South East European Journal of Economics and Business
Volume 18 (1) 2023, 115-144
DOI: 10.2478/jeb-2023-0009

MODELLING NATIONAL ECONOMIC SYSTEM: A CASE OF THE CROATIAN ECONOMY

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Abstract

In this study we evaluate a national economic model using a system dynamics approach. We use a set of macroeconomic data for a transition economy to validate the model behaviour in the past, and then simulate the alternative paths of key macroeconomic variables. Instead of studying only a fraction of the economy, or using simple and abstract models, we build a large-scale national economic model. As the study is based on system dynamics information feedback, it provides additional insights about the macroeconomic effects of the economic policy, making it a valuable tool for economic policy analysis. Such insights are instrumental for understanding the total effects of economic policies and their full economic consequences. To demonstrate this, we have simulated one actual economic policy intervention and its alternative scenario.

Keywords: *national economic model, system dynamics, macroeconomics, economic policy analysis*

JEL Classification: *C63, C65, O41, E62, E47*

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1. Introduction

Mainstream economics has become increasingly criticized for its unrealistic assumptions and high level of abstraction, in the light of the most recent global financial and economic crisis. The academia and the public are questioning the standard economics' paradigm and are calling for a wider application of sometimes neglected concepts such as complexity, dynamics, nonlinearity, psychology, etc. for example, as Forrester (2003) suggested, the economics should become a systems profession, such as management, by focusing on the proper policy analysis aimed at the improvements in economic policy making. Such reasoning has motivated us to apply a system dynamics (SD) approach to the issue of national economic modelling.

Having in mind that economic systems are dynamic, complex, nonlinear, and composed of many interacting agents, one should take a holistic approach to modelling a complete national economy (Cavana 2021). Our approach is based on the SD type of a structural national economic model (for a transition economy) developed by Yamaguchi (2013). We calibrate the model for a small open transition economy, Croatia, simulate an interesting fiscal policy scenario, discuss potential forecasting benefits of this type of model, and emphasize the usefulness of such model as an economic policy management tool and also as an aid in education as in Wheat (2007).

The main contribution of the paper is that, to the best of our knowledge, it delivers the first complete Croatian SD national economic model calibrated on real historical data. Besides, our results also provide an additional insight into the functioning of the Croatian economy and offer economic policy advice based on the simulation of different possible scenarios.

The model incorporates elements of older behavioural models for the SD national model of the US economy (Forrester 1980, Sterman 2000), and the accounting SD approach to macroeconomic modelling (Yamaguchi 2013). Model features a number of economic behaviour equations, including both real and monetary sector, implementation of feedback loops, and, most importantly, endogeneity by construction. On the other hand, most of the conventional general equilibrium type of models, rely on a number of highly restrictive assumptions about economic behaviour and describe economic systems which are exposed to entirely exogenous shocks (LeBaron and Tesfatsion 2008). According to some criticism by Colander (2011), the latter feature is the reason for poor performance of dynamic stochastic general equilibrium (DSGE) type models in explaining real world phenomena, especially related to the latest (2007-2009) global financial crisis.

The complete version of the Yamaguchi national economic model comprises the labour market and six different economic sectors: the central bank, commercial banks, consumers (households), producers (firms), the government and the foreign sector. These sectors interact in a dynamic monetary economy by exchanging goods and services for money. As these economic transactions between sectors have feedback effects, which are an important feature of the real-world economic systems, a national economic model should aim to include all transactions among all sectors, in order to ensure a consistent relational framework. As suggested by Yamaguchi (2013), the main analytical tool for such a model is the double entry accounting system, also used in the system of national accounts. System of national accounts (IMF 2008) is an internationally agreed comprehensive system used to organize all economic flows between sectors of the national economy, as well as resulting changes in the stocks, and thereby provide a consistent complete and comparable picture of a particular national economy (Keen 2011).

Failing to consistently entail the multitude of interconnections between economic sectors of the economy causes causal loopholes, an often case in some of the more abstract standard macroeconomic models - such as neoclassical DSGE and New Keynesian models. Moreover, a complete and holistic national economic SD model provides a synthesis of neoclassical and Keynesian school of economics, treating them as different behaviours of the same system, rather than behaviours of structurally and fundamentally different economic systems (Yamaguchi 2013).

SD macroeconomic research is relatively scarce and limited to a couple of studies. For example, Mashayekhi (1991) models the relationship between exchange rate policy and inflation rate for an oil-exporting economy. Klaus (2012) develops an SD version of the Stein's model (Stein 2012), using only one good and three sectors. Among the few attempts to use the SD approach to model a national economy is model by Nadezda (2011) and for the case of Croatia by Garača (2006). However, these models focus only on one sector, or one part of the economy and they are not intended for economic policy consideration. On the other hand, we try to develop a complete national economy model which can then be used for to evaluate economy-wide effects of the particular economic policy.

The rest of the paper is organized as follows. In the next chapter we present the SD model, its behavioural equations, and relations and interaction between economic sectors in the model. This chapter is then followed by the SD national economic model calibrated for the transition economy of Croatia. The last chapter discusses the results and concludes the paper.

