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Introducing Policy Analysis Croatian MAcroecoNometric Model (PACMAN)

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Abstract

This paper describes the latest version of the semi-structural macro model of Croatia – the PACMAN (Policy Analysis Croatian MAcroecoNometric) model. PACMAN is a medium-sized macroeconometric model with a high level of aggregation, which accounts for the relationships among key macroeconomic variables in a systematic manner. Although highly aggregated the model is sufficiently detailed to be able to describe the most important characteristics of the Croatian economy.

The model follows the approach of many central banks in the EU (e.g. Austria, France, Poland, Italy and ECB etc.). PACMAN is designed in a way as to be usable for: (i) forecasting, (ii) scenario and (iii) policy simulation exercises at the CNB. PACMAN is also used in the context of financial sector stress testing.

The model's core equations adhere to economic theory but are also modified so as to have a good empirical fit. Due to its theoretical consistency and numerous transmission channels, PACMAN can provide a narrative for sources and consequences of economic developments.

Keywords: semi-structural model, Croatia, simulations, forecasting

JEL: C32, C51, C53, E2, E3

Makroekonometrijski model za Hrvatsku (PACMAN)

Sažetak

Ovaj rad opisuje najnoviju verziju polustrukturnog makro modela Hrvatske – model PACMAN (Policy Analysis Croatian MAcroecoNometric). PACMAN je srednje veliki visoko agregirani makroekonometrijski model koji na sustavan način objašnjava veze između ključnih makroekonomskih varijabli. Iako visoko agregiran, model je dovoljno detaljan za opis ključnih karakteristika hrvatskog gospodarstva.

Struktura modela usklađena je s pristupom mnogih središnjih banaka u Europskoj uniji (npr. Austrija, Francuska, Poljska, Italija i ECB itd.). Pritom je model dizajniran na način da služi kao jedan od alata HNB-a pri: (i) prognoziranju, (ii) analizi različitih scenarija i (iii) simulacijama učinaka različitih ekonomskih politika. PACMAN se koristi i kod analize različitih scenarija pri provođenju testiranja otpornosti kreditnih institucija na stres (stres test).

Osnovne jednadžbe modela utemeljene su na ekonomskoj teoriji, ali su modificirane kako bi bolje odgovarale stvarnim podacima. Zbog svoje teoretske dosljednosti i brojnih transmisijskih kanala, PACMAN omogućuje narativno objašnjenje uzroka i posljedica brojnih gospodarskih kretanja.

Ključne riječi: polustrukturni makro model, Hrvatska, simulacije, prognoziranje

JEL: C32, C51, C53, E2, E3

Contents

Non-technical summary

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The model follows the approach of many central banks in the EU (e.g. Austria[1], France[2], Poland[3], Italy[4] and ECB[5] etc.). PACMAN is designed in a way as to be usable for: (i) forecasting, (ii) scenario and (iii) policy simulation exercises at the CNB. PACMAN is also used in the context of financial sector stress testing.

The model's core equations adhere to economic theory but are also modified so as to have a good empirical fit. Due to its theoretical consistency and numerous transmission channels, PACMAN can provide a narrative for economic developments observed. It provides details such as decomposition of the components of domestic demand, demand deflators and price (sub)components as well as relatively detailed supply, financial, trade and fiscal sectors. Generally, the model can be broadly divided into a supply, a demand and a financial block.

Although PACMAN is a medium-sized macroeconomic model it is too large for the simultaneous estimation of the entire model, so it is estimated equation-by-equation.

[1] See Fenz and Spitzer (2005).
[2] See Baghli et al. (2004).
[3] See Budnik et al. (2009).
[4] See Bulligan et al. (2017).
[5] See Angelini et al. (2019).

1 Introduction

This paper describes the latest version of the semi-structural macro model of Croatia - the PACMAN (Policy Analysis Croatian MAcroecoNometric) model. PACMAN is designed for the following purposes: (i) forecasting, (ii) scenario, and (iii) policy simulation exercises at the CNB. PACMAN is also used in the context of financial sector stress testing.

PACMAN is a medium-sized macroeconometric model with a high level of aggregation, which accounts for the relationships among key macroeconomic variables in a systematic manner. Although highly aggregated, the model is sufficiently detailed to be able to describe the most important relationships and stylized facts of the Croatian economy. The model is to a large extent data driven and less theoretically rigorous than other model types, such as for instance dynamic stochastic general equilibrium (DSGE) models. [6]

Although PACMAN is a medium-sized macroeconomic model, it is too large for the simultaneous estimation of the entire model, so it was estimated equation-by-equation. For most core variables, long- and short-run relationships are estimated using the so-called Engle and Granger two-step procedure for cointegration analysis. Parameter calibration is applied for a smaller number of structural parameters for which it was not possible to obtain suitable estimates. The main idea behind this approach is to maintain a flexible framework that is able to match Croatian data, but at the same time keep the model as theoretically consistent as possible. The structure of the model follows the approaches of many central banks in the EU (e.g. Fenz and Spitzer (2005) for Austria, Baghli et al. (2004) for France, Budnik et al. (2009) for Poland, Angelini et al. (2019) for the Euro area etc.) and globally (e.g. Minella and Souza-Sobrinho (2013) for Brasil, Daníelsson et al. (2009) for Iceland or Charry et al. (2014) for Rwanda or Burns et al. (2019) for the global economy).

The model can be broadly divided into a supply, a demand and a financial block. The **demand side** of the model reflects the open economy nature of the Croatian economy. Its structure includes the expenditure components of GDP: household consumption, investments (household, business and government), government consumption, exports and imports. The external impact is modelled through imports and exports equations and their deflators. Households can use their disposable income for consumption, real estate purchases or can deposit funds in bank accounts (or take out loans). The demand side also includes a set of fiscal variables and real-fiscal interactions. Most of these variables are modelled as standard fiscal accounting identities with a set of fiscal revenue and expenditure components. These fiscal variables are aggregated into the overall general government balance, which drives the existing stock of public debt. Fiscal variables (mainly in terms of implicit tax rates) have a distortionary impact on some real and nominal variables.

The core of the **supply side** of the model is the notion of potential output. It is

[6] See Section 2 for more details.

characterized by a constant-returns-to-scale Cobb-Douglas production function with diminishing marginal returns on the factor inputs, labour and capital. Labour demand is based on an Okun's law type relationship which accounts for the non-accelerating inflation rate of unemployment (NAIRU). This part of the model also includes modelling of prices and wages. The main components of the harmonized consumer price index are modelled separately thereby including most channels through which global commodity prices and foreign export and consumer prices transmit to domestic prices with an active exchange rate pass-through. Moreover, tax rate changes also affect the respective prices and wages.

The **financial block** consists of wealth, interest rates, household loans, non-performing loans (NPLs) and monetary policy. Household financial and housing wealth is derived using stock-flow accounting identities. The interest rates block includes a number of short and long-term interest rates. Domestic interest rates are modelled assuming uncovered interest parity which accounts for the risk premia and exchange rate depreciation with lagged domestic interest rates affecting current interest rates. Foreign nominal interest rates are exogenous and captured by euro area short- term interest rates. Finally, monetary policy is modelled through the nominal EUR/HRK exchange rate equation, as the CNB's monetary policy framework is based on the maintenance of the stability of the nominal exchange rate of the HRK against the EUR. The nominal exchange rate equation is given as a combination of AR(1) and moving exchange rate target level.

The model displays both nominal neutrality (the long-run real equilibrium is independent of the nominal price level) and inflation neutrality (the long-run real equilibrium is independent of the rate of inflation). However, the model also displays nominal and real inertia, thus allowing a short-run trade-off between the real economy and inflation.

Behavioural parameters are mostly estimated, while some are calibrated according to the relevant economic theory or by micro-econometric estimates. The model presented in this paper is estimated on the Croatian data over the 2000Q1 - 2019Q4 period, the equation-by-equation structure thus allowing estimation of individual equations using shorter samples in the case of missing data. The model is entirely backward-looking, which is a major simplification when compared to other macroeconomic model types.

The paper is structured as follows. Section 2 briefly describes the history of economic models and puts PACMAN in a historical context. Section 3 gives a brief overview of the main mechanisms of and the theory embedded in the model. Section 4 provides a detailed explanation of all important model equations. Sections 5 and 6 present the main properties of the model through impulse response analysis and a forecast simulation exercise. Section 7 concludes.

2 Putting PACMAN in a historical perspective

This section briefly puts PACMAN model in a historical context as described by Pagan (2019).

Macroeconometric models constantly evolve. Pagan (2019) describes this evolution as the "survival of the fittest". Four generations of models coexisted during the last 80+ years. Developments and changes were usually triggered by dissatisfactory performance of older generation models (resulting from some philosophical disagreement or external event).

According to Pagan (2019) the first generation (1G) of models began with Tinbergen (1936). Although this model made the greatest contribution to the modelling of "complete (macroeconomic) systems", his later work, which involved assessment of business cycle theories using the US model in Tinbergen (1939) received much more attention. Tinbergen (as cited in Pagan (2019)) described the methodological approach behind early 1G models as follows: "I think the best way of introducing a model is to start out by taking just one variable, say the price level, and ask yourself how it is to be explained. You write down an equation which indicates what factors determine the fluctuations in prices. Then of course some of these factors... have to be explained... And so you add an equation... That could be a clarification of how the idea of a model comes in almost by necessity." The structure of 1G macro models follows the structure of the national accounts. The famous Klein models are one of the most important representatives of this generation of models.[7] Although Klein was motivated by IS-LM constructs, the models became very large and complex Pagan (2019).

Second generation (2G) models were mostly used during 1970s and 1980s. One of the most prominent representatives of 2G macro models is the FRB-US model described in Brayton and Tinsley (1996). 2G models retained much of their structure from the previous generation, but more attention was devoted to the supply side. According to Pagan (2019), equations were frequently derived from economic theory, and "target" or long-run equilibrium values were introduced through the use of error correction mechanisms. The Phillips curve, usually based on deviations of unemployment from the natural rate of unemployment or the NAIRU (which was not a constant), became a standard feature of those models. Dynamics were introduced on an equation-by-equation basis, and the formulation of expectations gained much more attention. 2G models had diverse structures, but most were large and characterized by rich dynamics. Thus "the dynamic stability of the complete system became a pressing issue" (Pagan, 2019).

The third (3G) and fourth generation (4G) models have been developed and used from the 1990s onward. Third generation (3G) models had three main features: (1) they were centred around the "gaps" between the variables and their long-run equilibrium values, (2) they were calibrated, not estimated, and (3) shocks became the focus of attention, i.e. one of the key desirable properties of the model was its ability to mimic the response

[7] See Klein (1950).

to certain shocks. The motivation for this generation of models was mostly led by the notion that previous generations of models had given too little attention to underlying economics and had had a tendency to overfit the estimated equations (Pagan, 2019). One of the first exponents of this generation of models is the Canadian QPM model introduced in Poloz et al. (1994). It should be emphasized that the attention to underlying economic theory reduced their short-term forecasting performance. Therefore, the general rule is that expert judgment should heavily influence the first few quarters of the projection (Ravnik and Bokan, 2018).

The interest of central banks in fourth generation (4G) models rose in the 2000s. This class of model is a counterpart to the popular dynamic stochastic general equilibrium (DSGE) models in academic papers. Like 3G, 4G models have an underlying steady-state representation but are derived from economic theory. 4G models therefore had similar practical issues as 3G models; both 3G and 4G models were attractive storytelling devices used for analysing likely policy responses as well as the sources of business cycles, but the micro-theory used (especially) in 4G models led to results that were not always in line with stylized facts, and did not predict well at short horizons (Pagan, 2019).

Compared to 3G and 4G models, 2G models were better at both matching institutional knowledge and forecasting performance in the short run. However, due to their complexity and size, it was hard to explain the economic mechanism underneath the results. Long-run projections and dynamic stability were also an issue. It is therefore necessary to make sure that such a model converges to a reasonable long-term path. Additionally, identification of shocks in this class of models is often problematic. Regardless of these issues, some recently developed models indicate a tendency to retreat to earlier generations of models. However, there is still no obvious fifth generation of models. New hybrid models combine 2G models with the insights gained from 3G and 4G models. According to Pagan (2019) currently in use there are two types of hybrid models: (1) Type I models in which the long term paths are not articulated, leaving error correction mechanisms and policy rules to ensure convergence to some path, and (2) Type II models which fully articulate the long-run paths. The LENS model for Canada Gervais and Gosselin (2014) and the ECB-BASE model Angelini et al. (2019) for the euro area are examples of hybrid modelling approach.

The CNB followed the described developments in modelling. The model presented in this paper coexists and complements the existing set of macroeconomic models: the DSGE model developed by Bokan et al. (2009) and the Quarterly Projection Model (QPM) in Ravnik and Bokan (2018). PACMAN is the second model used for forecasting in addition to the QPM. It has, however, several differences. First, PACMAN is a semi-structural error-correction type macroeconometric model while the QPM can be categorized as a 3G new Keynesian gap type model. Second, PACMAN is estimated while QPM is calibrated. Third, PACMAN can be categorized as a hybrid model. In comparison to QPM, PACMAN is more driven by the empirical properties of the data. It has more variables and equations and a more detailed structure then QPM, so it can produce forecasts for a broader set of macroeconomic variables. Due to its size and type

PACMAN can be used for sophisticated scenario and policy analysis and stress tests while the main use of the QPM is mid-run forecasting.

3 Model overview

The PACMAN (Policy Analysis Croatian MAcroecoNometric) model is a medium-sized macroeconomic model written as a system of simultaneous equations (34 core behavioural equations and 76 identities). PACMAN includes 135 variables, of which 34 are core endogenous variables, 76 are identities and 25 are exogenous variables.

The main idea behind the modelling approach used to develop PACMAN was to maintain a flexible framework that is able to match stylized facts about Croatian data, but at the same time keep the model as theoretically consistent as possible. A distinctive feature of the Croatian economy is high euroisation and although decreasing, this remains a major vulnerability of the Croatian economy. Therefore, in the absence of a fully-fledged financial sector (banks' balance sheets are not explicitly modelled), the model required some adjustments to domestic sectors and monetary policy equations to account for high euroisation and the use of the nominal EUR/HRK exchange rate as monetary policy anchor. These adjustments enable PACMAN to capture different channels of exchange rate effects on the domestic economy. However, due to the relevance of euroisation-related issues for the Croatian economy and the CNB's policy, we deal with these adjustments in a separate paper (see Nadoveza Jelić and Ravnik (forthcoming)).

The model can be broadly divided into supply, demand and financial blocks.

The **demand side** of the model reflects the open nature of the Croatian economy, but also includes important domestic interactions. Its full detail comes from aggregating the separate expenditure components of GDP.

Households inter-temporally decide on their consumption expenditure and residential housing investment, while they can also decide on taking loans or depositing their money in a savings account in order to smooth out consumption. They can supply labour for which they request a gross wage out of which income taxes are paid. In addition to labour income, households receive additional income from enterprises they own. Households use both income categories for their consumption purchases. Total household wealth consists of net financial wealth (savings minus outstanding loans) and housing wealth. In the long run, private consumption is determined by total real disposable income (which consists of labour income and gross operating surplus), real household wealth and the real long-term interest rate. Interest rates capture inter-temporal substitution effects and interest rate effects on household debt burden. Households' residential housing investment in the long run is determined by total output and house prices relative to the cost of housing investment. In the short run, housing investments and private consumption are allowed to deviate from the long-run equilibrium.

Firms In the long run business investments are determined by the real cost of capital and output growth. To account for high euroisation of Croatian economy, and in the absence of a fully-fledged financial sector in the model, long-run business investments are also directly affected by the EUR/HRK exchange rate. Short-run fluctuations in business investments display adjusting behaviour, with lagged business investments and real unit labour costs growth affecting investment growth.

Government Real government consumption is assumed to be exogenous. This implies that nominal government consumption is driven by real government consumption and the endogenous movements of the implicit government consumption price deflator. The model provides detailed accounting of the main fiscal variables. Government revenues are modelled through implicit tax rates, which have distortionary effects on the respective real or nominal variables. Government expenditures are determined by government consumption, investments, subsidies, transfers and other expenditures plus endogenously determined government interest payments. Government interest payments depend on the risk premium and the debt level. The difference between total expenditure and revenue is defined as the government deficit, which accumulates to total government debt.

Total *fixed investment* is given as the sum of investment from all three sectors, i.e. business investment, households' housing investment and exogenous government investments.

