107]/ Note that by considering only the working and retirement age stages, the model ignores an initial period in which individuals receive education, see Boldrin and Montes (2015), for an analysis of overlapping generations that considers the decision to accumulate human capital via education in an early stage of the life cycle.
[108]/ See Aldunate et al. (2018)

Based on simulations of the immigration flow using the OLG model, which are summarized in Figure 4.8, we can highlight the following results: (i) the increase in the labor supply resulting from immigration generates downward pressure on formal sector wages; (ii) the wages that fall the most are those of less skilled workers, since the period of immigrants' underemployment results in the supply of lower skill workers outweighing the supply of workers with higher skills; (iii) given the general decline in wages in the formal sector, the informal sector becomes more attractive, leading to a reallocation to that sector, i.e., an increase in the average hours workers spend in the informal sector and a fall in the average hours in the formal sector; (iv) although GDP increases due to the increase in the labor force, the output per worker decreases; (v) finally, consumption per worker also decreases, although somewhat less than output per worker, due to the role the informal sector plays as income stabilizer[109]/.

Figure 4.8

Simulated macroeconomic effects of a migration shock (1)(2)



(1) Period length is 10 quarters.

(2) Responses are in deviation from their steady state, except for GDP growth.

Source: Arias and Guerra-Salas (2019).

[109]/ For more details on the informal sector as an income buffer, see Loayza and Rigolini (2011) and Fernández and Meza (2015).

Thus, the recent use of OLG models for studying the pension system and the immigration flow has allowed the CBC to incorporate this type of instrument into its analytical toolkit. These expand the type of questions that can be addressed with formal models, so it is expected that in the future they will continue to contribute to the analysis of various issues relevant to the Chilean economy.

5. CONCLUSIONS AND FUTURE AGENDA

The credibility of monetary policy rests on the professionalism with which the CBC approaches its price stability objective. The utilization of economic models, in a judicious and non-mechanical manner, is a fundamental component for achieving this purpose.

This book documents the use of macroeconomic models for analysis and projections, describing how the interaction between the results of different models and the expert judgment of the Board and staff allow the formation of a global vision of the current and future state of the economy, thus collaborating in a monetary policy decision-making conducive to efficiently achieving the price stability objective.

It should be noted that the methodologies presented in this book represent a snapshot within a continuous process of improvements and adjustments in the development of models. The economic environment is constantly changing, along with advances in the economic theory and in statistical and econometric techniques. The CBC's modeling agenda seeks to adapt the modeling tools available for analysis taking these considerations into account.

This agenda, which encompasses a series of short- and medium-term projects, seeks to improve the analysis in different dimensions, including the labor market, the interaction between the financial markets and the real economy, and the modeling of an optimal monetary policy, besides other relevant topics.

Regarding the first dimension —the labor market— two projects stand out. The first seeks to explore the aggregate implications of the so-called "job ladders" —defined as the possibility of successful transitions to other jobs where workers find better quality work relationships— and how these productivity gains are lost by the destruction of jobs. This considers a model calibrated with Chilean labor flows. The second project consists of the implementation of endogenous fluctuations in the labor force in a model built from the XMAS, considering flows between inactivity, unemployment and formal and informal employment.

With regard to the interaction between financial markets and the real economy, one important project consists in the development of a general equilibrium model that incorporates frictional financial markets in the XMAS structure, with interactions between the dynamics of the real economy and financial markets, and an explicit role for macroprudential policy by the CBC.

A third focus of the agenda relates to improvement projects regarding the way in which the appropriate monetary policy response to different economic shocks is modeled, beyond considering simple Taylor-type rules. On the one hand, it seeks to analyze the implementation of optimal rules in the models, understood as those where the prescribed response minimizes the economic costs caused by different shocks. A complementary project seeks to incorporate robustness considerations in the formulation of monetary policy decisions against the inherent uncertainty in models.

Furthermore, the future agenda considers other topics that can be relevant for better understanding the inflation phenomenon and for better calibrating monetary policy responses. One example of the foregoing is the modeling of heterogeneous agents, where changes in the distribution of assets among agents have implications in monetary policy transmission mechanisms. The development of models around this and other topics is constantly assessed according to the evolution of the economy and the Board needs, in a continuous feedback process, which aims to improve the analytical tools and, thereby, facilitate the decision-making process leading to the fulfillment of the CBC's objectives.

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7. GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ARIMA: Autoregressive Integrated Moving Average.
BU: Bottom-up.
CBC: Capital goods corporation (Corporación de Bienes de Capital).
CBC: Central Bank of Chile.
CPI: Consumer Price index.
CPI-EFE: Consumer Price index, excluding food and energy prices.
Dipres: Finance Ministry's Budget office (Dirección de Presupuesto del Ministerio de Hacienda)
DSGE: Dynamic Stochastic General Equilibrium.
ECB: European Central Bank.
EMBI: Emerging Markets Bond Index.
FAO: Food and Agriculture Organization.
FBCF: Capital gross formation, includes construction (CCOO) and machine and equipment (MyE)
FFR: Fed Funds Rate.
FOMC: Federal Open Market Comittee.
GDP: Gross Domestic Product.
GPM: Global Projection Model.
ICMO: Employement cost index (Índice de costo de mano de obra).
IMACEC: Monthly economic activity index (Índice Mensual de Actividad Económica).
IMCE: Monthly economic confidence index (Indicador mensual de confianza empresarial).

INE: National Statistics Institute (Instituto Nacional de Estadística).

IPE: Foreign Price index (Índice de Precios Externos).

IPEC: Consumer economic perception index (Índice de Percepción de la Economía de los Consumidores).

IPN: Bussiness perception report (Informe de Percepción de Negocios)

IPoM: Monetary Policy Report (Informe de Política Monetaria).

IVCM: Retail sales index (Índice de Ventas del Comercio al por Menor).

Libor: London Inter-bank Offered Rate.

MACRO: Macroeconomic consistency model (Modelo de consistencia macroeconómica).

MEPCO: Oil price stabilization mechanism (Mecanismo de estabilización del precio del petróleo).

MPR: Monetary Policy Rate.

MSEP: Semi Structural Forecast Model (Modelo Semi-Estructural de Proyecciones).

NER: Nominal Exchange Rate.

NMPR: Natural Monetary Policy Rate.

OECD: Organization for Economic Co-operation and Development.

OLG: Overlapping Generations Model.

PPI: Producer price index.

RER: Real Exchange Rate.

RNMPR: Real Natural Monetary Policy Rate.

RPM: Monetary policy meeting (Reunión de Política Monetaria).

RRNN: Natural Resources (Recursos Naturales).

SARIMA: Seasonal ARIMA.

TFP: Total Factor Productivity.

VAR: Vector Autoregression.

VIX: Chicago Board Options Exchange Market Volatility Index.

Xmas: Extended Model for analysis and simulations.

Beltran de Ramón A.

LEGAL REPRESENTATIVE

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