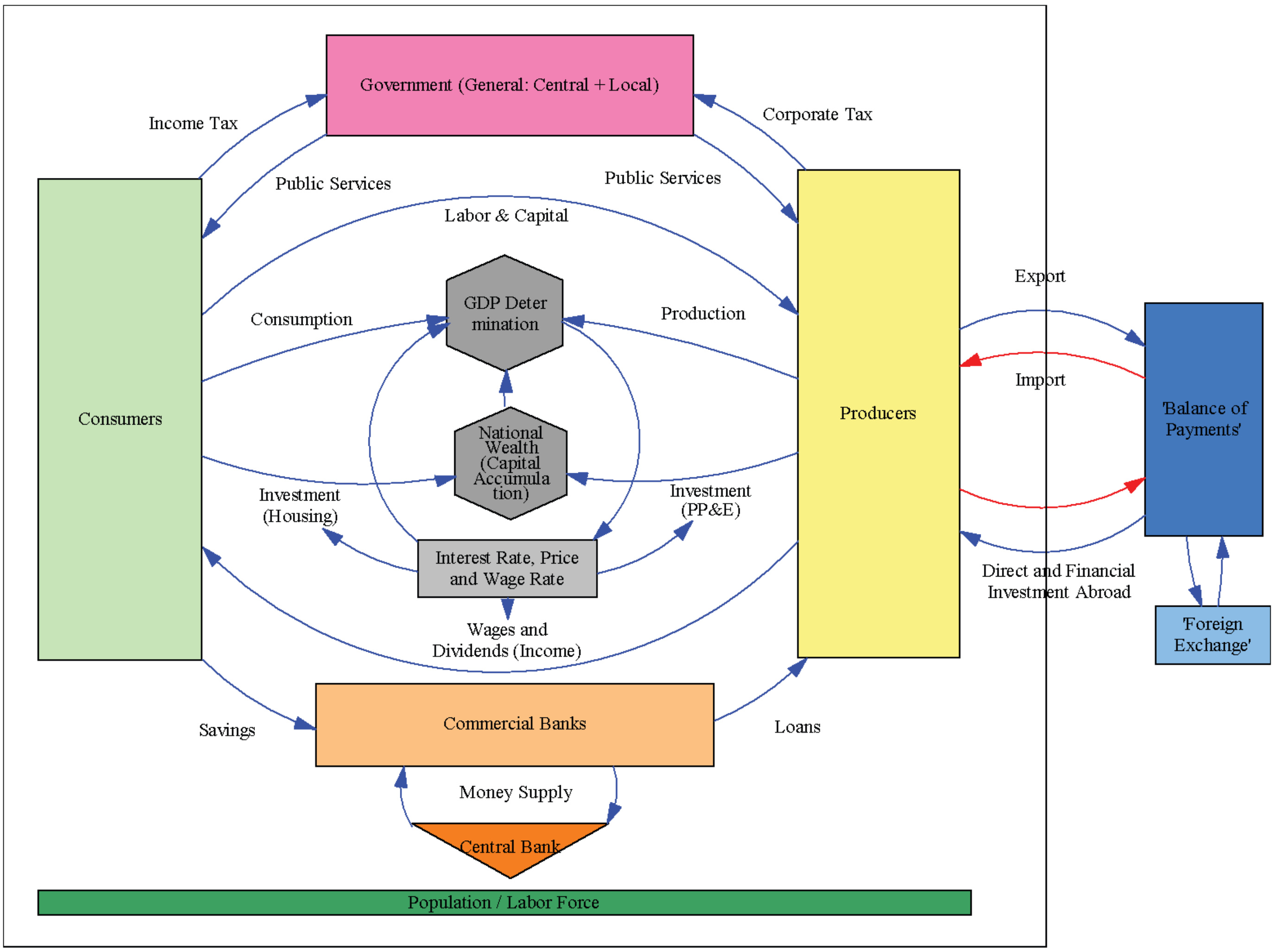
2. Methods

2.1. Model

Our version of SD national economic model comprises five sectors: producers (firms), consumers (households), government, commercial banks, and the central bank (Figure 1). In order to focus on the intra-national relations in the total economy, the foreign sector is modelled exogenously. In addition, due to a number of issues with Croatian labour market data, in the current version of the model we also abstract from the labour market.

In the core of the model there are 15 equations with 15 unknown variables and 12 exogenously determined parameters. These equations are systematically presented below and the names of the variables together with equivalent symbols and values for exogenous fixed parameters can be found in Table 1 of the Appendix.

Figure 1. High level model structure comprising of five sectors: Consumers, Producers, Government (both central and local), Commercial Banks, Central Bank and without an external sector and with the endogenous treatment of the labour market.



$$Y_{full} = AK^{\alpha} L^{\beta} = e^{\kappa t} Y_0 \left(\frac{K}{K_0} \right)^{\alpha} \left(\frac{L}{L_0} \right)^{\beta} \quad \textit{(Full Capacity Output)} \quad (1)$$

$$Y_{potential} = AK^{\alpha} LF^{\beta} = e^{\kappa t} Y_0 \left(\frac{K}{K_0} \right)^{\alpha} \left(\frac{L}{LF_0} \right)^{\beta} \quad \textit{(Potential GDP)}$$

$$Y = Min\left(Y_{full}, Y^D \right) \quad \textit{(Production Decision)} \quad (2)$$

$$\begin{aligned} Y^D &= \varphi\left(I_{nv}{}^{*} - I_{nv} \right) + AD_{forecast} \\ &= \frac{I_{nv}{}^{*} - I_{nv}}{Time\ to\ Adjust\ Inventory} + AD_{forecast} \\ \frac{dAD_{forecast}}{dt} &= \frac{AD - AD_{forecast}}{Forecasting\ Adjustment\ Time} \end{aligned} \quad \textit{(Desired Production)} \quad (3)$$

$$\begin{aligned} \frac{dI_{nv}}{dt} &= Y - AD \\ I_{nv}{}^{*} &= AD_{forecast} \cdot Normal\ Inventory\ Coverage \end{aligned} \quad \textit{(Inventory Adjustment)} \quad (4)$$

$$AD = C + I + G + X \text{ - } M \quad \textit{(Aggregate Demand)} \quad (5)$$

$$\begin{aligned} C(P) &= C_0 + c(P) \cdot Y_d \\ c(P) &= \frac{c}{\left(\frac{P}{P_0} \right)^{e}} \end{aligned} \quad \textit{(Consumption Decision)} \quad (6)$$

$$Y_d = Y - T \quad \textit{(Disposable Income)} \quad (7)$$

$$T = T_0 + T_{income} + T_{production} + T_{corporate} \quad \textit{(Tax Revenues)} \quad (8)$$

$$\begin{aligned} T_{income} &= t_{income} Y - T_r \\ &= Wages \cdot t_{income} \end{aligned} \quad \textit{(Income Tax)}$$

$$T_{production} = t_{production} \cdot GDP \,/\, (\, 1 + t_{production} \,) \quad \textit{(Production Tax)}$$