The *foreign sector* affects the domestic economy through its impact on domestic prices and real activity but also thorough nominal interest rates. The real sector impact is modelled through imports and exports and their deflators. Exports of goods and services depend on world demand and the relative prices of exports. Imports of goods and services depend on domestic absorption and the relative prices of imported and domestically produced goods. This part also models import and export deflators: (i) *Export price deflator* is given as a function of import price deflator and domestic GDP deflator as well as of effective exchange rate, (ii) *Import price deflator* is given as a function of international prices (world export, oil and food prices) as well as of the effective exchange rate. The model takes account of the fact that the CNB uses the nominal EUR/HRK exchange rate as its anchor. Therefore, domestic interest rates are modelled assuming uncovered interest parity (UIP), which accounts for the risk premium[8] and exchange rate depreciation, with lagged domestic interest rates affecting current interest rates. Foreign nominal interest rates are exogenous and are captured by EU short-term interest rates.

The **supply side** of the model is characterized by a constant-returns-to-scale Cobb-Douglas production function with diminishing marginal returns on the factor inputs, labour and capital. Hicks-neutral technological progress is assumed which, together with trend components of the factor inputs, shapes the potential output.

Capital formation. The constant factor shares implied by the Cobb-Douglas production function impose long-run restrictions on capital formation. These long-run restrictions

[8] Croatia's risk premium also includes spillover effects from other EU countries which are exogenous in the model.

are modelled using the error correction term in short-run equations for business and household investments.

Labour market. The labour market is concentrated around Okun's type unemployment rate based relation, which accounts for both output growth and structural unemployment rate. Demand for labour is affected by the relative price of labour (wages) and output. Total labour resources are determined by an exogenously given working age population and participation rate. Wages are set according to the current inflation rate, labour productivity and labour market tightness (deviation of unemployment rate from NAIRU). Wage stickiness is assumed in the short run, which allows us to better capture Croatian data.

This part of the model also includes the modelling of prices. A breakdown of the harmonized index of consumer prices (HICP) into the following three main components is made: food prices, energy prices and core consumer prices as the residual. Core consumer price inflation is explained by an expectations-augmented Phillips curve. The equation assumes that actual inflation depends on an expected inflation given by lagged inflation, the output gap and the unit labour cost. Changes in indirect tax rates also affect core inflation developments. Additionally, the model accounts for the fact that inflation expectations in Croatia depend on the expected EUR/HRK exchange rate. Import prices affect core inflation through traditional transmission channels. The other two consumer price components are modelled so that foreign export prices, global commodity prices, USD/HRK and EUR/HRK exchange rates, as well as indirect tax rates can affect the respective consumer price component.

Demand deflators are modelled as follows: (i) *Private consumption deflator* is assumed to evolve in line with consumer prices, (ii) *Business investments goods deflator* is given as a function of its lagged value, building costs and import prices in domestic currency, (iii) *Housing investments deflator* is assumed to fluctuate in line with general building costs and wages, (iv) *Government consumption deflator* is assumed to grow at the same rate as the housing investments deflator, (v) *Government consumption deflator* is assumed to evolve in line with unit labour costs and consumer prices. *Building costs* costs are also modelled in this part of the model and are determined by their past realizations and consumer prices.

The **financial block** models wealth, interest rates and monetary policy.

Wealth is derived using stock-flow accounting equations. As already explained, household wealth is composed of non-financial (housing) and net financial wealth. In the long run real residential house prices are determined by the housing stock, real disposable income, real interest rate and depreciation rate. Short-run fluctuations in real residential house prices are affected by lagged real residential house prices growth, output growth and the EUR/HRK exchange rate as well as by deviations from its long-run equilibrium level. The *interest rates* block includes a chain of interest rate transmissions. In a first step, the foreign (euro area) short term interest rate affects Croatia's short term interbank interest rate through an uncovered interest parity (UIP) condition with some additional interest rate smoothing. In a second step, the short-term money market rate affects household and firm lending rates. Furthermore, the *monetary policy rule* is determined by the nominal exchange rate equation which is given as a combination of AR(1) and a moving exchange rate target level instead of a usual interest rate reaction function.

The long-run path for the real economy is independent of nominal variables. Hence, the model displays both nominal neutrality (the long-run real equilibrium is independent of the nominal price level) and inflation neutrality (the long-run real equilibrium is independent of the rate of inflation). Finally, the model displays nominal and real inertia, thus allowing a short-run trade-off between the real economy and inflation.

4 Structure of the model

PACMAN is written in the form of a system of simultaneous equations consisting of 34 core (mostly estimated) equations and 76 identities. This section presents the structure of the model and its core equations and most important identities. All the equations and model variables, their definitions and sources are listed in appendices A and D.

Notation follows notation conventions, with uppercase letters denoting variables in levels and lowercase letters denoting log values. Δ denotes differentiated variables. Estimated coefficients are denoted by the letter c with an appropriate index. A few parameters are denoted by Greek letters.

4.1 The demand block

4.1.1 Household consumption and investment

In the **long run** consumer demand is determined by income in time t, i.e. real post-tax household income (rdy_t)[9], accumulated real wealth $(wel_t$[10] $- cpi_t)$ and households' real long-run lending rates $(RLHV_t)$ as shown in the following generalized consumption function (long-run equation in Table 1):

$$c_t = c_0^C + c_1^C rdy_t + (1 - c_1^C)(wel_t - cpi_t) + c_2^C RLHV_t \tag{1}$$

Wealth represents total household wealth which includes both housing stock and net financial wealth, which are in most cases positive since the household sector is a net saver. This means that households can spend part of their accumulated wealth stock in addition to current income for consumption expenditure. If households' wealth is negative, they have to borrow money to finance current consumption expenditure. This enables households to smooth consumption through time. The parameter c_1^C can be

[9]See appendix A for a detailed derivation of real post-tax household income.

[10]See Section 4 for a detailed derivation of wealth.

interpreted as the marginal propensity to consume, which we calibrate at 0.88. The calibration of this parameter is based on survey data, while all other parameters are estimated. This means that on average (in the long run) 88 percent of households' current income is used for current consumption, while the rest of their income is saved and accumulated as shown in Section 4. As in any IS-type equation, the real interest rate negatively affects consumption in time t which means that households postpone their spending and save a larger share of their current income when interest rates are relatively higher and *vice versa*.

In the **short run** consumption can deviate from its long-run equilibrium as depicted by the following short-run consumption equation (see Table 2):

$$\begin{aligned}\Delta c_t = c_0^{SC} + c_1^{SC}\Delta rdy_t + c_2^{SC}\Delta(nfw_t - cpi_t) + c_3^{SC}\Delta RLHV_t \\ + c_4^{SC}\Delta(c_{t-1}) + c_5^{SC}(c_{t-1} - (c_0^C + c_1^C rdy_{t-1} + (1 - c_1^C)(wel_{t-1} - cpi_{t-1}) \\ + c_2^C RLHV_{t-1})) + c_6^{SC} D_{2008q1}\end{aligned} \tag{2}$$

Household housing investments (housing supply)

In the **long run** private sector housing investments to GDP ratio is determined by a ratio between house prices and housing investment prices (see Table 3):

$$(i_t^H - gdp_t) = c_0^{IH} + c_1^{IH}(ph_t - pih_t) \tag{3}$$

The price ratio $(ph_t - pih_t)$ on the right-hand side represents the market price of existing house purchases relative to the cost of investing into a new house. This equation resembles a housing supply equation and we therefore expect c_1^{IH} to have a positive sign, meaning that households decide to investment more if the market price is relatively higher, or the investment into new houses is relatively cheaper. It needs to be emphasized that housing investment is expressed relative to GDP, which guarantees that in the very long run (steady state), the housing investment growth rate will converge with the GDP steady state growth rate if the investment deflator inflation converges with real estate price inflation.

In the **short run** housing investments can deviate from their long-run equilibrium. However, error correction mechanism ensures that housing investment returns to its balanced growth path (see Table 4):

$$\begin{aligned}\Delta i_t^H = c_0^{SIH} + c_1^{SIH}\Delta(ih_{t-1} - gdp_{t-1}) + c_2^{SIH} GDP_{gap_t} + c_3^{SIH}\Delta RLHV_t \\ + c_4^{SIH}((ih_{t-1} - gdp_t) - (c_0^{IH} + c_1^{IH}(ph_{t-1} - pih_{t-1}))) \\ + c_5^{SIH} D_{2008q1}\end{aligned} \tag{4}$$

4.1.2 Business sector (firms) investments

In the **long run** business sector investments are determined by the GDP trend and gap, real cost of capital and EUR/HRK exchange rate. Long-run business investment equation is in line with the neoclassical theory of investments, which assumes that investments depend on two factors: (1) the user cost of capital and (2) the stream of revenue that firms expect to earn on a marginal addition to capital.

Real user cost of capital is calculated as:

$$RCC_t = \frac{RLPV_t/4 + \delta}{1 - (TRCI_t + TRCS_t)}, \tag{5}$$

where $RLPV_t$ denotes firms real long-run interest rate, δ is depreciation rate of productive (business) capital while $TRCI_t$ and $TRCS_t$ denote taxes paid by the firms (see appendix A). This equation therefore includes all non-labour costs the firm has to pay.

If in the long run capital to GDP ratio is constant then the expected return is proportional to GDP. Therefore, in the long run business investments are determined by GDP and real cost of capital (see Table 5). To account for the high euroisation of Croatian economy, and in the absence of a fully-fledged financial sector in the model, long-run business investments are also affected by the EUR/HRK exchange rate. Since firms are net borrowers (on aggregate) in both the domestic and foreign currency (primarily euro), their exposure to exchange rate variation remains a major vulnerability of the Croatian economy. If the Croatian kuna depreciates with respect to the euro, the existing stock of euro-denominated debt will increase, leading to a worsening of the financial state of the firms and therefore leaving less space for investment growth. This effect is usually called the balance sheet effect of exchange rate changes. More details about the role of the exchange rate in this model and the estimation/calibration of the related parameters is provided in Nadoveza Jelić and Ravnik (forthcoming).

$$i_t^B = c_0^{IB} + c_1^{IB} gdpt_t + c_2^{IB} GDP_{gap_t} + c_3^{IB} RCC_t + c_4^{IB} eur/hrk_t \tag{6}$$

In the **short run** business investments can deviate from the long-run equilibrium. Short-run fluctuations in business investments display adjusting behaviour, with lagged business investments and real unit labour costs growth affecting investment growth (see Table 6).

$$\begin{aligned}\Delta i_t^B &= c_0^{SIB} + c_1^{SIB} \Delta rulc_t + c_2^{SIB} \Delta i_{t-1}^B + c_3^{SIB} D2008q1 + c_4^{SIB} D2010q1 \\ &+ c_5^{SIB} (i_{t-1}^B - (c_0^{IB} + c_1^{IB} gdpt_{t-1} + c_2^{IB} GDPgap_{t-1} + c_3^{IB} RCC_{t-1} \\ &+ c_4^{IB} eur/hrk_{t-1}))\end{aligned} \tag{7}$$

4.1.3 Government

The modelling of the government sector implies modelling of government expenditures (mostly exogenous) and revenues as reported in the state budget as well as government spending which is part of domestic demand in the national accounts statistics. Government expenditures consist of nominal government consumption (GN_t) and investments (IN_t^G), transfers to households (HG_t) and subsidies ($SUBS_t$) as well as of other expenditures (OEX_t) and interest payments (DI_t). In most part government expenditures are either exogenously given using experts' forecasts (G_t and I_t), or projected using simple satellite models ($SUBS_t$ and OEX_t).[11]

Government expenditures

$$G_t^{ex} = GN_t + IN_t^G + HG_t + DI_t + SUBS_t + OEX_t \tag{8}$$

Government debt is described as a standard law of motion where in each period the deficit (G_t^{def}) is added to the debt level from the previous quarter. However, the law of motion is controlling for the ratio of euro-denominated debt in total outstanding public debt (currently around 60 percent) and therefore the EUR/HRK exchange rate is included into this equation. For simplicity we ignore the impact of the debt denominated in USD.

Public debt

$$DEBT_t = (1 + 0.6\Delta eur\_hrk)DEBT_{t-1} + G_t^{def} \tag{9}$$

Government interest payments

The only component of government expenditures that is explicitly modelled is government interest payments (see Table 7), which are determined by the government debt, risk premium (proxied with 5Y CDS spreads) and its past value. Government debt is included in this equation since the total amount of interest expenses will depend on the existing stock of debt, while the risk premium directly affects the borrowing costs i.e. the interest rate that the government pays on its debt.

$$di_t = c_0^{di} + c_1^{di} DEBT_t + c_2^{di} CDS5Y_{t-1} + c_3^{di} di_{t-1} \tag{10}$$

Government tax revenues

The revenue side is modelled through implicit tax rates, which are exogenous in the model. The implicit tax rates are projected over the forecasting horizon through satellite

[11] Trajectory of nominal values is endogenously determined by the explicitly modelled deflators (see equations 114 and 113).

models or using expert judgment inputs. These implicit tax rates enter various equations in all sectors, therefore affecting real and nominal variables throughout the model. For instance, income tax affects disposable income of households and consequently private consumption, while value added tax (VAT) enters consumer prices and thus also affects private consumption. Government revenues consist of total taxes paid by households (TJ_t), total corporate taxes (TC_t), taxes on goods and services (TP_t), and of other tax revenues (OT_t).[12]

$$G_t^{tax} = TJ_t + TC_t + TP_t + OT_t \tag{11}$$

Each of the revenue categories from this equation is defined by multiplying the implicit tax rate by its respective tax base as depicted by the fiscal equations listed in appendix A.

Finally, the overall government balance is computed by subtracting total revenues G_t^{tax} from total expenditures G_t^{ex}.

4.1.4 International trade

The primary channel through which the foreign sector affects the domestic economy is international trade, i.e. through its impact on domestic prices and real activity. The foreign sector impact is modelled through imports and exports and their deflators.

Modelling trade is started by setting the empirical counterpart to the standard trade model export equation. We take the traditional approach to trade modelling in empirical macro literature by assuming imperfect substitutability of domestic and foreign goods within a two-region (home and rest of the world) formulation. Under this formulation domestic exports to the rest of the world are determined by foreign demand for domestic goods and can be also interpreted as the rest-of-the-world import demand for domestic goods. In theory, foreign demand for domestic goods is determined by the same variables as demand for any good. Therefore, domestic exports are the function of the rest of the world's real income (proxied by the weighted average of GDP of Croatia's main trade partners) and relative export prices. The higher the foreign income the higher will be the demand for domestic export. On contrary, the higher domestic prices are relative to foreign export prices, the lower the international competitiveness of the domestic economy is. Lower international competitiveness reduces the demand for domestic goods and leads to a decrease of exports. Note that nominal exchange rate fluctuations do not enter the export equation directly but are implicitly included in domestic export prices, which are denominated in domestic currency. Also note that under the assumption that domestic producers do not change export prices in domestic currency too much after a depreciation, the international competitiveness of domestic economy will increase. This should be reflected in the fall of relative export prices.

[12] See appendix A for detailed representation of different government tax revenues.

Mirroring the export modelling approach, import depends on domestic absorption (proxied by domestic demand and exports) and relative prices of imported to domestic goods and services prices. The higher domestic absorption is the higher imports will be. On contrary, the higher import prices are compared to the prices of domestically produced goods the lower imports will be. Again, import prices are denominated in the domestic currency. Therefore, the impact of exchange rate changes is implied in import prices which should increase in the event of currency depreciation.

Exports

In the empirical setup, the **long-run** exports are therefore determined by foreign GDP and relative export prices. Note that due to the high share of tourism and the importance of the export of services in the Croatian economy, export equations are estimated separately for goods and for services (see Tables 8 and 10).

Long-run goods exports

$$exg_t = c_0^{EXG} + c_1^{EXG} wgdp_t + c_2^{EXG}(px_t - wpx_t) \tag{12}$$

Long-run services exports

$$exs_t = c_0^{EXS} + c_1^{EXS} wgdp_t + c_2^{EXS}(px_t - wpx_t) \tag{13}$$

The first variable on the right hand side is the demand effect and we therefore expect c_1^{EXG} and c_1^{EXS} to be positive. Due to a relatively volatile export series this parameter is usually higher than 1. The second term stands for a price effect and it is clear that for a negative value of c_2^{EXG} and c_2^{EXS}, relatively higher prices of exported Croatian goods and services (px_t) or relatively lower competitors prices (wpx_t) will lead to a decrease in exports of goods and services and *vice versa*.

In the **short run**, exports of goods and services can deviate from their long-run equilibrium values (see Tables 9 and 11). The short-run dynamics of exports of goods and services is driven by the error correction mechanism, world GDP growth and by changes in relative export prices.

Short-run goods exports

$$\begin{aligned}\Delta exg_t = {} & c_1^{EXGS}\Delta wgdp_t + c_2^{EXGS}\Delta(exg_{t-1} - imp_{t-1}) + c_3^{EXGS}D_{EU} + c_4^{EXGS}D_{2010q1} \\ & + c_5^{EXGS}(exg_{t-1} - (c_0^{EXG} + c_1^{EXG} wgdp_{t-1} + c_2^{EXG}(px_{t-1} - wpx_{t-1})))\end{aligned} \tag{14}$$

Short-run services exports

$$\begin{aligned}\Delta exs_t = {} & c_1^{EXSS}\Delta wgdp_t + c_2^{EXSS}\Delta(exs_{t-1} - imp_{t-1}) + c_3^{EXSS}D_{EU} + c_4^{EXSS}D_{2010q1} \\ & + c_5^{EXSS}(exs_{t-1} - (c_0^{EXS} + c_1^{EXS} wgdp_{t-1} + c_2^{EXS}(px_{t-1} - wpx_{t-1})))\end{aligned} \tag{15}$$

Total exports are given by the sum of their two components (exports of goods and exports of services):

$$EX_t = EXG_t + EXS_t \tag{16}$$

Relative export prices are determined by the export price deflator, which is modelled as a function of imports and the GDP deflator as well as of the effective exchange rate (see Table 12). Therefore, export prices are determined by both domestic and import prices, since domestic products usually consist of domestic and imported components. The expected effective exchange rate effect on export prices is explained in the introductory part of this subsection. As argued above, exchange rate increase (depreciation) leads to lower export prices and therefore increases the competitiveness of domestic products and exports.

Export price deflator

$$\Delta px_t = c_1^{px}\Delta pm_t + c_2^{px}\Delta pgdp_t + c_3^{px}\Delta eer_{t-1} + c_4^{px} D_{2011q1} \tag{17}$$

For simplicity, the *effective exchange rate* is modelled as the weighted sum of the EUR/HRK and USD/HRK exchange rate, abstracting from all other currencies that enter the effective exchange rate definition (see Table 13):

$$\Delta eer_t = w_{eur}\Delta eur\_hrk_t + w_{us}\Delta us_t \tag{18}$$

Imports

As argued in the introductory part of this subsection, in the **long run** imports are determined by domestic absorption and relative (imported versus domestic goods) prices. The modelling strategy also takes into account the significant import content of Croatian exports. Therefore, in the long run imports are estimated using the following equation (see Table 14):

$$im_t = c_0^{IM} D_{recession} + c_1^{IM}(dd_t + ex_t) + c_2^{IM}(pm_t - pgdp_t) \tag{19}$$

In the **short run** imports can deviate from their long-run equilibrium value (see Table 15). The short-run fluctuations of imports are determined by the deviation of imports from their long-run path, domestic demand and export growth as well as by changes in the relative prices of imported vs domestically produced goods and services.

$$\Delta im_t = c_0^{IMS} + c_1^{IMS}\Delta dd_t + c_2^{IMS}\Delta ex_t + c_3^{IMS}\Delta(pm_t - pgdp_t) + c_4^{IMS}D_{EU} \\ + c_5^{IMS}(im_{t-1} - (c_0^{IM} + c_1^{IM}(dd_{t-1} + ex_{t-1}) + c_2^{IM}(pm_{t-1} - pgdp_{t-1}))) \quad (20)$$

Import price deflator

Import price deflator is modelled as a function of world export prices, world oil and food prices in domestic currency as well as of the effective exchange rate (see Table 16). Again, the expected effective exchange rate effect on import prices has been explained in the introductory part of this subsection. An exchange rate increase (depreciation) leads to higher import prices and therefore decreases demand for imported goods and services since domestic goods become relatively cheaper. However, in the short run, currency depreciation increases the price of imported goods. The effects of currency depreciation on net exports implied by estimated equations in PACMAN are studied in detail in Nadoveza Jelić and Ravnik (forthcoming). At this point it is sufficient to say that according to their simulations, the Marshall-Lerner condition holds in Croatia. More precisely, in the mid-run, currency depreciation leads to mild trade balance improvements, which are in line with the J-curve dynamics.

It should be noted that parameters related to these three variables are normalized to one. The effect of tariff changes on import prices upon EU accession is also taken into account.

$$\Delta pm_t = c_1^{pm}(\frac{\Delta wpx_t + \Delta wpx_{t-1}}{2}) + c_2^{pm}(\frac{\Delta poil\_kn_t + \Delta poil\_kn_{t-1}}{2}) \\ + (1 - c_1^{pm} - c_2^{pm})(\frac{\Delta p_t^{w_{food}} + \Delta p_{t-1}^{w_{food}}}{2}) + c_3^{pm} eer_t \\ + c_4^{pm}\Delta trcar_t D_{EU} \quad (21)$$

4.1.5 Inventories

Real inventories are modelled as a function of net exports and their own lagged value (see Table 17). On the other hand, real inventories are assumed to be the only determinant of nominal inventories (see Table 18). However, as explained in Section 6, during the forecasting exercises, inventories are excluded from endogenous variables since it is hard to give a reasonable forecast for this GDP component.

$$ii_t = c_0^{II} + c_1^{II}(ex_t - im_t) + c_2^{II} ii_{t-1} \quad (22)$$

$$iin_t = c_0^{IIN} + c_1^{IIN} ii_t \tag{23}$$

4.2 The supply block

The supply side of the economy is centred around a standard Cobb-Douglas production function with diminishing marginal returns on the factor inputs, labour and capital. Use of the production function-based method implicitly defines potential GDP as the level of output that can be sustained over a long period without excessive (overutilization) or insufficient use (underutilization) of existing capacity. Labour and capital shares are assumed to be constant and are calibrated to 0.65 and 0.35 respectively.[13] Hicks-neutral technological progress is assumed.

4.2.1 Potential output

The Cobb-Douglas production function that is used to calculate potential output is given by:

$$GDPT_t = EMPT_t^{0.65} K_t^{0.35} TFP_t. \tag{24}$$

Equation 24 implies that trend employment ($EMPT_t$) defined by equation 81 and capital[14] (see equation 92) and total factor productivity (TFP_t) determine potential GDP.

It should be noted that in some cases we exclude potential GDP from endogenously determined variables and model potential output outside of PACMAN using the calculations provided by experts.[15]

During the regular business cycle GDP deviates from its potential level. The short-run deviations of output from its potential level generate a GDP gap, given by the following formula:

GDP gap

$$GDP_{gap_t} = \frac{GDP_t - GDPT_t}{GDPT_t}. \tag{25}$$

[13] Although empirical evidence points to downward trend of the labour share during recent years, the average labour share during the last 20 years is still very close to 0.65 according to Penn World Data.

[14] The level of capital is constructed using the perpetual inventory method (see Table 19), and it is assumed that capital is always fully utilized.

[15] Usually, when the CNB considers it important to ensure consistency in estimates of potential GDP and the gap in PACMAN with official potential GDP and gap estimates.

4.2.2 Labour market

The labour market is concentrated around Okun's (unemployment rate based) type relation which accounts for output growth but also for structural unemployment rate or the non-accelerating inflation rate of unemployment (see Table 20).[16] Demand for labour will decrease (unemployment increases) if the relative price of labour (real wages) increases. Therefore, in the **long run** *labour demand*, expressed in terms of the unemployment rate, is defined as:

Unemployment

$$ur_t = c_0^{LD} + (0.5nairu_t + 0.5nairu_{ss}) + c_1^{LD} gdp_t + c_2^{LD}(w_t - pgdp_t) \tag{26}$$

Where $nairu_{ss}$ is set at 10 percent based on historical data and more recent demographic developments. The first term ensures that the unemployment rate is in the steady state anchored by the NAIRU rate and accounts for slow adjustment of labour markets. However, in the **short run** unemployment rate can deviate from its long-run trend. Short-run fluctuations of unemployment rate display its adjusting behaviour with lagged unemployment and GDP growth as well as the deviations of the unemployment rate from its long-run trend affecting changes in unemployment rates (see Table 21).

$$\begin{aligned}
&\Delta ur_t = c_0^{SLD} + c_1^{SLD}\Delta^4 gdp + c_2^{SLD}\Delta ur_{t-1} \\
&+ c_3^{SLD}(ur_{t-1} - (c_0^{LD} + (0.5nairu_{t-1} + 0.5nairu_{ss}) + c_1^{LD} gdp_{t-1} \\
&+ c_2^{LD}(w_{t-1} - pgdp_{t-1})) + c_4^{SLD} D_{2007q3} + c_5^{SLD} D_{2007q4}
\end{aligned} \tag{27}$$

Employment

Labour demand, which is expressed in terms of the unemployment rate, is translated to the total number of employees through the following identity:

$$EMP_t = PA_t POWA_t (1 - UR_t), \tag{28}$$

where $POWA_t$ and PA_t denote potential labour force (or potential labour supply) and both are exogenously given.

[16]The structural unemployment rate is defined by the expression in parentheses, i.e. $nairu_t 0.5 + nairu_{ss} 0.5$.

4.2.3 Wages and prices

Wages

Wages in the **long run** evolve according to the adjusted wage-setting relationship. Total *labour supply* is therefore modelled through the following equation in which wages depend on inflation, labour market tightness or the unemployment gap (difference between trend unemployment rate and structural unemployment rate) and on labour productivity (see Table 22):

$$w_t = c_0^{LS} + c_1^{LS} cpi_t + c_2^{LS} \frac{(ur_t + ur_{t-1} + ur_{t-2} + ur_{t-3})}{4} - (0.5nairu_t + 0.5nairu_{ss}) + c_3^{LS} prod_t \quad (29)$$

This wage-setting equation implies that a relatively higher unemployment rate reduces the negotiating power of workers and consequently their wage. CPI is included in equation 29 to control for the transmission (or indexation) of nominal wages to consumer price inflation. According to the standard economic theory more productive workers will receive a higher wage, i.e. the productivity of a worker is directly linked to the compensation received for their work. This is captured by the last term of the equation 29.

In the **short run** wages are allowed to fluctuate around their long-run trend. These short-run fluctuations are determined by lagged wage and current GDP growth, CPI inflation as well as by the adjusting parameter which corrects for deviations of wages from their long-run equilibrium level (see Table 23). Therefore, wage stickiness is taken into account, which is in line with the observed data.

$$\Delta w_t = c_0^{SLS} + c_1^{SLS} \Delta w_{t-1} + c_2^{SLS} \Delta gdp_t + c_3^{SLS} \Delta cpi_t + c_4^{SLS}(w_{t-1} - (c_0^{LS} + c_1^{LS} cpi_{t-1} + c_2^{LS} \frac{(ur_{t-1} + ur_{t-2} + ur_{t-3} + ur_{t-4})}{4} - (0.5nairu_{t-1} + 0.5nairu_{ss}) + c_3^{LS} prod_{t-1}) \quad (30)$$

Prices

A breakdown of the harmonized index of consumer prices (HICP) to the following three main components is made: food prices, energy prices and core consumer prices as a residual component (prices excluding food and energy). Three components are modelled separately and aggregated afterwards.

Core consumer price inflation is given by a standard expectations-augmented *Phillips curve*. The equation assumes that actual inflation depends on expected inflation which is given by lagged inflation in the absence of forward-looking agents in the model, the output gap and the unit labour cost. The equation is therefore in line with a standard new-Keynesian Phillips curve in which costs, demand and inflation expectations affect current inflation (see Table 24). All foreign prices are transmitted to domestic ones through the remaining two components: food and energy prices. Changes in indirect tax rates (VAT and excise duties) can also affect core inflation developments with parameters calibrated according to simulations based on observed episodes of tax changes.[17]

$$\begin{aligned}\Delta cpi_t^{core} = &\ c_0^{core} + c_1^{core} GDPgap_t + c_2^{core} \Delta ulc_t + c_3^{core} \Delta cpi_{t-1}^{core} \\ &+ c_4^{core} \Delta trt_t + c_5^{core} \Delta trpdv_t \\ &+ c_6^{core} D_{2015q4}. \end{aligned} \tag{31}$$

CPI food inflation is determined by world food prices and the import price deflator. It is also affected by the changes of VAT and excise duties rates (see Table 25). World food prices are converted into HRK by multiplying them with the effective exchange rate.

$$\begin{aligned}\Delta cpi_t^{pe} = &\ c_0^{pe} + c_1^{pe} \Delta (p_t^{w_{food}} + eer_t) + c_2^{pe} \Delta pm_{t-1} \\ &+ c_3^{pe} \Delta trt_t + c_4^{pe} \Delta trpdv_t + c_5^{pe} D_{2005q1} \end{aligned} \tag{32}$$

CPI energy inflation is primary determined by the world oil prices denominated in domestic currency. However, the changes of VAT and excise duty rates (see Table 26) also affect CPI energy inflation. Furthermore, a simple long-run equation is assumed as followed: in the long run domestic energy consumer price inflation changes 1-to-1 with global oil prices denominated in HRK. This long-run equation is included into the short-run equation where c_2^{en} presents an error-correction adjustment parameter. By including this parameter, domestic energy price inflation is anchored in the long run to the global energy price inflation. In other words, after the effects of short-run autoregressive dynamics and tax changes have faded, domestic energy prices will depend only on global energy prices and the nominal HRK/USD exchange rate.

[17]The model also accounts for the fact that inflation expectations in Croatia depend on the expected EUR/HRK exchange rate. In the normal regime (with anchored expectations), in which exchange rate volatility is low, import prices affect core inflation through the traditional transmission channels i.e. through global commodity prices and trade partners' export prices. However, in the case of larger deviations of exchange rate from its long-run equilibrium, import prices are presumed to affect core inflation also more directly, i.e. through the Phillips curve itself. More details about this non-linear effect that exchange rate changes have on prices and real activity are provided in Nadoveza Jelić and Ravnik (forthcoming).

$$\Delta cpi_t^{en} = c_0^{en} + c_1^{en}\Delta poil\_kn_t + c_2^{en}(cpi_{t-1}^{en} - 1poil\_kn_{t-1}) + c_3^{en}\Delta trt_t + c_4^{en}\Delta trpdv_t + c_5^{en} D_{2012q2_t} \tag{33}$$

In equation 33 $POIL\_KN_t$ is defined as the product of the world oil prices and the nominal HRK/USD exchange rate. This means that the HRK/USD exchange rate also affects domestic inflation as explained above:

$$POIL\_KN_t = POIL_t US_t \tag{34}$$

Overall CPI inflation, measured by the HICP, is calculated as the weighted average of its main components. The respective components' weights are held at their last observed levels throughout the entire forecast horizon:

$$\Delta^4 cpi_t = \Delta^4 cpi_t^{core} W_{cpi^{core}} + \Delta^4 cpi_t^{pe} W_{cpi^{pe}} + \Delta^4 cpi_t^{en} W_{cpi^{en}} \tag{35}$$

4.3 The financial block

4.3.1 Monetary policy and exchange rate

Exchange rate target

The CNB uses the EUR/HRK nominal exchange rate as an anchor for inflation due to the prevailing euroisation. Since the CNB was not committed to any predefined exchange rate level prior to recent ERM II accession, the moving exchange rate target reflects CNB's willingness to conduct foreign exchange market interventions when exchange rate fluctuation is excessive. A detailed description of the CNB monetary policy reaction function through the lenses of a macro model is given in Ravnik and Bokan (2018), while PACMAN simplifies monetary policy due to the absence of forward-looking agents. Monetary policy is therefore modelled through a simple backward-looking monetary policy target and an augmented autoregressive equation that describes a simplified monetary policy exchange rate rule. The monetary authority keeps the exchange rate close to its target throughout the simulation horizon. The EUR/HRK exchange rate never drifts too far away from its slow-moving target. This is also in line with the ERM II regime that Croatia entered in July 2020 where the exchange rate is kept inside a ± 15 percent range around the central parity. It is thus realistic to assume that in the forecast horizon the exchange rate will not drift too far from its exogenously defined steady state.

The exchange rate target is defined as an average value of the steady state value of EUR/HRK and a one-year moving average of the past EUR/HRK trends.

$$EUR\_HRK^{*} = 0.5(\frac{EUR\_HRK_{t-1} + ... + EUR\_HRK_{t-4}}{4}) + 0.5EUR\_HRK^{*}_{ss} \quad (36)$$

The *monetary policy rule* is determined by the nominal exchange rate equation, which is given as a combination of AR(1) and the moving exchange rate target level from equation 36 (see Table 31).

$$EUR\_HRK_t = c_1^{fx} EUR\_HRK^{*} + (1 - c_1^{fx}) EUR\_HRK_{t-1} \quad (37)$$

4.3.2 Interest rates

As explained in the previous section, the interest rate block consists of a number of short and long-term interest rates with an active transmission channel from foreign interest rates and risk premia to domestic interbank and lending rates.