$$T_{corporate} = t_{corporate} \cdot Profit \quad \textit{(Corporate Tax)}$$

$$\begin{aligned} I &= \frac{K^{*}(i) - K}{Capital\ Adjustment\ Time} + \delta K \\ K^{*}(i) &= \frac{\alpha\left(1 - t_{production} \right) Y^{*}}{i + \delta} \\ &(\text{or } I_{real}(r) = \frac{I_0}{r} - \alpha_1 r) \\ I &= I_{real}(r) \cdot P \end{aligned} \quad \textit{(Investment Decisions)} \quad (9)$$

$$\frac{dK}{dt} = I - \delta \cdot K \quad \textit{(Net Capital Accumulation)} \quad (10)$$

$$\frac{dG}{dt} = g \cdot G_0 \quad (\text{or } G = \beta_{PB}\text{T}) \qquad \textit{(Government Expenditures)} \qquad (11)$$

$$\begin{aligned} \frac{dP}{dt} &= \psi_1\left(Y^D - Y_{full},\ I_{nv}{}^* - I_{nv}\right) + \psi_2\left(\frac{\log(w)}{dt}\right) \\ &= \frac{P^* - P}{Delay\,Time} \\ P^* &= \frac{P}{\left[(1-\omega)\frac{Y_{full}}{Y^D} + \omega\frac{I_{nv}}{I_{nv}{}^*}\right]^e} \end{aligned} \qquad \textit{(Price Adjustment)} \qquad (12)$$

$$\begin{aligned} & m^s = \frac{M^s}{P}V \\ & (\text{or } M^s = Currency\ in\ Circualtion + Deposits) \end{aligned} \qquad \textit{(Real Money Supply)} \qquad (13)$$

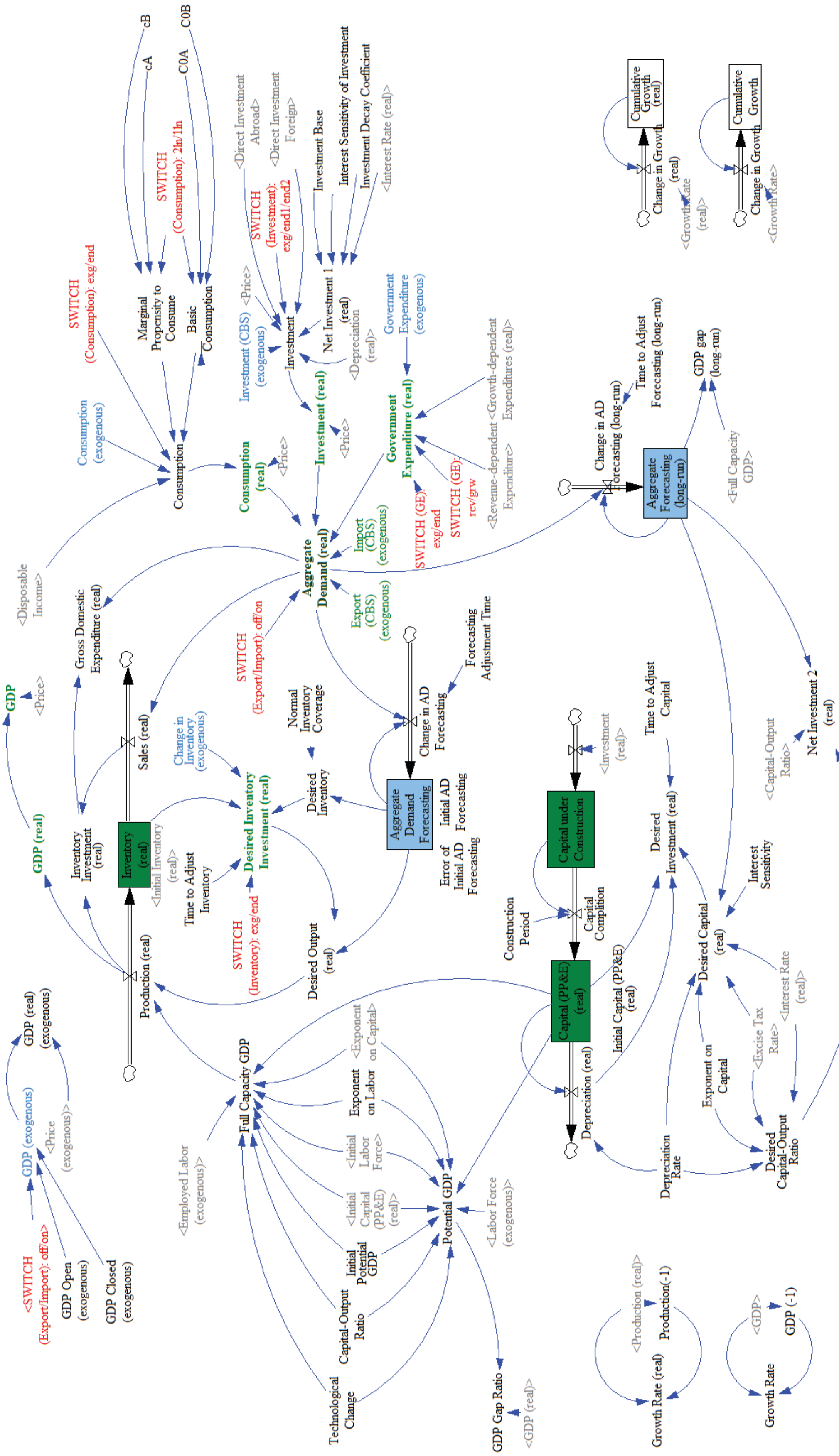
$$\begin{aligned} & m^d = a \cdot Y / P - b \cdot r \\ & (\text{or } M^d = Demand\ for\ Money(Consumers) \\ & + Demand\ for\ Money(Producers) \\ & + Demand\ for\ Money(Governmet) \\ & + Demand\ for\ Money(Banks)) \end{aligned} \qquad \textit{(Real Money Demand)} \qquad (14)$$

$$\begin{aligned} \frac{dr}{dt} &= \Phi\left(m^d - m^s\right) \\ &= \frac{r^* - r}{Delay\,Time} \\ r^* &= \frac{r}{(m^s / m^d)^e} \\ i &= r + \pi \end{aligned} \qquad \textit{(Interest Adjustment)} \qquad (15)$$

In addition to the core equations presented above, we also introduce supplementary equations that define the relationship between the nominal interest rate *i*, the real interest rate *r*, the inflation rate *π*, the *premium rate*, and the *premium rate spread*. These relationships are presented as follows:

$$\begin{aligned} & i = r + \pi \\ & prime\,rate = i + premium\,rate\,spread \end{aligned} \qquad (16)$$

Figure 2. GDP determination model.



Note: Rectangular represents stock, double (bold) arrow represents flow, and the variable is connected to stock and flow using the feedback information (thin) arrow.

2.2. GDP Determination

According to the standard production function approach, an economy produces its total output Y_{full}, by using the capital stock K and the labour force L. As there is no guarantee that the temporary Keynesian equilibrium GDP Y^*, is equal to the full production output Y_{full}, the situation $Y^*<Y_{full}$ implies that the capital stock is under-utilized, a part of the labour force is unemployed, and the economy is in a recession (Yamaguchi 2013). It has to be noted that total output can differ from the potential amount of output $Y_{potential}$, which is produced when the amount of existing capital stock K and total available labour force LF used do not create inflation pressures.

Figure 2 illustrates the GDP determination model. Inventory stock I_{nv}, is the key variable of the model because it captures the discrepancy between the production and sales (shipment) and thereby reflects short-term demand fluctuations; this relationship is characterized by equation (4). Mainstream macroeconomics, by treating inventory as undesired investment, equalizes the produced output production and the aggregate demand. In Yamaguchi-type models, however, the introduction of inventory stock allows that aggregate demand and production mismatch the equilibrium, implying an intrinsically cyclical and fluctuating nature of the Keynesian adjustment process, as opposed to smooth adjustment suggested by conventional macroeconomics (Yamaguchi 2013).

Government tax revenues, represented by the equation (8), consist of four types: lump-sum taxes such as property taxes (T_0), income taxes proportional to the level of income ($t_{income} \cdot Y$), with t_{income} the income tax rate, production taxes ($T_{production}$) that are defined by the production tax rate ($t_{production}$), and from which government subsidies (T_r) are deducted, and profit or corporate taxes ($T_{corporate}$).

Investment decision (9) is determined by the capital depreciation δ and the difference between desired K^* and actual capital K level, where desired capital K^* is defined by the interest rate i, exponent on capital α, production tax rate $t_{production}$, depreciation rate δ, and desired output Y^* (18), which is obtained by maximizing producer's profit function Π (17).

$$\begin{aligned}\Pi &= \left[\left(1-t_{production}\right)P\cdot Y_{full}-\left(i+\delta\right)P_K K-wL\right]\cdot\left(1-t_{corporate}\right)\\ &=\left(1-t_{production}\right)\left(1-t_{corporate}\right)\left(1-\alpha-\beta\right)P\cdot Y_{full}\\ &\frac{\partial\Pi}{\partial K}=0 \quad\rightarrow\quad K^* \qquad\qquad \frac{\partial\Pi}{\partial L}=0\quad\rightarrow\quad L^*\end{aligned} \qquad \textit{(Profit Maximization)} \qquad (17)$$

$$K^*=\frac{\alpha\left(1-t_{production}\right)Y^*}{i+\delta} \qquad \textit{(Desired Capital)} \qquad (18)$$

$$\begin{aligned}L^* &= \frac{\beta\left(1-t_{corporate}\right)P\cdot Y^*}{w^e}\\ w^e &= w\left(1+\pi\right)\end{aligned} \qquad \textit{(Desired Labour)} \qquad (19)$$

Same producers' profit maximization function (17) determines a desired amount of labour L^* (19).

2.3. Interest Rate, Price and Wage Rate

The real interest rate is adjusted dynamically as suggested by (15), and money market equilibrium is reached when money supply m^s (13) is equal to money demand m^d (14). Money velocity is represented by V and it comes in units of $1/year$, M^s is nominal money supply, a is a fraction of income assigned for transactional demand of money, b represents interest sensitivity of demand for money and P is price level.

The interest rate adjustment process can be further specified as:

$$\frac{dr}{dt}=\frac{r^*-r}{DelayTime} \qquad (20)$$

where the desired interest rate i^* is obtained as:

$$r^*=\frac{r}{\left(MoneyRatio\right)^e}=\frac{r}{\left(\frac{m^s}{m^d}\right)^e} \qquad (21)$$

in which e denotes a money ratio elasticity of desired interest rate. Figure 3 illustrates the interest rate adjustment process model.

The price adjustment mechanism (12) is obtained through the adjustment of the GDP gap (discrepancy between full capacity output Y_{full} and desired production Y^D) and the inventory gap (discrepancy between current inventory I_{nv} and desired inventory I_{nv}^*). The weight ratio ω controls the contribution that each of the gaps has on the desired price change, while elasticity e determines the overall effect of gaps on the desired price change.

The nominal wage rate w is determined in the labour market (22), where L^* denotes desired labour (19) and L^s denotes labour supply that is for the moment determined exogenously in the model. Parameter e presents labour market elasticity, while W stands for the total wage bill in the economy.

$$\frac{dw}{dt} = \phi\left(L^* - L^s\right)$$
$$\frac{dw}{dt} = \frac{w^* - w}{Delay\,Time} \qquad \text{(Wage } Rate\text{)} \quad (22)$$
$$w^* = \frac{w}{\left(\frac{L^s}{L^*}\right)^e}$$

$$W = w \cdot L_{employed} \qquad \text{(Wages)} \quad (23)$$
$$(or = GDP \cdot Distribution\,Ratio\,of\,Wages)$$

GDP and the interest rate in the aggregate demand equilibrium (Y^*, i^*) are determined by the intersection of the IS curve (that presents the equilibrium condition in the goods market), and the LM curve (that presents the equilibrium condition in the money market), while keeping prices fixed in the short run, as in the typical Keynesian model.