In the first step, foreign interest rates affect domestic rates through the standard uncovered interest rate parity (UIP) condition augmented by a lagged domestic rate (see Table 32). The interest rate parity also includes a risk premium $CDS5Y_t$ which is endogenous in the model (see equation 39).

Interbank interest rates

$$RNTB_t = c_1^{RNTB} RNTB_{t-1} + (1 - c_1^{RNTB})(EONIA_t + CDS5Y_t + 4\Delta eur\_hrk_t) \quad (38)$$

In equation 38 $CDS5Y$ is determined by the ratio of government debt to GDP as a simple and widely used indicator of fiscal fundamentals as well as by the NPL growth rate as an indicator of banking sector health. It is well-known that in addition to economic fundamentals, Croatian risk premium and sovereign bond yields are also affected by spillovers from EU countries (see Table 33). We therefore include a common component of EU countries' sovereign spreads PC_CDS_t as a measure of spillover effect in line with Kunovac (2013).

Risk premium

$$CDS5Y_t = c_0^{CDS} + c_1^{CDS}(\frac{\frac{DEBT_t}{4GDPN_t} + ... + \frac{DEBT_{t-15}}{4GDPN_{t-15}}}{16}) + c_2^{CDS} PC\_CDS_t + c_3^{CDS} \Delta npl_t \quad (39)$$

Non-performing loans

The share of non-performing loans in total loans is modelled as a function of its past level, deviation of trend (HP_{EUR/HRK_t})[18] of nominal EUR/HRK exchange rate from its steady state[19], GDP growth and short-term household interest rates (see Table 34).

$$\begin{aligned} NPL_t = c_1^{npl} NPL_{t-1} + c_2^{npl}(hp_{EUR/HRK_t} - EUR\_HRK_{ss}^{*}) \\ + c_3^{npl}\Delta^4 gdp_t + c_4^{npl} RSH_t + c_5^{npl} D2016q2 \end{aligned} \tag{40}$$

Banks' financing costs

Since the literature suggests that banks' financing costs act as a transmission channel for macroeconomic shocks (Breitenlechner et al., 2016), bank lending channel is represented by banks' financing costs as these costs are not fully represented by the interbank interest rates.[20] Banks' financing costs are also modelled through UIP using the following equation (see Table 35):

$$RLTB_t = c_1^{RLTB} RLTB_{t-1} + (1 - c_1^{RLTB})(EONIA_t + CDS5Y_t + 4\Delta eur\_hrk_t) \tag{41}$$

The final two steps in the transmission chain of interest rates include several equations linking the interbank interest rate and banks' financing costs with domestic short-term and long-term lending rates thereby disentangling the effect on the respective business (see Tables 36 and 37) and household loans interest rates (see Tables 38 and 39).

For businesses the following short- and long-term rate equations are assumed:

Short-term business interest rates

$$RSP_t = c_0^{RSP} + c_1^{RSP} RNTB_t + (1 - c_1^{RSP}) RSP_{t-1} + c_2^{RSP} D_{2016q2} \tag{42}$$

Long-term business interest rates

$$RLP_t = c_0^{RLP} + c_1^{RLP} RLP_{t-1} + (1 - c_1^{RLP}) RLTB_t \tag{43}$$

[18]Trend values are obtained using a Hodrick-Prescott filter with a default smoothing parameter $\lambda = 1600$, which is appropriate for quarterly data.

[19]Due to the high share of debt denominated in (or linked to) EUR in total debt of households, firms and government. See Ravnik and Bokan (2018) for a more detailed explanation.

[20]In addition to the fact that bank lending channel works through banks' financing costs, interbank interest rates series which used to be represented by Zagreb Interbank Offered Rates (ZIBOR) was replaced by the National Reference Rate (NRR) at the beginning of 2020.

In equations 42 and 43 additional autoregressive terms are included in order to capture rather smooth interest rate dynamics.

Real long-term business interest rates are obtained by deflating nominal ones with annual core inflation.

$$RLPV_t = RLP_t - (cpi_t^{core} - cpi_{t-4}^{core}) \tag{44}$$

For households, nominal and real lending rates are estimated with the use of equations similar to those used for businesses.

Short-term household interest rates

$$RSH_t = c_0^{RSH} + c_1^{RSH} RNTB_t + (1 - c_1^{RSH}) RSH_{t-1} \tag{45}$$

Long-term household interest rates

$$RLH_t = c_0^{RLH} + c_1^{RLH} RLH_{t-1} + (1 - c_1^{RLH}) RLTB_t \tag{46}$$

Real long-term household interest rates

$$RLHV_t = RLH_t - (cpi_t^{core} - cpi_{t-4}^{core}) \tag{47}$$

4.3.3 Real gross operating surplus

As explained earlier, households' income is defined as the sum of labour income and income that households receive from firms they own. Gross operating surplus is the variable capturing this second income component. In the **long run** real gross operating surplus is determined by real unit labour costs, real GDP and its deflator. Due to its specific trending behaviour real gross operating surplus equation additionally includes a trend and quadratic trend in the long-run equation (see Table 40).

$$gos_t = pgdp_t + c_0^{gos} + c_1^{gos} rulc_t + c_2^{gos} gdp_t + c_3^{gos} t + c_4^{gos} t^2 \tag{48}$$

However, in the **short run** gross operating surplus share fluctuates around its long-run level in accordance with its lagged dynamics, real unit labour and real cost of capital growth (see Table 41). Still, error correction mechanism ensures that real gross operating surplus returns to its balanced growth path:

$$
\begin{aligned}
\Delta gos_t &= \Delta pgdp_t + c_0^{goss} + c_1^{goss}\Delta(gos_{t-1} - pgdp_{t-1}) + c_2^{goss}\Delta rcc_{t-1} + c_3^{goss}\Delta rulc_t \\
&+ c_4^{goss}(gos_{t-1} - (pgdp_{t-1} + c_0^{gos} + c_1^{gos} rulc_{t-1} + c_2^{gos} gdp_{t-1} \\
&+ c_3^{gos} t_{t-1} + c_4^{gos} t_{t-1}^2)) \qquad (49)
\end{aligned}
$$

4.3.4 Wealth

The following equations are a series of accounting identities connecting the financial sector with the demand and supply side of the economy. They primarily relate consumption, housing investment and household disposable income to household financial wealth and debt. These are important stock-flow relationships that allow us to consistently connect these sectors into a closed-form model.

Household wealth is composed of *non-financial/housing* (HW_t) and *net financial wealth* (NFW_t):

$$WEL_t = HW_t + NFW_t \qquad (50)$$

$$HW_t = PH_t KH_t \qquad (51)$$

$$NFW_t = GFW_t - DH_t \qquad (52)$$

Where GFW_t denotes *gross financial wealth.* Gross financial wealth accumulation is modelled by a law of motion including a simple income identity as shown below.

$$
\begin{aligned}
GFW_t &= (1 + RLH_t/3)^{(1/4)} REV_t^A GFW_{t-1} + \frac{para_G}{(para_G - 1)} \\
&(CPI_t RDY_t - CN_t - PH_t(I^H - \delta^H K_{t-1}^H)) \qquad (53)
\end{aligned}
$$

Gross financial wealth is thus equal to financial wealth from the previous period $(t-1)$ carried over to current period (t) and unspent (saved) income. The first term on the right hand side represents financial wealth from $t-1$ which is carried over to the current period including revaluation of the invested wealth as well as interest rate gains. The interest rate used is a proxy for the deposit interest rate which is, according to historical data, assumed to be one third of the lending rate. In addition to that, the second term on the right hand side represents total disposable income which is not spend in period t (disposable income minus consumption expenditure, net housing investment and depreciated housing capital) and it is added to the first term.

Despite the fact that household financial balance is on aggregate positive, households still take loans to finance part of their investment and expenditure which is a direct consequence of household heterogeneity observed in the real world as well as with the idea that agents prefer a stable path of consumption. Since we are not explicitly modelling heterogeneous agents in PACMAN, we added a separate law of motion for *household financial debt* which is given by:

$$DH_t = (1 + RLH_t)^{(1/4)} REV_t^D DH_{t-1} + \frac{1}{(para_G - 1)}$$
$$(CPI_t RDY_t - CN_t - PH_t(I^H - \delta^H K_{t-1}^H)). \quad (54)$$

It can be noted that both equations include some combination of the parameter $para_G$ which is calibrated at 3.5, i.e. the average household deposits-to-loans ratio. By the way these two parameters are set in this model, it is assumed that in every period one part of the households save their unspent money and another smaller part takes loans such that on aggregate net financial wealth (the difference of those two equations) changes exactly by the amount not spent from the disposable income, abstracting from revaluation and interest effects. In other words, when considering only the second terms of both equations and if subtracting household debt from gross financial wealth (subtracting equation 54 from 53) the parameter combination guarantees that net financial wealth will rise precisely by $(CPI_t RDY_t - CN_t - PH_t(I^H - \delta^H K_{t-1}^H))$.We are therefore affecting only the relative relationship between changes in debt and gross wealth when choosing a parameter value for $para_G$, while the impact on net financial wealth and consequently consumption remains exactly the same as in the case of an accounting identity.

Both equations include revaluation terms which are given by the following equations, which are approximations based on observed household sector financial accounts.

$$REV_t^A = 0.1(\frac{EQP_t}{EQP_{t-1}}) + 0.2(\frac{EUR\_HRK_t}{EUR\_HRK_{t-1}}). \quad (55)$$

$$REV_t^D = 0.8(\frac{EUR\_HRK_t}{EUR\_HRK_{t-1}}) + 0.2 \quad (56)$$

In equation 55 EQP_t is a stock price index which is given by the *CROBEX* and is modelled as (see Table 42):

$$\Delta eqp_t = c_0^{eqp} + c_1^{eqp} \Delta eqp_{t-1} + c_2^{eqp} \Delta gdpt_t$$
$$+ c_3^{eqp} D2008q4 + c_4^{eqp} D2011q1 + c_5^{eqp} D2009q2 \quad (57)$$

House prices

The financial block also includes house prices, which directly affect household's non-financial/housing wealth and consequently total wealth, consumption and all other variables in the economy. We model house prices through a housing demand equation. In the **long run** real house prices are determined by the level of household capital and its depreciation rate and long-run household real interest rates (user cost) as well as by households' real disposable post-tax income (see Table 43):

$$(ph_t - pgdp_t) = c_0^{ph} + c_1^{ph} k_t^H + c_2^{ph} rdy_t + c_3^{ph} (RLHV_t + \delta^H) \tag{58}$$

House prices are deflated by the GDP deflator. The existing stock of housing capital enters the equation as a term capturing potential housing demand such that a higher level of housing stock leads to a decrease in potential current and future demand leading to lower house prices and vice versa. Real disposable income positively affects housing demand and prices. The relative cost of property purchase financing is depicted by the real interest rate and deprecation rate. If the financing cost increases, part of the household will postpone their purchase leading to a price decrease.

In the **short run** real house prices can deviate from their long-run equilibrium. These short-run fluctuations are determined by lagged real house price growth and current GDP and EUR/HRK nominal exchange rate growth as well as by the adjusting parameter which corrects for deviations of real house prices from their long-run level (see Table 44).

$$\begin{aligned}(\Delta ph_t - \Delta pgdp_t) = {} & c_0^{phs} + c_1^{phs} \Delta gdp_t + c_2^{phs} \Delta (ph_{t-1} - pgdp_{t-1}) \\ & + c_3^{phs} \Delta (eur\_hrk_t) + c_4^{phs} ((ph_{t-1} - pgdp_{t-1}) - (c_0^{ph} + c_1^{ph} k_{t-1}^H \\ & + c_2^{ph} rdy_{t-1} + c_2^{ph} (RLHV_{t-1} + \delta^H)))\end{aligned} \tag{59}$$

5 Illustrative simulations

This section provides simulation results in the form of a set of standard generalised impulse response functions (IRFs) in order to illustrate the model's mechanics. These impulse response functions represent the difference of two dynamic solutions of the model where one of those solutions includes an exogenous change to a specific equation. In the first step, the model is dynamically solved according to the given paths of all exogenous variables. The solution of the model is usually labelled as the baseline solution. In the second step, the same model is solved over the same period, however, with one variable/equation increased or decreased by some percentage i.e. by the shock size. The percentage difference of an endogenous variable between these two scenarios is the IRF of the respective variable. Although most shocks have some economic interpretation they should not be seen as pure structural shocks. They are rather reduced-form shocks that through a specific semi-structural equation enter the system and can thus be assigned an economic interpretation. IRFs are, however, very useful for demonstrating the properties of the model and for understanding the main model mechanisms by presenting numerical results. Only a system that consists of meaningful relationships between variables is able to produce consistent forecasts with a clear economic interpretation. The analysis of IRFs is therefore crucial for a better understanding of the model. Moreover, as PACMAN is also used for scenario analysis and stress tests of the banking sector, the users of the model should be aware of the sign and magnitude of the dynamic reaction of endogenous variables to a set of standard economic shocks.

Three types of shock can be computed. The first one is a so-called *add-factor* (or add-on or temporary one-off shock) to a specific endogenous equation. These shocks resemble a shock in a VAR model. For instance, a so-called consumer confidence shock would be modelled through an add-factor (temporary one-off shift) to the consumption equation. Consumption would still depict a dynamic reaction to this shock thereby affecting indirectly all other endogenous variables in the model. The second type of shock is a shift to an *exogenous* variable that can be either permanent or temporary. In other words, it is possible to define a specific path of the exogenous variable which is different to its path in the baseline solution. The results thus represent dynamic reactions of endogenous variables to a shift in the exogenous variable. In practice, either one-quarter shock or a permanent level shift of a exogenous variable is assumed. The third shock category is an *exogenization of an endogenous variable* which is shifted the same way as the aforementioned exogenous variable. The main difference with respect to an add-factor is that in this case the endogenous variable which is shocked cannot react to itself, i.e. the entire path throughout the simulation horizon is chosen by the modeller and is not affected by other variables.

IRFs of a selected set of endogenous variables to four shocks are shown in the paragraphs below. These simulations are mainly shown for illustrative purposes with all of the three described shock types. A detailed analysis of the exchange rate shock simulation is provided in Nadoveza Jelić and Ravnik (forthcoming) and this important shock is therefore not analysed in the present paper. The simulation period extends over 20 quarters (5 years) and the model is estimated using data from 2000q1 to 2019q4.

5.1 Consumer confidence shock

The shock simulated in this subsection is a temporary one quarter shock (add-factor) to domestic consumption and can be interpreted as a non-fundamental consumer confidence shock. It is a shock of type one as described above and, given its temporary nature, convergence towards zero of all impulse responses is expected. In some cases this convergence takes longer than the horizon depicted in this paper. Simulation results are presented in Figure 1.

Consumption increases slightly more than the initial 1 percent shock between the second and fourth quarter and slowly decreases thereafter converging towards its steady state. Translated to growth rates, this implies that the IRF of consumption growth would be positive in the first few quarters but would turn negative and remain so for the rest of the simulation horizon, returning to zero after more than five years. Housing investment would follow a similar pattern. Due to an accelerator effect, business investment would also increase, but would be somewhat delayed when compared to consumption, and would reach its peak after 8 quarters and would slowly return towards its initial level/steady state after several years. As a result of these domestic demand developments, import volume is rising following the same pattern as consumption and converging to its steady state within the simulation horizon. Negligible changes in exports are caused by export price developments as a consequence of consumer price changes, assuming unchanged foreign variables. The export reaction remains negative over an extended period or as long as it takes for domestic prices to return to zero. As a result of all component reactions, domestic GDP increases, reaching its peak around the fourth quarter after which it starts to return very slowly to zero. This shows that a demand shock caused by domestic factors, although temporary, might have medium term consequences for an economic activity. Only over the long run will the model return to its steady state.

Wages and employment indicators show very weak reaction to this demand shock.

Similarly as for the foreign demand shock, only core inflation reacts to the mentioned demand developments through the Phillips curve, while oil and food prices remain unchanged. The reaction of aggregate consumer prices is sluggish and is in line with the modelled price setting behaviour and backward-looking expectations. It will return to zero after a very long period for the same reasons as the foreign demand shock.

The response of household wealth to a domestic demand shock, however, differs significantly from the foreign demand shock. Given an exogenous jump in consumption not related to higher wages or productivity, households spend more of their budget, which includes both disposable income as well as wealth. The IRF therefore shows an immediate decrease in gross financial wealth, but also a decrease in net financial wealth. Housing wealth and property prices on the other hand react positively to higher aggregate demand and more dynamic housing investment developments. These two opposing effects cancel out conditionally on the current parametrization, leading to an almost zero reaction of total household wealth. NPLs also slightly decrease, given an increase in real GDP, followed by slight increases and an alternating backward path.