As mentioned previously, this equilibrium (Y^*) is not necessarily equal to the full capacity output level (Y_{full}); in order to achieve full capacity equilibrium where $Y^*=Y_{full}$, prices would need to be flexible. The latter can be easily introduced into the model by setting e to 1.0.

In the following subchapters, we describe five main sectors of the economy, and we explain the transaction between these sectors.

2.4. Producers

Producers are faced with two decisions: how much to produce this year and how much to invest for the future. In our model, production decisions are made by inventory management (3 and 4), while investment decisions are described by (9) and stem from the standard macroeconomic investment function. Based on these two decisions, usual producer's transactions are the following:

(1) producers are constantly in a state of cash flow deficits, and to make new investments they have to borrow money from banks to which they pay interest,
(2) producers pay production tax (value added tax gathered from sales) to the government, gross wages to the workers (consumers), interest to the banks, and deduct the amount of depreciation out of their revenues; remaining revenues become profits before taxation,
(3) producers pay corporate tax to the government, and
(4) remaining profits after corporate tax are paid to the owners as dividends (domestic and foreign depending on the accumulation of capital liabilities from abroad).

Direct domestic investments abroad (I_{DDI}) and direct foreign investment from abroad (I_{FDI}) are treated exogenously in the model. Total investment is a sum of domestic investment and foreign direct investment from abroad.

Figure 4 illustrates the producer's sector in the model.

Figure 3. Interest Rate, Price and Wage Rate adjustment process model.

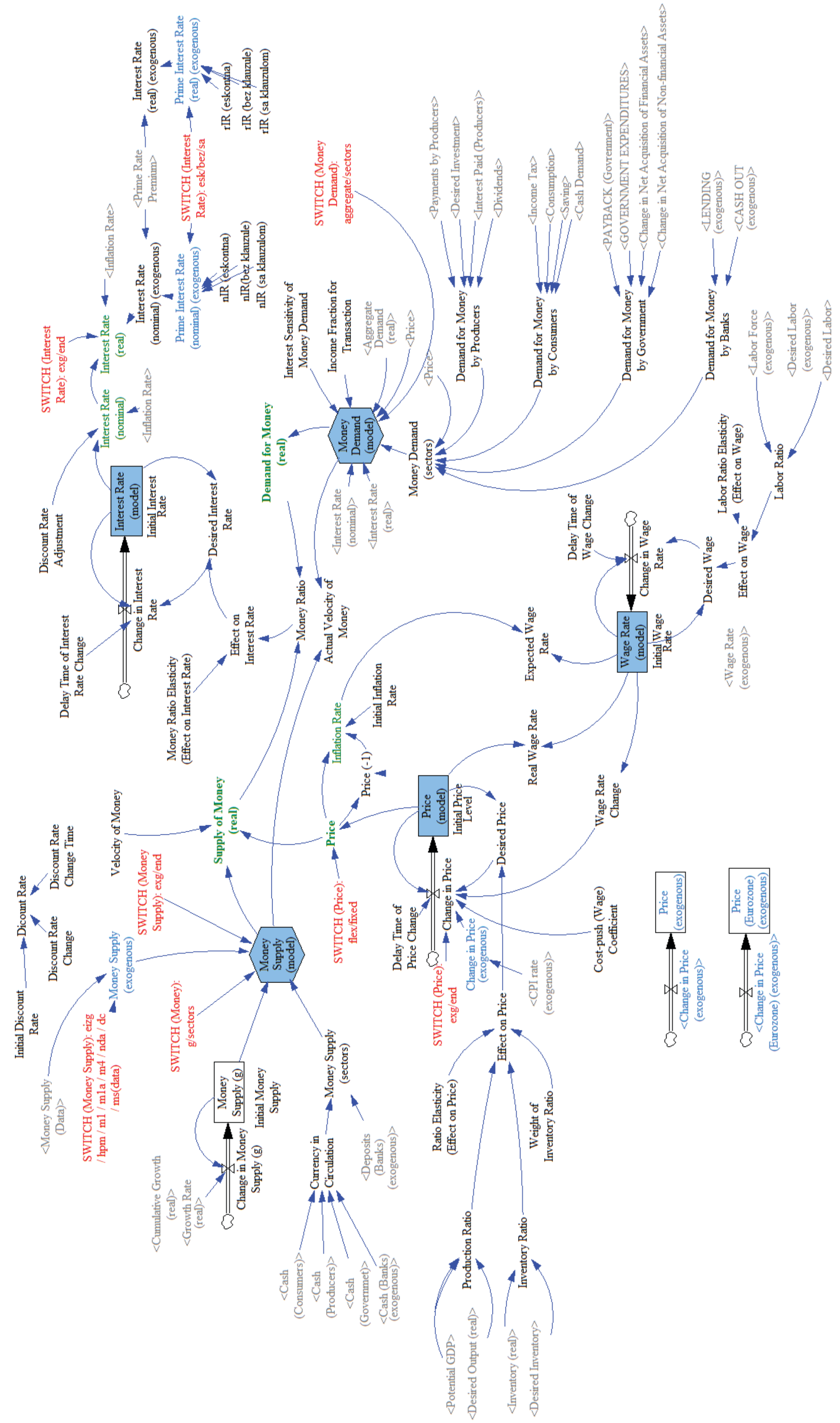
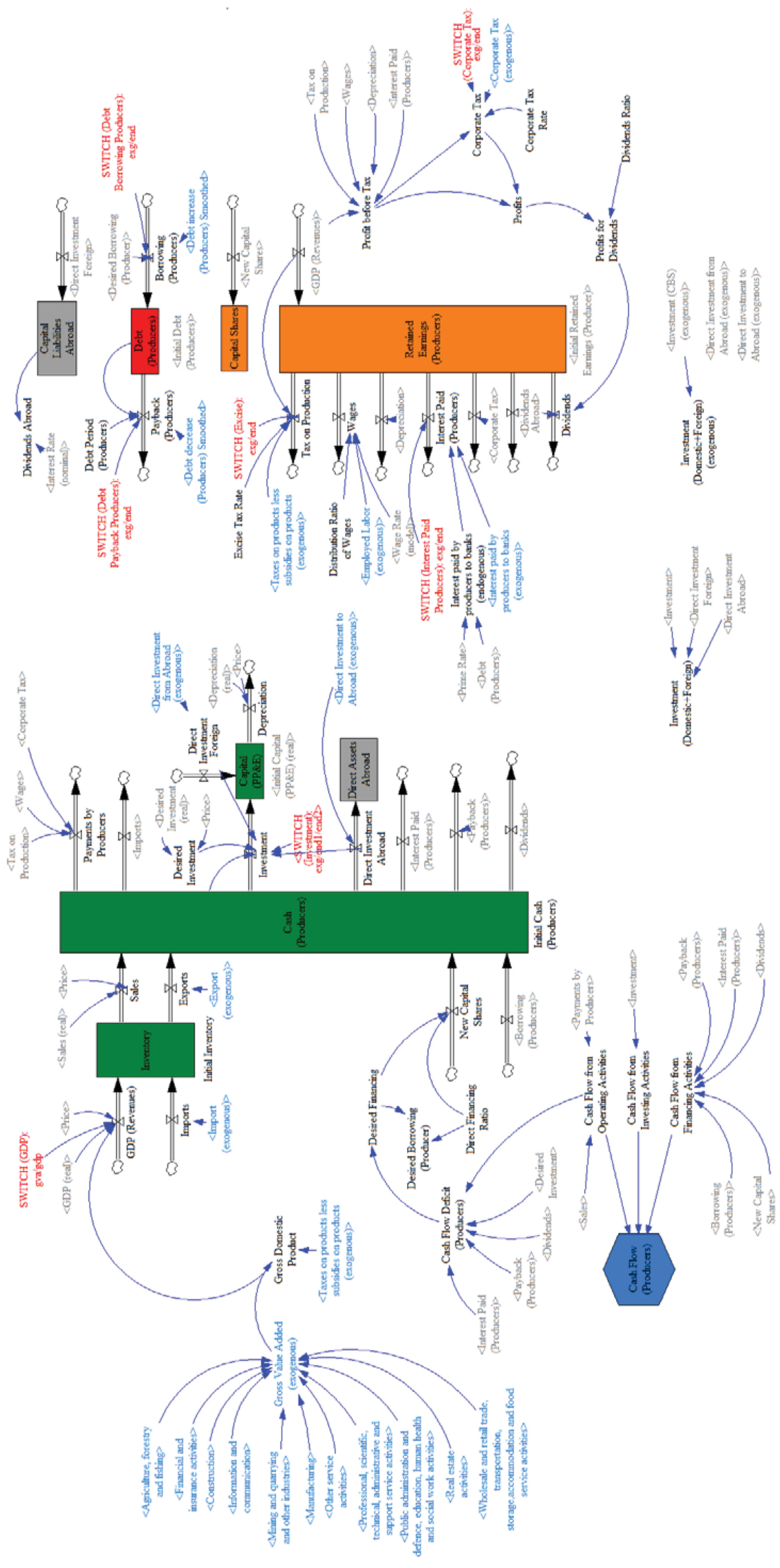