5.2 Foreign demand shock

Given the small open nature of the Croatian economy, characterized by strong dependence on tourism flows and foreign trade, it is clear that a change in Croatia's trading partners' GDP is expected to significantly affect economic activity in Croatia. This dependence was confirmed, for example, in Krznar and Kunovac (2010), Jovančević et al. (2012), Kotarac et al. (2017) and Deskar-Škrbić and Kunovac (2020). We are therefore analysing the consequences of a trading partner's GDP shocks through the lenses of the PACMAN model. For that purpose, we simulate a permanent 5-year positive 1 percent foreign GDP (foreign demand) shock. This shock is applied to the level of Croatia's trading partners' GDP, therefore increasing its growth rate only in the first quarter of the simulation horizon but moving the level permanently 1 percent above the baseline level during the entire 5-year period. This is the second shock type described earlier.

According to the results shown in Figure 2 Croatian GDP reacts sluggishly but reaches a 0.9 percentage cumulative reaction by the end of the 5th year. Therefore, according to PACMAN, a demand shock with a source that is purely outside the domestic economy will over time almost fully be transmitted to the Croatian economy (the positive reaction reaches around 1 percentage over seven years and stabilizes around this level which is not shown on the IRF figures). This shock enters directly into the system only via the export equations, moving total exports of goods and services by around 1.6 percent up and slightly decreasing after this overshooting and stabilizing at around 1.5 percent above steady state. Such a strong export reaction is not surprising given the relatively high parameter related to foreign GDP in the long-run export equation. The rather sluggish GDP reaction is mainly caused by the slow reaction in private consumption due to consumption smoothing. Both endogenous investment variables (business and housing) also react positively with some lag given the accelerator effect and both reach around 2 percent over 5 years, while exogenous government investment is assumed to remain unchanged. Due to the mentioned reaction of domestic demand components, but also due to the import content of exports, imports will also increase by more than 1-to-1 to a foreign demand shock thereby slightly dampening the positive effect.

Given a relatively low elasticity of labour demand to real economic activity, the unemployment rate decreases and the number of employees increases by 0.12 percentage points by the third year and stabilizes slightly below 0.1 percent in the long run. However, the real wage reacts slightly stronger.

The domestic inflation reaction follows the pattern of domestic demand components as the demand is transmitted through the Phillips curve to domestic prices. As we assume that GDP is the only foreign variable shifting due to the absence of a fully-fledged foreign block, the inflation reaction is completely transmitted via core inflation, leaving food and energy prices unchanged. It should be noted that inflation and core inflation continue their upwards path and they do not stabilize over the medium run. The main reason for such a reaction is caused by the output gap reaction which enters the Phillips curve. The output gap remains open over the medium term horizon as it takes very long for the reaction of potential output to catch the actual output reaction to close the gap.

The financial sector will also react to a foreign demand shock, however, only indirectly via responses of domestic real variables as we do not model any direct financial transmissions. The gross financial wealth stock rises at the beginning of the simulation horizon but eventually decreases, which is also the case with total household debt. This happens due to relatively high levels of consumption and housing investment reached by the end of the fourth year which are growing faster than disposable income. These variables reach negative territory during the fifth year and stay negative over an extended period, returning very slowly over the long run (not shown in the figures). The reactions of all interest rates are negligible due to a relatively low elasticity of interest rates to economic activity changes, which is not surprising given the monetary policy setup without an interest rate rule, and are therefore not shown. The NPL ratio decreases slightly as a result of an increase in real GDP. The NPL ratio decreases due to an improved economic environment and stabilizes around 4 percentage points below the steady state. Increased aggregate demand is transmitted to higher housing demand leading to a strong and steady increase in house prices and housing wealth.

5.3 House price shock

This subsection presents the results of a house price shock which is introduced as an exogenization of house prices which are increased by 1 percent over the forecast horizon. This means that house prices do not react to this shock and their level is kept 1 percent above the baseline level throughout the entire simulation horizon (flat IRF). Since house prices are modelled by a housing demand equation, this could be interpreted as an exogenous shift in housing demand or preferences in households to invest into properties. Simulation results are presented in Figure 3.

House prices enter the system through two main channels. The first one is the housing investment equation (housing supply) according to which housing investment will react positively to the mentioned changes in house prices and therefore lead to an increase of housing wealth stock (accumulated investment). The second one is related to the valuation of housing wealth as higher house prices lead to higher housing wealth for a given level of housing stock. Housing wealth, which enters total household wealth, enters the private consumption equation and will therefore also affect GDP. GDP IRF increases steadily and reaches 0.1 percent after five years where it starts to stabilize.

Employment and real wages also rise as a reaction to the increase in GDP. Inflation shows similar behaviour to other demand-type shocks. NPLs decrease due to the step-up in economic activity.

5.4 Personal income tax shock

The simulation of an expansionary shock to the personal income tax rate presented in this subsection is applied to the implicit tax rate (computed as the tax revenue to the mass of gross wages ratio) and represents a 1 percentage point decrease of this tax rate applied to the average income tax rate. In the absence of a detailed heterogeneous tax rate model, this is a fairly good approximation of a reduction in this tax rate applied to all income classes which is slightly different to the tax rate cuts implemented recently in Croatia. Since this overall income tax shock includes reactions of workers in all income categories one can expect a relatively stronger overall reaction given the fact that low-income households are characterized by higher propensities to consume when compared to high-income households targeted in the mentioned real-world tax cuts. It is important to note that this is a permanent tax rate cut. This means that all IRFs will converge to some generally non-zero fixed point. Simulation results are presented in Figure 4.

As explained in the previous section, the income tax rate directly enters the household's budget constraint as it affects net wages which are part of disposable income. Changes to disposable income consequently change private consumption and financial wealth of households which can have longer-term effects on aggregate demand. These channels are clearly depicted by the consumption, GDP, disposable income and wealth impulse responses. The increase in consumption is slow but it lasts through the entire simulation horizon. Such an increase in consumption is directly transmitted to GDP, which is slightly accelerated by business and housing investment developments. This leads to a fiscal multiplier of around -0.44 after one year. It needs to be noted that GDP increases almost permanently in terms of its growth rate. GDP growth IRF is approximated by the rate of change of the GDP level IRF. It stays in positive territory over the medium run, returning to a zero after almost 10 years. This slow adjustment process is caused by several factors but mainly by the stock-flow relations included in this model. More precisely, gross and net financial wealth accumulate since part of the additional income is saved leading to an inter-temporal distribution of these funds to the future. This leaves additional space for consumption expenditure and investment over the medium run. Moreover, increased housing demand and investment are increasing housing wealth through accounting identities. This will push up future consumption expenditure and the capital stock. Consequently, GDP and potential GDP will also increase.

Given the demand nature of this shock, core and thus aggregate consumer prices will be positively affected through the Phillips curve. Demand for labour increases as a consequence of higher domestic demand and the requested wages rise.

Increased economic activity pushes NPLs down, which puts a downward pressure on the risk premium and therefore all interest rates. On the other hand, lower tax revenues increase the deficit and public debt, which pushes the risk premium into the opposite direction. The net effect is a negligible reduction in CDS spreads and interest rates (not shown). The export reaction can be explained by the same driving forces as in the case of previously described shock.

6 Forecasting exercise

6.1 Forecasting exercise setup and assumptions

As already mentioned, this version of PACMAN is designed for three main purposes, one of which is to facilitate the forecasting process at the CNB. However, it should be noted that forecasting is not the primary purpose of semi-structural models such as PACMAN. The CNB, like other central banks, uses the same model for both policy/scenario analysis and forecasting.[21] This involves a trade-off between the model's forecasting performance and its theoretical coherence (Pagan, 2005). However, due to the model's role in the CNB's regular forecasting exercises, it is important to make sure that the model produces reasonable forecasts of the main macroeconomic variables. This section illustrates the forecasting performance of the model. However, the results of the forecasting exercise illustrated in this section cannot be considered a standard out-of-sample forecasting exercise, neither can we provide a standard assessment of the out-of-sample forecast performance of the model, due to at least five reasons.

The first reason is related to the general proposition of Angelini et al. (2019) that a purely model-based prediction with zero residuals, which we present in this section, can be challenging within this class of model since the model is misspecified in various dimensions, and can therefore generate biased forecasts. Although we present a purely model-based prediction, which we consider a baseline projection in the forecasting exercises at the CNB, it should not be viewed as a pure, unconditional model-based prediction. That is, baseline forecasts in PACMAN are conditioned on exogenous paths for a number of external variables such as foreign GDP, inflation, interest rates etc. Therefore, in the baseline projection we take the path of these variables as exogenously given through the entire forecasting horizon. We find this approach appropriate due to the small-open-economy characteristics of the Croatian economy. Forecasts of foreign variables which are usually taken into account are taken from other institutions such as the ECB or IMF. Additionally, a few domestic variables, such as government investments or implicit tax rates, are also taken as exogenous. These are usually modelled as simple autoregressive processes and are combined with expert judgments.

Second, the forecasts presented in this section are not a standard out-of-sample forecasting exercise since we use realized, and not projected, values for exogenous external and domestic variables. Although not completely impossible, it would be time consuming to perform pure out-of-sample forecasts as there is no ready-to-use historical forecast dataset for these variables. Also note that with this forecasting exercise design, although we try to replicate the real-time application of the PACMAN model as closely as possible, we do not have real historical time datasets (vintage) at hand nor are these available.

Third, the version of PACMAN introduced in this paper was fully developed in 2019 and is estimated on Croatian data from over the 2000Q1 - 2019Q4 period. Therefore,

[21] See for example Giacomini (2014).

parameter estimates and model properties presented in this paper reflect the precise state of the model, estimated parameters and its properties only in 2019Q4. However, when running this exercise at each forecasting period the model is re-estimated using the dataset available up to the point when forecasting exercise is performed (recursive forecast). In other words, we start our 8 quarters ahead forecasting exercise in 2012Q1 by estimating all model equations using only the data from 2000Q1 to 2011Q4 for all observed endogenous variables. Therefore, at the beginning of the forecasting exercise performed, the sample available for model estimation is rather small and not sufficient for robust parameter estimates. Also, due to the data limitations some equations are estimated on a smaller-than-full-sample, starting from 2003 or in some cases even from 2006. Additionally, as PACMAN played an important role in the forecasting process just recently, the model properties and estimates of parameters have not been evaluated in the past. This essentially means that model properties and estimated parameters might be different from those presented in this paper as well as be of a theoretically unexpected sign, which could be particularly problematic in the case of error correction terms in cointegrating relationships. Having in mind these pitfalls, and given the realized paths of exogenous variables, we produce forecasts for all the endogenous variables 8 quarters ahead starting from 2012Q2. In the following period we expand the estimation sample by one period and obtain another 8 quarter-ahead forecasts. We successively expand the sample until the 2019Q4 which gives us 32 8-steps-ahead forecasts.

Fourth, given the equation 60, in this forecasting exercise we assume that real GDP components sum up into the headline GDP figure which in reality does not hold except for the base year. Still, the error made by this assumption should not be large and during the 2000-2019 period it is 0 on average and it exceeds 1% in only a few quarters in the case of seasonally non-adjusted data. However, PACMAN is estimated on seasonally and calendar adjusted data, whereas the Croatian Bureau of Statistics (CBS) uses direct approach to correct the GDP and its components for seasonal and calendar effects. This procedure is another source of deviations between projected GDP growth implied by the equation 60 and GDP growth rate(s) which would be consistent with the GDP components forecasts at the forecasting horizon. Due to these non-additive properties of volume (chain-linked) seasonally adjusted series, different GDP aggregation rules are assessed during the regular forecasting exercises at the CNB.

On top of this, the historical real inventories series is calculated using the identity implied by equation 60. Yet the real inventory series implied by the residual GDP series looks very different from the real inventories series published by the CBS. Although the CBS provides real inventories series, the model uses residual inventory series since, according to Eurostat (2020), chain-linking cannot be performed directly on variables that can take both negative and positive values. Therefore, Eurostat does not provide chain-linked series for changes in the inventories.[22] Having said that, note that to produce a model-based GDP growth forecast it is necessary to forecast real inventories. It is common practice to assume neutral contributions from inventories since inventories do

[22]See Eurostat (2020).

not show predictable behaviour and it is therefore hard to give meaningful forecast for this GDP component. However, due to the (in some quarters extremely)[23] high contribution of inventories to GDP there is a relatively wide range of aggregate GDP growth figures consistent with the main GDP components forecasts - depending on the assumed inventories trajectory.[24] We do not deal with these inventories-related uncertainties in the exercise performed in this paper but it should be emphasized that during the regular forecasting cycle at CNB (see Section 6) these uncertainties are taken into account.

Finally, as described in the next subsection, the forecasting process at the CNB is not a one-stop procedure. It rather includes multiple steps, one of which assesses a purely model-based (baseline) forecast. Therefore, forecasts evaluated in this section are considered only in the early stages of the forecasting exercise procedure (see Section 6).

6.2 Forecasting performance

Figure 5 shows all 8-steps-ahead forecasts for GDP, household consumption, investments, exports, imports and CPI. However, we do not show 2020 forecasts due to the COVID-19 pandemic-related massive economic shocks and the impossibility of predicting the disruptions associated with the pandemic-control measures.

The forecasts plotted in Figure 5 show different forecasting performances of the model in three distinctive periods for all endogenous GDP components. In the first period from the beginning of 2012 until early 2014 PACMAN captures the dynamics of most variables surprisingly well; it needs to be kept on mind that at each forecasting period the model is estimated using the dataset available up to the point when the forecasting exercise is performed. This essentially means that at the beginning of 2012 model equations are estimated using 48 data points at most (as for some variables data for the early periods are unavailable).

The second distinctive period coincides with the Croatian business cycle turning point. After a stagnation in 2014, Croatia finally started to recover in 2015 after a six-year-long recession. A relatively poor forecasting performance during this period is not surprising. It is difficult to predict turning points in the business cycle and to forecast the amplitude of GDP changes around turning points ECB (2014). In addition, during this period the model-based forecasts underestimate the realized growth rates (forecasts performed from early 2014 until early 2016). This is in line with the general notion that there might

[23]During 2000Q1 to 2019Q4 share of inventories in GDP in Croatia fluctuated between ±10% (the highest in the EU, there are only few countries with comparable shares), and compared to other EU countries Croatia has extremely volatile share of inventories in GDP. Median inventories share to GDP is around 3% in Croatia during this period while it is only slightly positive in most other EU countries.

[24]In Croatia this range can be as high as $\pm 4pp$ in some quarters. This range is estimated using the following inventories assumptions: 1) neutral inventories contribution (naive forecast for inventories), 2) growth in inventories equals the largest historical positive change in inventories in the corresponding quarter, and 3) decline in inventories equals the largest historical negative change in inventories in the corresponding quarter.

be a tendency to systematically underestimate the strength of recoveries (but also to underestimate the depths of recessions). Part of the explanation of such bias in forecasts comes from the inventories cycle. According to ECB (2003) inventory changes often play an amplifier role in economic cycles. In 2015 inventories contributed 1.2pp to the overall annual GDP growth (2.4%) in Croatia, while our forecasting exercise assumes neutral inventories contribution.[25]

Also, this exercise uses realized data as reported at the end of 2019 for some exogenous domestic variables. Therefore, some of these variables, such as tax revenues, are aligned to realised and not projected GDP figures, which affects GDP growth forecast negatively during this period.

We find the third distinctive period, from 2017 onward, the most important from the perspective of forecasting performance evaluation given all the constraints mentioned above. During this period a larger data set is used for parameter estimation. Therefore, properties of the model and estimated parameters should be close to those presented in this paper. The model captures the dynamics of most variables reasonably well during most of this period. As emphasised previously, forecasting is not the main application of semi-structural models such as PACMAN, and stable forecasts which are in line with variables dynamics during the periods of stable moderate growth are not a general feature of this class of models. Investments show the largest forecasting error during this period which is something one can expect since overall investments growth forecast consists of forecasts of three components, i.e. government investments, which are exogenously given in this exercise, and household and business investments. However, a relatively large error partially reflects the data constraints regarding the shares of households and businesses in private investments (these investments' sub-components are constructed, not observed) and the volatility of the series, which is a stylized fact for investments in any country. For example, Júlio and Esperança (2012) found that IMF and OECD forecasts for investment, exports and imports have the lowest accuracy due to their high volatility.

Finally, the last diagram in Figure 5 shows baseline 8-steps-ahead forecasts of the HICP inflation during the 2012-2019 period. The resulting forecasts point to two distinctive periods. Model-based forecasts seem to capture inflation dynamics quite well up to the end of 2013. However, from that point onward the model tends to over-predict inflation in both the short- and the medium-run. However, this has a sample-dependent explanation which is taken into account during regular forecasting exercises at the CNB as explained in Section 6.[26] Generally, a combination of low inflation and low unemployment rates during this period motivated significant amount of research regarding the flattening or

[25] Since it is impossible to give reasonable inventories forecast during forecasting exercises we use naive forecast for inventories. However, in practice, the CNB usually performs a sensitivity analysis by taking into account different assumptions regarding the inventories cycle as explained previously.

[26] There is a break in inflation after 2013 in Croatia. We run few break-point unit root tests, most of which suggested significant break in intercept in 2013 or 2014. Angelini et al. (2019) also report forecasting performance deterioration issues in the EA during the low inflation regime in the post GFC era.

even disappearing of the Phillips curve in many countries. However, to our knowledge there is still no broad consensus on the issue of the persistence of low inflation in the future. The CNB is monitoring this issue closely, and puts more weight on satellite models' inflation forecasts and expert judgment using add-factor in the short run as described in the following section. Having said that, we need to point to the fact, that despite systemically over-predicting inflation during the mentioned period, the forecast error is relatively low in absolute terms. Only a small number of episodes with more than 1 percentage point errors can be detected.

6.3 Forecasting process at Croatian National Bank

The forecasting exercise described above assesses the pseudo real-time forecasting performance of conditional model-based (baseline) forecast.[27] Forecasts in the previous section are obtained under the assumption of zero estimated errors of endogenous variables at the forecasting horizon which is usually set to three or four years. As explained in Angelini et al. (2019) misspecification issues in this kind of model, the dimensions of which are difficult to establish and are driven by the equation-by-equation estimation approach, might lead to residuals that are not white noise even in-sample. Even in the case of good in-sample properties, out-of-sample properties do not have to maintain these properties.

Therefore, in the forecasting exercises at the CNB we consider these baseline (judgmental-free) model forecasts only in early stages of the typical forecasting exercise. After the baseline forecasts are generated, these are distributed among sectoral experts who evaluate them and use them as inputs in satellite models. In the next step sectoral experts provide their views and judgments as well as information not captured by the model. The expert judgments are then introduced in the model using add-factors as described in section 5 in the case of temporary consumer confidence shock.[28] The exogenous information at each forecasting cycle may vary depending on the available information. Therefore, the model is re-run and new conditional forecasts are obtained and distributed among sectoral experts. The described procedure may be repeated several times before the forecast is finalized. Additionally, due to previously mentioned non-additive properties of volume (chain-linked) seasonally adjusted series, different GDP aggregation rules are assessed during this process.

The CNB usually uses a nowcast of domestic GDP in the quarter of forecasting exercise. The use of this nowcast proved to be useful for the forecasting performance of PACMAN due to the superiority of high-frequency nowcasting models in the very short run (see Kunovac and Špalat (2014)).

[27]As mentioned in the previous section all external variables are taken as exogenous during the entire forecasting horizon due to the Croatian having the properties of a small open economy. As evident from model description some domestic variables are taken as exogenous as well and are usually based on expert judgments (e.g. government consumption) or are modelled as simple AR processes (e.g. implicit tax rates if tax rate changes were not announced by the government).

[28]These also include policy changes. For example, add-factors can also be used in the case of announced economic policy changes (e.g. value added or income tax reforms).

7 Concluding remarks

This paper described the latest version of the medium-sized semi-structural macro model of Croatia - the PACMAN (Policy Analysis Croatian MAcroecoNometric) model. The version of the model presented in this paper is aligned to its main purposes: (i) to provide model-based forecasts, (ii) to serve as a tool in scenario analysis and (iii) for policy simulation exercises at the CNB. The model successfully captures many of the established stylized facts and much of the empirical evidence of the Croatian economy and reflects its nature as a small open economy. Therefore, we find it to be a suitable primary tool for explaining or making predictions about economic developments in Croatia.

Illustrative examples show the dynamic responses of the system to selected shocks such as foreign demand shock, consumer confidence shock, personal income tax shock and house price shock. The results of the illustrative simulations are in line with economic theory and demonstrate both nominal and inflation neutrality as well as nominal and real inertia. The forecasting capability and practical use are demonstrated using a non-standard quasi-out-of-sample forecasting exercise. Generally, the model produces reasonable forecasts for the main macroeconomic variables, which are in practical applications further improved using add-factors features and expert inputs.

The distinguishing features of the model include a modified monetary policy rule and a relatively detailed fiscal sector. Namely, the CNB uses the nominal EUR/HRK exchange rate as the intermediate objective (target), so the monetary policy is described by the nominal exchange rate equation consisting of an AR(1) term and moving exchange rate target level. Since the CNB has not committed to any predefined level of the exchange rate prior to recent ERM II accession, the moving exchange rate target reflects CNB's willingness to conduct foreign exchange interventions when exchange rate fluctuation are excessive. This is also in line with the ERM II regime that Croatia entered in July 2020. We do not expect that major adjustments of monetary policy rule will be needed since the CNB successfully maintained the exchange rate stability even before joining the ERM II.[29]

Besides adjustments made to monetary policy rule, the prevailing euroisation required some additional adjustments to domestic sector equations. However, due to the relevance of euroisation-related issues for the Croatian economy and CNB policy we describe these adjustments and their consequences in a separate paper (see Nadoveza Jelić and Ravnik (forthcoming)).

Finally, like any macroeconomic model, PACMAN constantly evolves. Therefore, at this point the CNB plans to adjust PACMAN to allow for the possibility of forward-looking behaviour, to further improve the fiscal sector with more consistency in stock-flow fiscal relationships, and to revise the supply side of the economy by modifying potential output estimation methodology as well as by considering joint (system based) estimation of the Phillips curve and Okun's law-related equations.

[29] During last two decades fluctuations around the average EUR/HRK exchange rate have been kept in narrow range from -4,7% to +3,8%).

A Identities

Notation:

- All calculations and estimations are based on seasonally adjusted data where appropriate.
- Uppercase letters denote levels.
- Lowercase letters denote log values.
- Δ denotes differentiated variables.

A.1 Gross domestic product

Real gross domestic product

$$GDP_t = C_t + I_t + G_t + EX_t + IMP_t + II_t \tag{60}$$

Nominal gross domestic product

$$GDPN_t = DDN_t + EXN_t + IMPN_t + IIN_t \tag{61}$$

GDP deflator

$$PGDP_t = \frac{GDPN_t}{GDP_t} \tag{62}$$

Domestic demand *Real domestic demand*

$$DD_t = C_t + I_t + G_t + II_t \tag{63}$$

Nominal domestic demand

$$DDN_t = CN_t + IN_t + GN_t + IIN_t \tag{64}$$

Consumption *Nominal consumption*

$$CN_t = PC_t C_t \tag{65}$$

PC_t is private consumption deflator.

Investments *Total real investments*

$$I_t = I_t^H + I_t^B + I_t^G \tag{66}$$

Total nominal investments

$$IN_t = PI_t I_t \tag{67}$$

Households nominal investments

$$IN_t^H = PIH_t I_t^H \tag{68}$$

Government nominal investments

$$IN_t^G = I_t^G PG_t \tag{69}$$

Business nominal investments

$$IN_t^B = IN_t - IN_t^G - IN_t^H \tag{70}$$

Government consumption *Government nominal consumption*

$$GN_t = G_t PG_t \tag{71}$$

A.2 Current account balance

$$BAL_t = BALT_t + BIPD_t + BTRF_t \tag{72}$$

Trade balance

$$BALT_t = EXN_t - IMPN_t \tag{73}$$

Terms of trade

$$ToT_t = \frac{PX_t}{PM_t} \tag{74}$$

Real exchange rate

$$REX_t = \frac{EER_t WCPI_t}{CPI_t} \tag{75}$$

Nominal export

$$EXN_t = EX_t PX_t \tag{76}$$

Nominal import

$$IMN_t = IM_t PM_t \tag{77}$$

Primary income

$$BIPD_t = \frac{WRS_t}{4} (\frac{NFA_t + NFA_{t-1}}{2}) \tag{78}$$

Net foreign assets

$$NFA_t = NFA_{t-1} + NFA_{t-1}(EER_t / EER_{t-1}) + BAL_t \tag{79}$$

A.3 Labour market

Unemployment

Number of unemployed persons is given by the following identity:

$$UN_t = \frac{(UR_t EMP_t)}{(1 - UR_t)} \tag{80}$$

Trend employment

$$EMPT_t = PAT_t POWA_t (1 - NAIRU_t) \tag{81}$$

where $NAIRU_t$ is natural unemployment rate and $POWA_t$ represents labour force which is exogenously given. In the short run, unemployment rate can deviate from its "natural" level depending on labour market conditions.

Trend participation rate

$$PAT_t = \frac{(PA_t + PA_{t-1} + PA_{t-2} + PA_{t-3})}{4} \tag{82}$$

where the *participation rate* equals $PA_t = \frac{UN_t+EMP_t}{POWA_t}$.

Labour productivity

$$PROD_t = \frac{GDP_t}{EMP_t} \tag{83}$$

Unit labour cost

$$ULC_t = W_t(\frac{1+TRCS_t}{PROD_t}) \tag{84}$$

Real unit labour cost

$$RULC_t = \frac{ULC_t}{CPI_t} \tag{85}$$

A.4 Income

Real household post-tax income is given by:

$$RDY_t = \frac{NDY_t}{CPI_t} \tag{86}$$

where *nominal household post-tax income* is defined as:

$$NDY_t = YJ_t - (TJ_t + TCI_t) \tag{87}$$

where TJ_t and TCI_t denote taxes paid by the households (see part A). Implicitly, *saving rate* is calculated as:

$$SR_t = \frac{(NDY_t - CN_t)}{CN_t} \tag{88}$$

Total household income before taxes is defined as:

$$YJ_t = YE_t + GOS_t \tag{89}$$

Here, GOS_t is gross operating income and YE_t *wage income of households*:

$$YE_t = W_t EMP_t \tag{90}$$

and *wage income growth*

$$\Delta ye_t = \Delta w_t + \Delta emp_t \tag{91}$$

A.5 Capital accumulation

$$K_t = (1 - \delta)K_{t-1} + I_t \tag{92}$$

where δ represents quarterly depreciation rate.

Total capital stock is composed of private (business and household) and public (government[30]) capital stock , i.e. $K_t = K_t^H + K_t^B + K_t^G$.

Household capital accumulation

$$K_t^H = (1 - \delta^H)K_{t-1}^H + I_t^H \tag{93}$$

Government capital accumulation

$$K_t^G = (1 - \delta^G)K_{t-1}^G + I_t^G \tag{94}$$

Business capital accumulation

$$K_t^B = K_t - K_t^H - K_t^G \tag{95}$$

Where I_t^H, I_t^B and I_t^G denote household, business and government investment demand.

A.6 Fiscal Policy

Public deficit

$$G_t^{def} = G_t^{ex} - G_t^{tax} \tag{96}$$

[30]Exogenous.

Direct taxes

Household direct taxes

$$TJ_t = TLH_t + OHT_t \tag{97}$$

Household income taxes

$$TLH_t = TRLH_t YE_t \tag{98}$$

Other taxes paid by households

$$OHT_t = TROH_t GDPN_t \tag{99}$$

Firms direct taxes

$$TC_t = TCI_t + TCS_t \tag{100}$$

Profit taxes

$$TCI_t = TRCI_t(\frac{GDPN_t + GDPN_{t-1} + GDPN_{t-2} + GDPN_{t-3}}{4}) \tag{101}$$

Income taxes paid by firms

$$TCS_t = TRCS_t YE_t \tag{102}$$

Indirect taxes

$$TP_t = TPDV_t + TT_t + TCAR_t + OTP_t \tag{103}$$

VAT

$$TPDV_t = TRPDV_t(CN_t + 0.5EXN_t) \tag{104}$$

Excise taxes

$$TT_t = TRT_t(CN_t + 0.5EXN_t) \tag{105}$$

Import taxes

$$TCAR_t = TRCAR_t(IMN_t) \tag{106}$$

Other taxes on goods and services

$$OTP_t = TROTP_t(CN_t) \tag{107}$$

Other revenues

$$OT_t = TROT_t(GDPN_t) \tag{108}$$

Real tax revenues

$$G_t^{rtax} = \frac{G_t^{tax}}{PGDP_t} \tag{109}$$

A.7 Prices

A.7.1 Deflators

Consumption deflator[31]

$$\Delta pc_t = c_0^{pc} + c_1^{pc}\Delta cpi_t \tag{110}$$

Business investments goods deflator[32]

$$\Delta pi_t = c_0^{pi} + c_1^{pi}\Delta pm_t + (1 - c_1^{pi})\Delta bc_t + c_2^{pi} pi_{t-1} \tag{111}$$

Housing investment deflator[33]

$$\Delta pih_t = c_0^{pih} + c_1^{pih}\Delta bc_t + (1 - c_1^{pih})\Delta w_t + c_2^{pih} D_{2009q1_{t-1}} + c_3^{pih} D_{2008q4} \tag{112}$$

Government investments deflator

$$\Delta pig_t = \Delta pih_t \tag{113}$$

Government consumption deflator[34]

$$\Delta pg_t = c_0^{pg} + c_1^{pg}\Delta ulc_t + c_2^{pg}\Delta cpi_{t-1} \tag{114}$$

[31] See Table 27.
[32] See Table 28.
[33] See Table 29.
[34] See Table 30.

A.7.2 Building costs

Building costs[35]

$$\Delta bc_t = c_1^{bc}\Delta cpi_t + (1 - c_1^{bc})\Delta bc_{t-1} + c_2^{bc}D_{2008q4} + c_3^{bc}D_{2007q2} \tag{115}$$

[35] See Table 45.

B Tables

Model parameter estimates and calibrations

Consumption

Table 1: *Long-run consumption* (equation 1)

Parameter	Estimate/calibration	Standard error
c_0^C	-0.407	0.011
c_1^C	0.880	-
c_2^C	-0.36	0.179

Table 2: *Short-run consumption* (equation 2)

Parameter	Estimate/calibration	Standard error
c_0^{SC}	-0.002	0.001
c_1^{SC}	0.289	0.049
c_2^{SC}	0.136	0.047
c_3^{SC}	-0.277	0.211
c_4^{SC}	0.343	0.083
c_5^{SC}	-0.165	0.037
c_6^{SC}	0.044	0.004

Household housing investments (housing supply)

Table 3: *Long-run household housing investments (housing supply)* (equation 3)

Parameter	Estimate/calibration	Standard error
c_0^{IH}	-3.393	0.021
c_1^{IH}	0.596	0.152

Table 4: *Short-run household housing investments (housing supply)* (equation 4)

Parameter	Estimate/calibration	Standard error
c_0^{SIH}	-0.001	0.003
c_1^{SIH}	0.461	0.163
c_2^{SIH}	0.322	0.096
c_3^{SIH}	-0.500	-
c_4^{SIH}	-0.348	0.095
c_5^{SIH}	0.089	0.007

Business sector (firms) investments

Table 5: *Long-run business sector (firms) investments* (equation 6)

Parameter	Estimate/calibration	Standard error
c_0^{IB}	-4.165	1.305
c_1^{IB}	1.200	0.114
c_2^{IB}	2.077	0.162
c_3^{IB}	-2.023	1.304
c_4^{IB}	-1.400	-

Table 6: *Short-run business sector (firms) investments* (equation 7)

Parameter	Estimate/calibration	Standard error
c_0^{SIB}	0.003	0.003
c_1^{SIB}	-0.697	0.268
c_2^{SIB}	0.154	0.089
c_3^{SIB}	0.098	0.008
c_4^{SIB}	-0.086	0.006
c_5^{SIB}	-0.247	0.083

Government interest payments

Table 7: *Government interest payments* (equation 10)

Parameter	Estimate/calibration	Standard error
c_0^{di}	5.764	0.998
c_1^{di}	$2.4e-6$	$5.3e-7$
c_2^{di}	5.959	1.449
c_3^{di}	0.185	0.142

Exports of goods and services

Table 8: *Long-run exports of goods* (equation 12)

Parameter	Estimate/calibration	Standard error
c_0^{EXG}	9.375	0.023
c_1^{EXG}	3.648	0.166
c_2^{EXG}	-0.155	0.196

Table 9: *Short-run exports of goods* (equation 14)

Parameter	Estimate/calibration	Standard error
c_1^{EXGS}	2.716	1.182
c_2^{EXGS}	-0.204	0.124
c_3^{EXGS}	0.097	0.009
c_4^{EXGS}	0.158	0.021
c_5^{EXGS}	-0.316	0.163

Table 10: *Long-run exports of services* (equation 13)

Parameter	Estimate/calibration	Standard error
c_0^{EXS}	9.447	0.018
c_1^{EXS}	2.964	0.128
c_2^{EXS}	-1.644	0.134

Table 11: *Short-run exports of services* (equation 15)