Figure 4. Producer's sector model.



2.5. Consumers

Consumers make two decisions: how much to consume, and how to make a portfolio choice (how much of their remaining income to invest in either saving, newly issued shares, or government securities). The consumption decision is presented by (6), while the portfolio decision is treated exogenously and defined as a simple rule - consumers first save the remaining income as deposits, and then they purchase government securities or newly issued shares in initial public offers. Typical consumer's transactions are the following:

(1) consumers receive wages and dividends from producers and income from abroad (the latter is taken as exogenous),
(2) they receive financial income from interest on deposits from banks, and interest on government securities, while the accumulation of capital gains from the equity market is proportional to the Zagreb Stock Exchange equity index (Crobex),
(3) cash is received when the government partly redeems its securities,
(4) out of the above-defined income, consumers pay income taxes (less government transfers such as subsidies and social benefits), and the remaining amount becomes their disposable income, and
(5) out of this disposable income, they spend on consumption, and then they save or invest in government securities.

We assume consumers do not invest in corporate bonds, and hold cash proportional to the currency ratio. Figure 5 illustrates the consumer's sector in the model.

2.6. Government

As government expenditures G, are determined by a democratic political process they can be treated exogenously in the model. However, they can also become endogenous variables, either by relating them to economic growth, or by relating them to tax revenues. In the former case, governments act procyclical, they change expenditures proportionally to the change in GDP, implying the following set of equations $g(t)=\Delta Y(t)/Y(t)$, such that $dG/dt=g(t)\cdot G$. In the latter case, $G=\beta_{PB}T$, the government targets the primary balance ratio β_{PB}, a ratio of expenditures and tax revenues. The budget is balanced when $\beta_{PB}=1$, and it is in deficit when $\beta_{PB}>1$.

Government faces decisions about its revenues and expenditures; how much taxes to levy to collect revenues, and how much revenues to spend as expenditures. Tax revenues are collected according to (8), while expenditures are defined either by economic growth or revenues as set out in (11). We allow for both rules, the growth-dependent, and the revenue-dependent. Government transactions are as follows:

(1) government receives tax revenues from consumers (income tax), and from producers (corporate tax and tax on production),
(2) government spending consists of expenditures and payments to consumers (partial debt redemption and interest on government securities),
(3) expenditures are determined by either the growth- or revenue-dependent rule,
(4) in case when expenditures exceed revenues (deficit), the government must borrow cash from banks or from consumers by issuing new securities.

Figure 6 illustrates the government sector in the model.

Figure 5. Consumer's sector model.