Parameter	Estimate/calibration	Standard error
c_1^{EXSS}	1.656	0.486
c_2^{EXSS}	-0.144	0.117
c_3^{EXSS}	-0.000	0.004
c_4^{EXSS}	-0.043	0.007
c_4^{EXSS}	-0.304	0.079

Export price deflator

Table 12: *Export price deflator* (equation 17)

Parameter	Estimate/calibration	Standard error
c_1^{px}	0.613	0.208
c_2^{px}	0.432	0.179
c_3^{px}	-0.316	0.263
c_4^{px}	0.073	0.005

Effective exchange rate

Table 13: *Effective exchange rate* (equation 18)

Parameter	Estimate/calibration	Standard error
w_{us}	0.120	-
w_{eur}	0.880	-

Imports of goods and services

Table 14: *Long-run imports of goods and services* (equation 19)

Parameter	Estimate/calibration	Standard error
c_0^{IM}	-0.079	0.009
c_1^{IM}	0.484	0.001
c_2^{IM}	-0.333	0.126

Table 15: *Short-run imports of goods and services* (equation 20)

Parameter	Estimate/calibration	Standard error
c_0^{IMS}	-0.001	0.001
c_1^{IMS}	1.218	0.069
c_2^{IMS}	0.457	0.058
c_3^{IMS}	-0.119	0.159
c_4^{IMS}	0.013	0.004
c_5^{IMS}	-0.143	0.057

Import price deflator

Table 16: *Import price deflator* (equation 21)

Parameter	Estimate/calibration	Standard error
c_1^{pm}	0.963	0.029
c_2^{pm}	0.017	0.010
c_3^{pm}	0.419	0.159
c_4^{pm}	0.002	0.001

Inventories

Table 17: *Real inventories* (equation 22)

Parameter	Estimate/calibration	Standard error
c_0^{II}	54.550	202.62
c_1^{II}	-0.237	0.600
c_2^{II}	0.399	0.109

Table 18: *Nominal inventories* (equation 23)

Parameter	Estimate/calibration	Standard error
c_0^{IIN}	-51.401	79.599
c_0^{IIN}	0.988	0.043

Capital

Table 19: *Capital* (equation 92)

Parameter	Estimate/calibration	Standard error
δ	0.012	-
δ^H	0.005	-
δ^G	0.006	-

Labour market

Table 20: *Okun's law* (equation 26)

Parameter	Estimate/calibration	Standard error
c_0^{LD}	35.483	6.402
c_1^{LD}	-2.408	0.375
c_2^{LD}	2.108	0.596

Table 21: *Short-run unemployment* (equation 27)

Parameter	Estimate/calibration	Standard error
c_0^{SLD}	0.001	0.002
c_1^{SLD}	-0.233	0.085
c_2^{SLD}	0.723	0.060
c_3^{SLD}	-0.041	0.193
c_4^{SLD}	0.068	0.003
c_5^{SLD}	-0.079	0.003

Wages

Table 22: *Long-run wages* (equation 29)

Parameter	Estimate/calibration	Standard error
c_0^{LS}	-2.457	0.124
c_1^{LS}	0.984	0.023
c_2^{LS}	-0.793	0.077
c_3^{LS}	0.449	0.042

Table 23: *Short-run wages* (equation 30)

Parameter	Estimate/calibration	Standard error
c_0^{SLS}	-0.002	0.002
c_1^{SLS}	-0.054	0.129
c_2^{SLS}	0.397	0.161
c_3^{SLS}	1.515	0.335
c_4^{SLS}	-0.591	0.134

Prices

Table 24: *Phillips curve* (equation 31)

Parameter	Estimate/calibration	Standard error
c_0^{core}	0.003	0.001
c_1^{core}	0.045	0.011
c_2^{core}	0.057	0.015
c_3^{core}	0.215	0.105
c_4^{core}	0.050	-
c_5^{core}	0.080	-
c_6^{core}	-0.009	0.001

Table 25: *CPI food inflation* (equation 32)

Parameter	Estimate/calibration	Standard error
c_0^{pe}	0.005	0.001
c_1^{pe}	0.035	0.019
c_2^{pe}	0.171	0.085
c_3^{pe}	0.050	-
c_4^{pe}	0.010	-
c_5^{pe}	0.014	0.002

Table 26: *CPI energy inflation* (equation 33)

Parameter	Estimate/calibration	Standard error
c_0^{en}	0.001	0.003
c_1^{en}	0.134	0.011
c_2^{en}	-0.014	0.007
c_3^{en}	0.200	-
c_4^{en}	0.200	-
c_5^{en}	0.071	0.004

Deflators

Table 27: *Consumption deflator* (equation 110)

Parameter	Estimate/calibration	Standard error
c_0^{pc}	0.000	0.000
c_1^{pc}	0.977	0.083

Table 28: *Business investments goods deflator* (equation 111)

Parameter	Estimate/calibration	Standard error
c_0^{pi}	-0.002	0.002
c_1^{pi}	0.905	0.047
c_2^{pi}	-0.271	0.153

Table 29: *Housing investments goods deflator* (equation 112)

Parameter	Estimate/calibration	Standard error
c_0^{pih}	-0.006	0.002
c_1^{pih}	0.159	0.051
c_2^{pih}	0.009	0.010
c_3^{pih}	0.076	0.016

Table 30: *Government consumption deflator* (equation 114)

Parameter	Estimate/calibration	Standard error
c_0^{pg}	0.002	0.001
c_1^{pg}	0.169	0.066
c_2^{pg}	0.408	0.133

Monetary policy rule - exchange rate

Table 31: *Monetary policy rule* (equation 37)

Parameter	Estimate/calibration	Standard error
c_1^{fx}	0.119	0.079

Interbank interest rates

Table 32: *UIP* (equation 38)

Parameter	Estimate/calibration	Standard error
c_1^{RNTB}	0.871	0.039

Risk premium

Table 33: *5Y CDS* (equation 39)

Parameter	Estimate/calibration	Standard error
c_0^{CDS}	0.015	0.002
c_1^{CDS}	0.019	0.005
c_2^{CDS}	0.003	0.000
c_3^{CDS}	0.031	0.014

Non-performing loans

Table 34: *NPLs* (equation 40)

Parameter	Estimate/calibration	Standard error
c_1^{npl}	0.927	0.039
c_2^{npl}	0.252	0.159
c_3^{npl}	-0.087	0.016
c_4^{npl}	0.096	0.045
c_5^{npl}	-0.011	0.005

Interest rates

Table 35: *Banks' financing costs* (equation 41)

Parameter	Estimate/calibration	Standard error
c_1^{RLTB}	0.994	0.008

Table 36: *Short term - business* (equation 42)

Parameter	Estimate/calibration	Standard error
c_0^{RSP}	0.003	0.000
c_1^{RSP}	0.081	0.014
c_2^{RSP}	-0.005	0.002

Table 37: *Long term - business* (equation 43)

Parameter	Estimate/calibration	Standard error
c_0^{RLP}	0.009	0.002
c_1^{RLP}	0.693	0.072

Table 38: *Short term - households* (equation 45)

Parameter	Estimate/calibration	Standard error
c_0^{RSH}	0.003	0.001
c_1^{RSH}	0.051	0.018

Table 39: *Long term - households* (equation 46)

Parameter	Estimate/calibration	Standard error
c_0^{RLH}	0.007	0.002
c_1^{RLH}	0.818	0.048

Real gross operating surplus

Table 40: *Long term - GOS* (equation 48)

Parameter	Estimate/calibration	Standard error
c_0^{gos}	-4.076	0.643
c_1^{gos}	-0.416	0.098
c_2^{gos}	1.237	0.055
c_3^{gos}	0.005	0.000
c_4^{gos}	0.000	0.000

Table 41: *Short term - GOS* (equation 49)

Parameter	Estimate/calibration	Standard error
c_0^{goss}	0.003	0.002
c_1^{goss}	0.077	0.095
c_2^{goss}	-1.211	1.488
c_3^{goss}	-0.990	0.274
c_4^{goss}	-0.661	0.195

Stock price index

Table 42: *CROBEX* (equation 57)

Parameter	Estimate/calibration	Standard error
c_0^{eqp}	-0.011	0.010
c_1^{eqp}	0.403	0.097
c_2^{eqp}	3.922	1.773
c_3^{eqp}	-0.494	0.011
c_4^{eqp}	0.185	0.013
c_5^{eqp}	0.265	0.027

House prices

Table 43: *Long term house prices* (equation 58)

Parameter	Estimate/calibration	Standard error
c_0^{ph}	-9.629	1.188
c_1^{ph}	-0.423	0.037
c_2^{ph}	1.377	0.103
c_3^{ph}	-0.788	0.393

Table 44: *Short term house prices* (equation 59)

Parameter	Estimate/calibration	Standard error
c_0^{phs}	0.001	0.002
c_1^{phs}	0.459	0.143
c_2^{phs}	0.397	0.089
c_3^{phs}	0.725	0.255
c_4^{phs}	-0.233	0.043

Building costs

Table 45: *Building costs* (equation 115)

Parameter	Estimate/calibration	Standard error
c_1^{bc}	1.194	0.143
c_2^{bc}	-0.128	0.039
c_3^{bc}	0.047	0.043

C Figures

Figure 1: Impulse response functions of selected variables to consumer confidence shock (see section 5)
Sources: Model output.

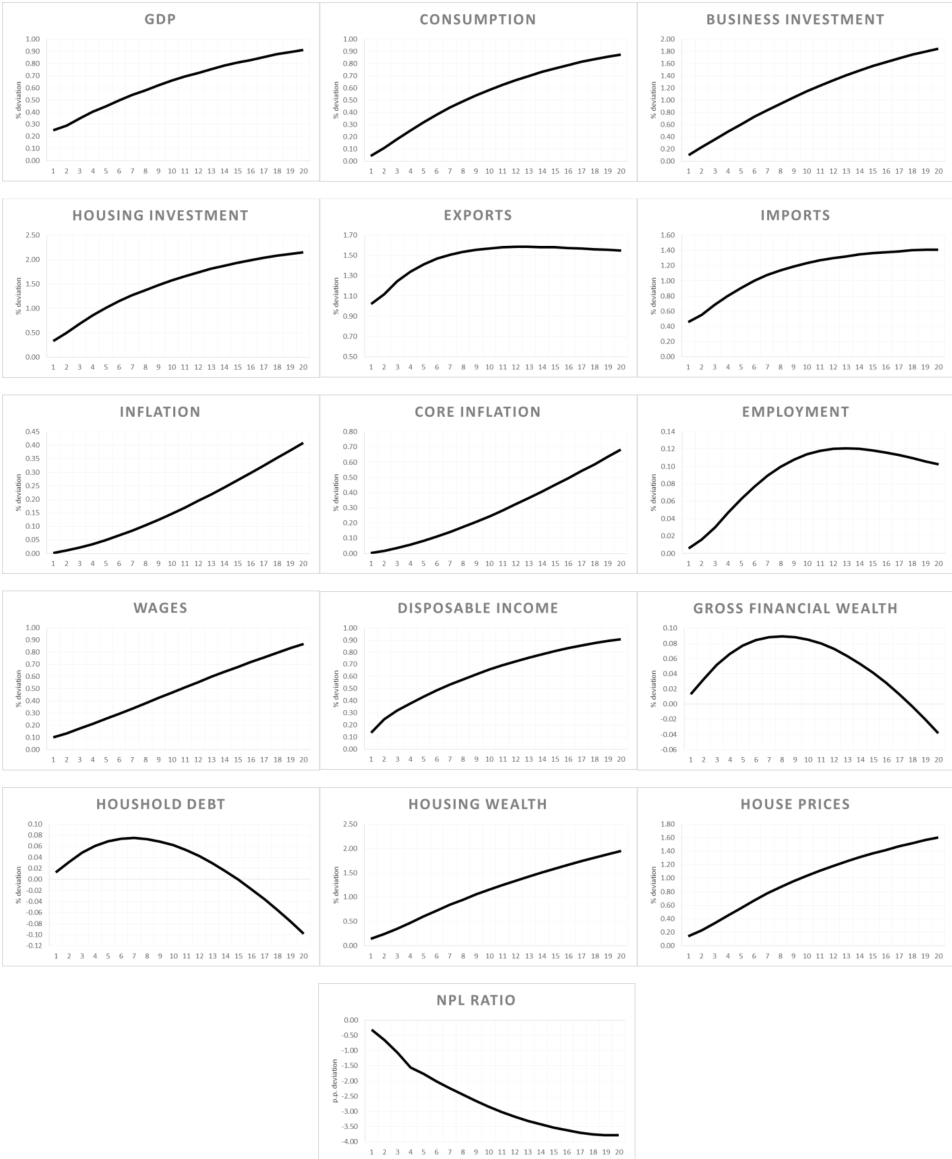

Figure 2: Impulse response functions of selected variables to foreign demand shock (see section 5)
Sources: Model output.

Figure 3: Impulse response functions of selected variables to house price shock (see section 5)
Sources: Model output.

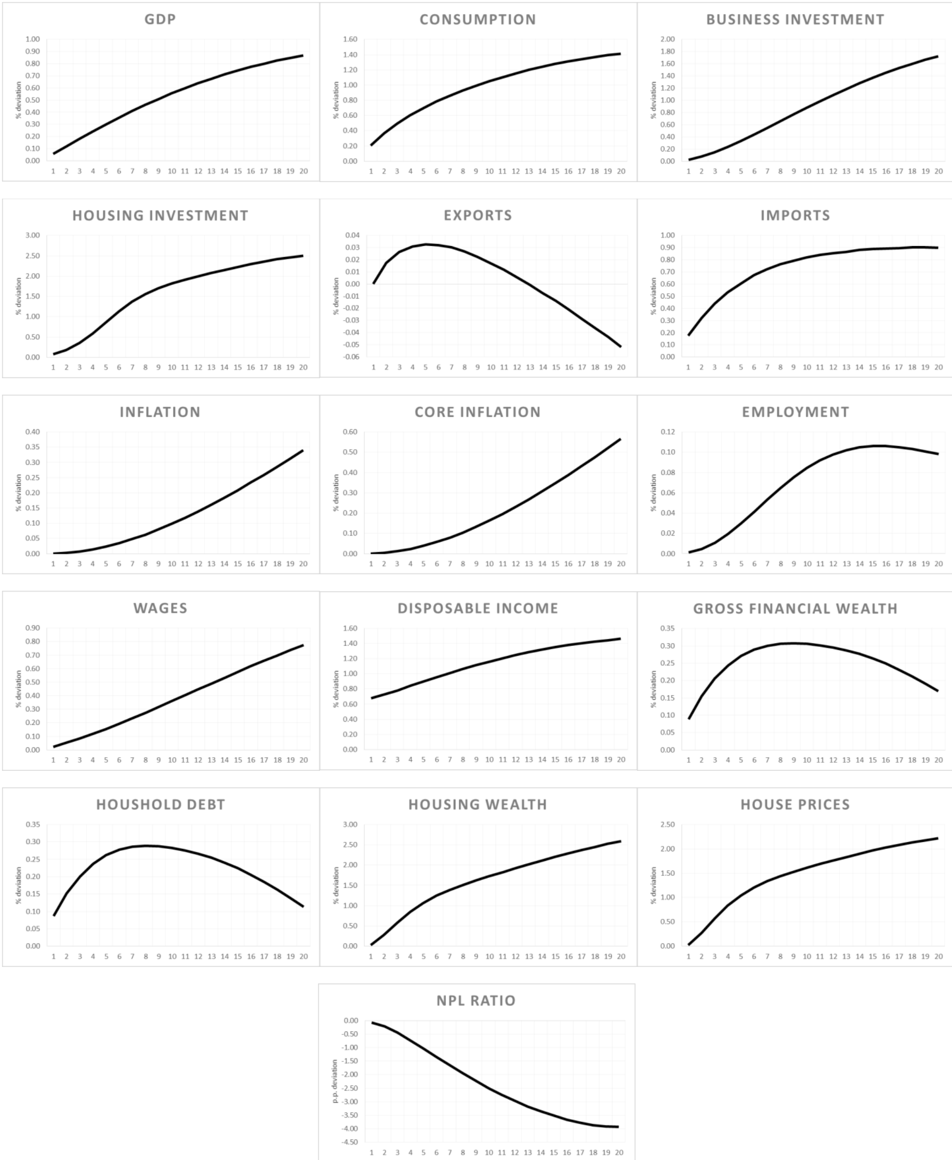

Figure 4: Impulse response functions of selected variables to personal income tax shock (see section 5)
Sources: Model output.