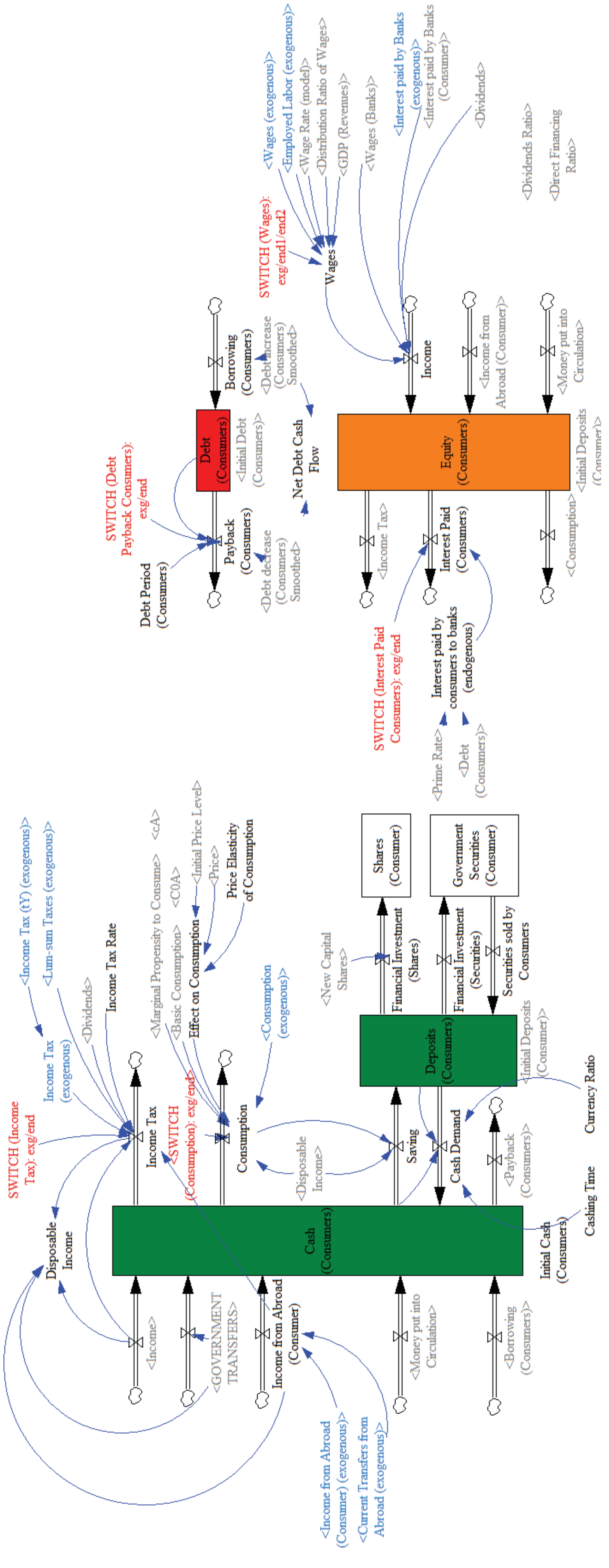


Figure 6. Government sector model.