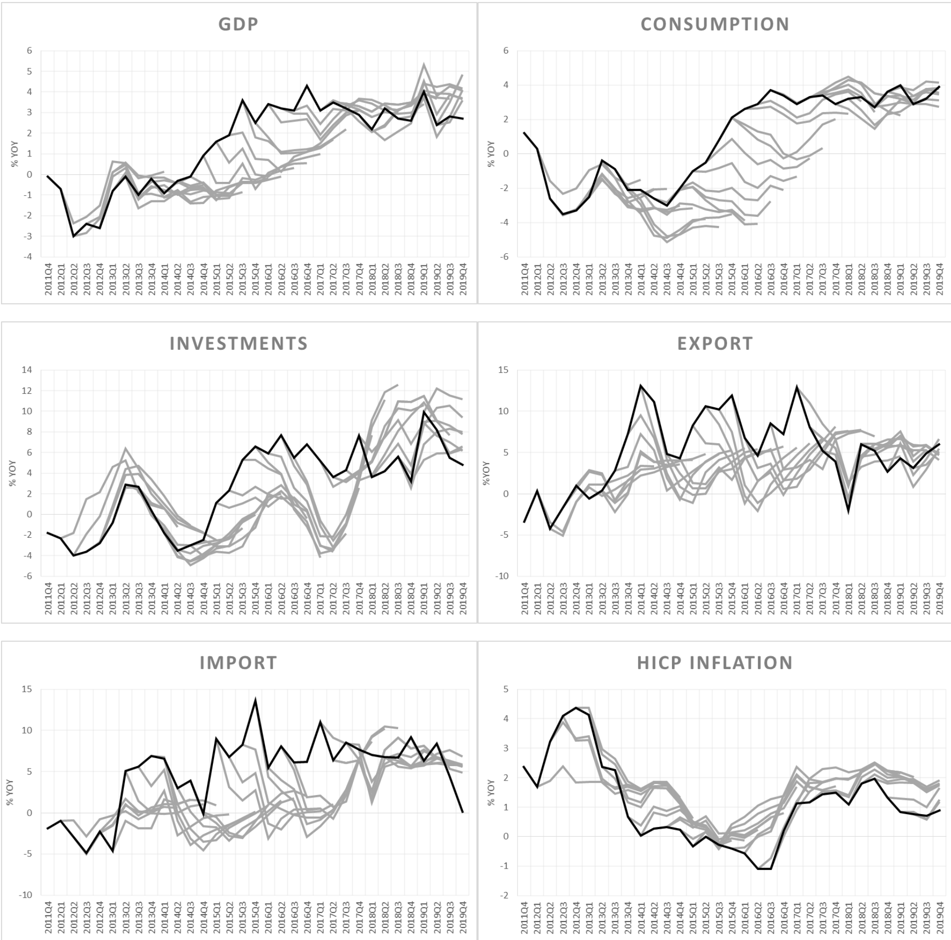

Figure 5: GDP and HICP inflation forecasts (see section 6)
Sources: Model output.

D Database

D.1 Endogenous variables

Core Variables

Variable	Desription	Source, equation No.
$BC_t{}^{**}$	Building Costs	Eurostat, [sts_copi_q], 115
$C_t{}^{*}$	Real Household Consumption	Eurostat, [namq_10_gdp], 1 2
$CDS5Y_t$	5Y Credit Default Swap	Bloomberg, 39
cpi_t^{core**}	HICP Core Inflation	Eurostat, "prc_hicp_midx", 31
cpi_t^{en**}	HICP Energy Inflation	Eurostat, "prc_hicp_midx", 33
cpi_t^{pe**}	HICP food inflation	Eurostat, "prc_hicp_midx", 32
$DI_t{}^{**}$	Government Interest Payments	Eurostat, "gov_10q_ggnfa", 10
$EER_t{}^{**}$	Effective Exchange Rate	Croatian National Bank, 18
$EUR\_HRK_t{}^{**}$	EUR Exchange Rate	Croatian National Bank, Table G10a, 37
EQP_t	CROBEX	Croatian stock exchange, 57
$EXG_t{}^{*}$	Real Exports of Goods	Eurostat, [namq_10_gdp], 12 14
$EXS_t{}^{*}$	Real Exports of Services	Eurostat, [namq_10_gdp], 13 15
$GOS_t{}^{*}$	Real Gross Operating Surplas	Eurostat, [namq_10_gdp], 48 49
I_t^{BUS***}	Real Business Investments	ECB and Eurostat, 6 7
I_t^{H}	Real Households Investments	ECB "QSA.Q.N.HR.W0.S1.S1.N.D.P51G. _Z. _Z. _Z.XDC. _T.S.V.N. _T" and Eurostat, 3 4
$II_t{}^{***}$	Real Inventories	$GDP_t - (C_t + I_t + G_t + EX_t - IMP_t)$, 22
$IIN_t{}^{***}$	Nominal Inventories	$GDPN_t - (CN_t + IN_t + GN_t + EXN_t - IMPN_t)$, 23
$IM_t{}^{*}$	Real Imports of Goods and Services	Eurostat, [namq_10_gdp], 19 20
NPL_t	Non Performing Loans Ratio	Croatian National Bank, Table SP8, 40
$PC_t{}^{***}$	Private Consumption Deflator	Eurostat, [namq_10_gdp], 110
$PG_t{}^{***}$	Government Consumption Deflator	Eurostat, [namq_10_gdp], 114
$PH_t{}^{**}$	House Price Index	Croatian National Bank, Table J3, 58 59
$PI_t{}^{***}$	Investments Deflator	Eurostat, [namq_10_gdp], 111
$PIH_t{}^{***}$	Household Investment Deflator	Identity, 112
$PM_t{}^{***}$	Imports Deflator	Eurostat, [namq_10_gdp], 21
$PX_t{}^{***}$	Exports Deflator	Eurostat, [namq_10_gdp], 17
RLH_t	Long-term Household Interest Rates	Croatian National Bank, Tables: h_g5a-c, h_g6a-c, 46

Variable	Desription	Source, equation No.
RLP_t	Long-term Business Interest Rates	Croatian National Bank, Tables: h_g5a-c, h_g6a-c, 46
$RLTB_t$	Banks' Financing Costs	Croatian National Bank, Table e-m2-AT-KI_year-month, 41
$RNTB_t$	Interbank Interest Rate	Croatian National Bank, Table h-g7a, 38
RSH_t	Short-term Household Interest Rates	Croatian National Bank, Tables: h_g5a-c, h_g6a-c, 45
RSP_t	Short-term Business Interest Rates	Croatian National Bank, Tables: h_g5a-c, h_g6a-c, 45
${UR_t}^*$	Unemployment Rate	Eurostat, "une_rt_q", 26 27
${W_t}^{***}$	Wages	Eurostat, [namq_10_gdp], 29 30

Identities

Variable	Desription	Source, equation No.
${BAL_t}^{***}$	Current Account Balance	Identity, 72
${BALT_t}^{***}$	Trade Balance	Identity, 73
${BIPD_t}^{**}$	Primary Income	ECB, "BP6.Q.N.HR.W1.S1.S1.T.B.IN1. _Z ._Z._Z.HRK._T._X.N", 78
${CN_t}^*$	Nominal Household Consumption	Eurostat, [namq_10_gdp], 65
${CPI_t}^{**}$	HICP inflation	Eurostat, "prc_hicp_midx", 35
${DD_t}^{***}$	Real Domestic Demand	Identity, 63
${DDN_t}^{***}$	Nominal Domestic Demand	Identity, 64
${DEBT_t}^{***}$	Government Debt	Identity, 9
${DH_t}^{**}$	Household Debt	Eurostat, "nasq_10_f_bs", 54
$EUR\_HRK_t^{E**}$	Expected Exchange Rate	Identity, $EUR\_HRK_t^E = EUR\_HRK_{t-1}$
${EMP_t}^{***}$	Employment	Identity, 28
${EMPT_t}^{***}$	Trend Employment	Identity, 81
EUR_HRK^*	EUR Exchange Rate Target	Identity, 36
${EX_t}^*$	Real Exports of Goods and Services	Eurostat, [namq_10_gdp], 16
${EXN_t}^{**}$	Nominal Exports of Goods and Services	Eurostat, [namq_10_gdp], 76
G_t^{def***}	Government Deficit	Identity, 96
G_t^{ex***}	Government Expenditures	Eurostat, "gov_10q_ggnfa", 8
${GDP_{gap_t}}^{***}$	GDP gap	Identity, 25
${GDP_t}^*$	Real Gross Domestic Product	Eurostat, [namq_10_gdp], 60

Variable	Desription	Source, equation No.
$GDPN_t{}^*$	Nominal Gross Domestic Product	Eurostat, [namq_10_gdp], 61
$GDPT_t{}^{***}$	Potential GDP	Identity, 24
$GFW_t{}^{**}$	Gross Financial Wealth, households	Eurostat, "nasq_10_f_bs" , 53
$GN_t{}^*$	Nominal Government Consumption	Eurostat, [namq_10_gdp], 71
$GOSN_t{}^{***}$	Nominal Gross Operating Surplas	Eurostat, [namq_10_gdp], $GOSN_t = GOS_t PGDP_t$
G_t^{tax***}	Nominal Tax Revenues	Identity, 11
$G_t^{rtax***}$	Real Tax Revenues	Identity, 109
$HW_t{}^{***}$	Household Wealth	Identity, 51
$I_t{}^*$	Real Investments	Eurostat, [namq_10_gdp], 66
$IN_t{}^*$	Nominal Investments	Eurostat, [namq_10_gdp], 67
IN_t^{B***}	Nominal Business Investments	ECB, 70
IN_t^G	Nominal Government Investments	ECB, 69
IN_t^H	Nominal Household Investments	ECB, 68
$IMN_t{}^*$	Nominal Imports	Eurostat, [namq_10_gdp], 77
K_t	Capital	Identity, 92
K_t^{B***}	Business Capital	Identity, 95
K_t^G	Government Capital	Identity, 94
K_t^H	Households Capital	Identity, 93
$NFA_t{}^{**}$	Net Foreign Assets (BoP)	ECB, "BP6.Q.N.HR.W1.S1.S1.LE.N.FA._T.F._Z.HRK._T._X.N", 79
$NFW_t{}^{***}$	Net Financial Wealth (Households)	Identity, 52
$NDY_t{}^{***}$	Nominal Household Post-Tax Income	Identity, 87
$OEX_t{}^{**}$	Other Government Expenditures	Eurostat, "gov_10q_ggnfa"
$OHT_t{}^{***}$	Other Taxes Paid by Households	Eurostat, "gov_10q_ggnfa", 99
$OT_t{}^{**}$	Other Taxes	Eurostat, "gov_10q_ggnfa", 108
$OTP_t{}^{**}$	Other Taxes on Goods and Services	Eurostat, "gov_10q_ggnfa", 107

Variable	Desription	Source, equation No.
PAT_t***	Trend Participation Rate	Identity, 82
$PGDP_t$***	GDP Deflator	Eurostat, [namq_10_gdp], 62
PIG_t***	Government Investment Deflator	Identity, 113
$POIL\_KN_t$	Oil Prices	Identity, 34
$PROD_t$***	Productivity	Identity, 83
RCC_t***	Real Cost of Capital	Identity, 5
REV_t^{A***}	Revaluation of Assets (GFW)	Identity, 55
REV_t^{D***}	Revaluation of Debt (DH)	Identity, 56
REX_t***	Real Exchange Rate	Identity, 75
RDY_t***	Real Household Post-Tax Income	Identity, 86
$RLHV_t$	Real Long-term Households Interest Rates	Identity, 47
$RLPV_t$	Real Long-term Business Interest Rates	Identity, 44
$RULC_t$***	Real Unit Labour Costs	Identity, 85
SR_t***	Saving Rate	Identity, 88
TC_t***	Total Corporate Taxes	Eurostat, "gov_10q_ggnfa", 100
$TCAR_t$**	International Trade Taxes	Eurostat, "gov_10q_ggnfa", 106
TCI_t**	Corporate Income Tax	Eurostat, "gov_10q_ggnfa", 101
TCS_t**	Contributions Paid by Corporate Sector	Eurostat, "gov_10q_ggnfa", 102
THW_t**	Households' Taxes (Income and Wealth)	Identity, $THW = TLH - TSS$
TJ_t**	Total Taxes Paid by Households	Identity, 97
TLH_t***	Taxes on Labour Paid by Households	Identity, 98
TOT_t***	Terms of Trade	Identity, 74
TP_t***	Taxes on Goods and Services	Identity, 103
$TPDV_t$**	Value Added Tax	Eurostat, "gov_10q_ggnfa", 104
TSS_t**	Households' Social Contributions	Eurostat, "gov_10q_ggnfa"
TT_t**	Excises	Eurostat, "gov_10q_ggnfa", 105
ULC_t***	Unit Labour Cost	Identity, 84
UN_t*	No of Unemployed Persons	Identity, 80
WEL_t***	Household Wealth	Identity, 50
WPX_KN_t***	World Export Prices in HRK	Identity, $WPX\_KN_t = WPX_t EER_t$
YE_t*	Compensantion of Employees	Eurostat, [namq_10_gdp], 90 91
YJ_t***	Gross Income	Identity, 89

D.2 Exogenous variables

Variable	Desription	Source
$BTRF_t{}^{**}$	Secondary Income	ECB, "BP6.Q.N.HR.W1.S1.S1.T.B.IN2. _Z._Z._Z.HRK._T._X.N"
US_t	USD Exchange Rate	Croatian National Bank, Table G10a
$G_t{}^{*}$	Real Government Consumption	Eurostat, [namq_10_gdp]
$HG_t{}^{**}$	Government Transfers to Households	Eurostat, "gov_10q_ggnfa"
HP_{EUR/HRK_t}	HP Filter EUR Exchange Rate	-
TFP_t	Technological Progress	Croatian National Bank estimate
I_t^G	Real Government Investments	ECB and Eurostat, "QSA.Q.N.HR.W0.S13.S1.N.D.P51G. _Z. _Z._T.XDC. _T.S.V.N. _T"
$NAIRU_t$	Non-Accelerating Inflation Rate of Unemployment	Croatian National Bank estimates
PA_t	Participation Rate	Calculated as $PA_t = \frac{UN_t+EMP_t}{POWA_t}$
PC_CDS_t	Common component of EU sovereign spreads	Bloomberg (principal component of EU sovereign CDS spreads)
$POIL_t$	Oil Prices	Bloomberg (Brent crude oil prices in USD)
$SUBS_t{}^{**}$	Government Subsidies	Eurostat, "gov_10q_ggnfa"
$TRCAR_t{}^{***}$	International Trade Implicit Tax Rate	Calculated using 106
$TRCI_t{}^{***}$	Corporate Income Implicit Tax Rate	Calculated using 101
$TRCS_t{}^{***}$	Contributions Paid by Corporate Sector - Implicit Tax Rate	Calculated using 102
$TRLH_t{}^{***}$	Implicit Tax Rate on Labour Paid by Households	Calculated using 98
$TROH_t{}^{***}$	Other Taxes Paid by Households - Implicit Tax Rate	Calculated using 99
$TROT_t{}^{***}$	Other Taxes- Implicit Tax Rate	Calculated using 108
$TROTP_t{}^{***}$	Other Taxes on Goods and Services - Implicit Tax Rate	Calculated using 107
$TRPDV_t{}^{***}$	Value Added Implicit Tax Rate	Calculated using 104
$TRT_t{}^{***}$	Implicit Excise duties Rate	Calculated using 105

Variable	Desription	Source
$P_t^{W_{food}}$	World Food Prices	International Monetary Fund, Primary Commodity Price System
$WGDP_t$	World GDP	Eurostat, "naidq_10_gdp", Croatian main trade partners' weighted average
WRS_t	World Interest Rate (EA)	ECB, "FM.M.U2.EUR.RT.MM. EURIBOR3MD_.HSTA"
WPX_t	World Export Prices	OECD.Stat (Quarterly National Accounts), Croatian main trade partners' weighted average

D.3 Parameters

Variable	Desription	Source
$W_{cpi^{core}}$	HICP core inflation weight	Eurostat, "prc_hicp_inw"
$W_{cpi^{en}}$	HICP energy inflation weight	Eurostat, "prc_hicp_inw"
$W_{cpi^{food}}$	HICP food inflation weight	Eurostat, "prc_hicp_inw"
δ	Capital Depreciation	0.0122
δ^G	Government Capital Depreciation	0.006
δ^H	Household Capital Depreciation	0.005
$EUR\_HRK^*_{ss}$	EUR Exchange Rate Target Steady State	1.011

Notation:

- No asterisk - original data (no seasonal adjustment).
- One asterisk (*) - seasonally adjusted data by Eurostat.
- Two asterisks (**) - data adjusted by x12-ARIMA seasonal adjustment program in EViews.
- Three asterisks (***) - indirectly seasonally adjusted data (from identities).

List of Equations

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