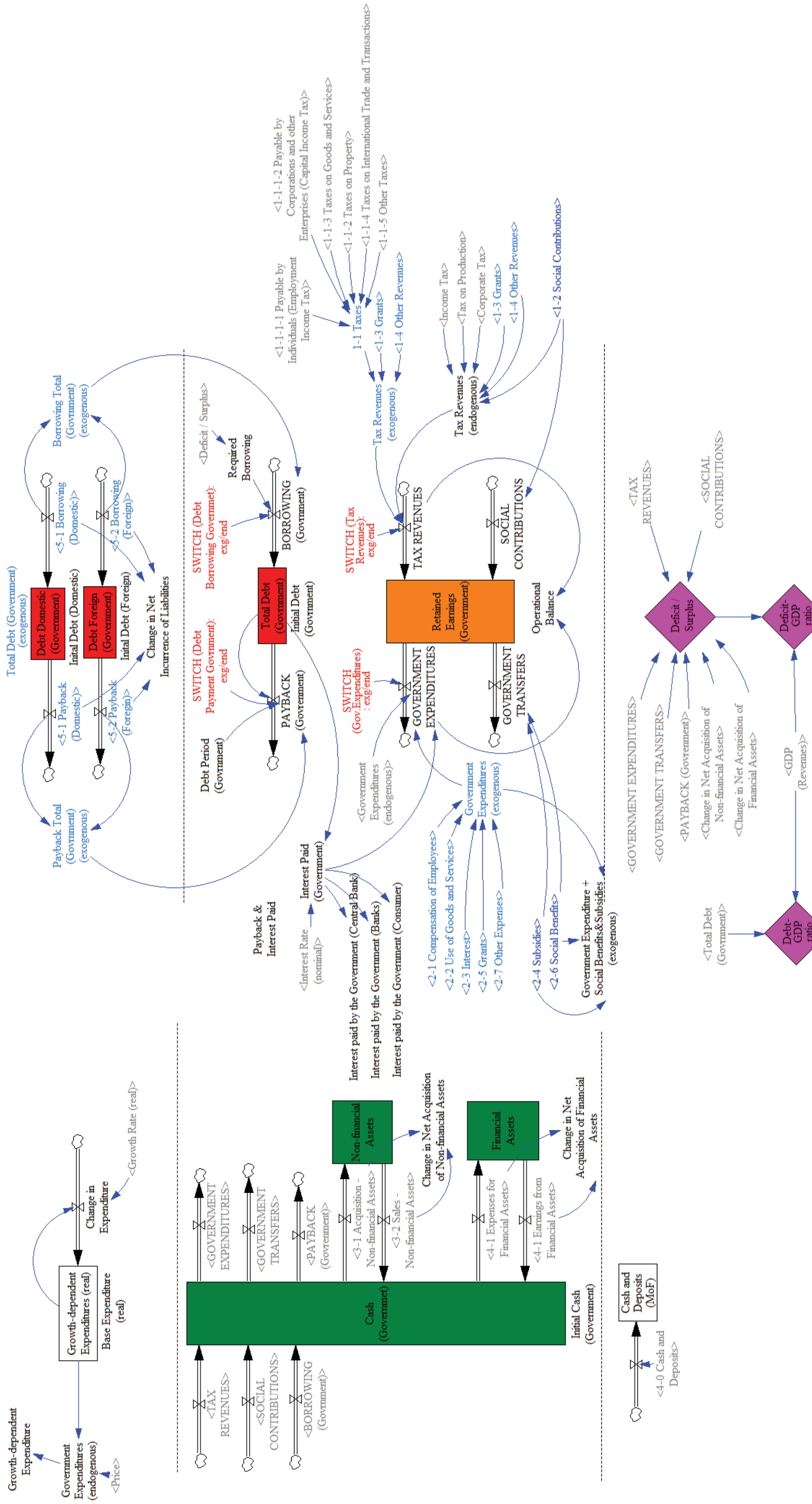
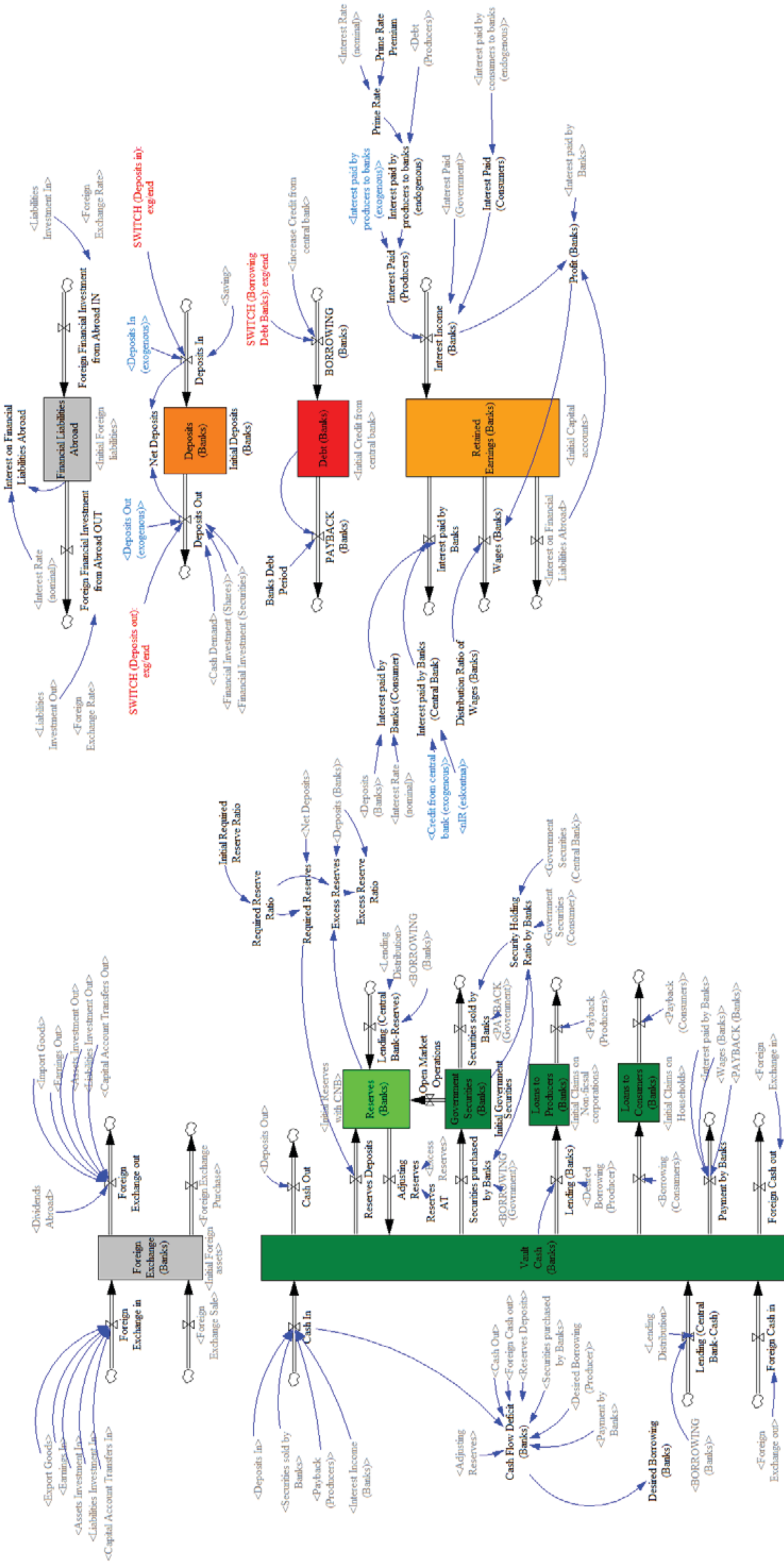


Figure 7. Banking sector model.



2.7. Banks

Banks are part of a fractional-reserve banking system. They make limited portfolio decisions in the sense that they invest in government securities or make loans to producers. Their transactions are the following:

(1) banks receive deposits from consumers against which they pay interest,

(2) they must deposit a fraction of deposits as required reserves with the central bank,

(3) banks invest in government securities out of remaining deposits and receive interest,

(4) banks make loans to producers and receive interest defined as prime interest rate,

(5) bank's retained earnings are equal to interest received from producers and the government, less interest payment to consumers. Positive earnings are distributed among bank owners and workers as consumers.

Figure 7 illustrates the banking sector in the model.

2.8. Central Bank

The central bank controls the money supply by controlling the amount of monetary base consisting of currency outstanding and reserves. The instruments at disposal are the required reserves ratio, open market operations and direct lending control. Assets against which currency is issued can be gold, loans, or government securities, but nowadays money is mostly issued against the debt by the government and commercial banks.

Central bank's transactions are the following:

(1) central bank issues currency against gold deposited at the central bank, by buying government securities from the public, banks, or through open market operations and by making discount loans to banks,

(2) it also withdraws currency by selling government securities and by banks repaying debt,

(3) central bank controls monetary policy using the reserve requirements ratio, open market operations, the discount rate, and discount loans to banks.

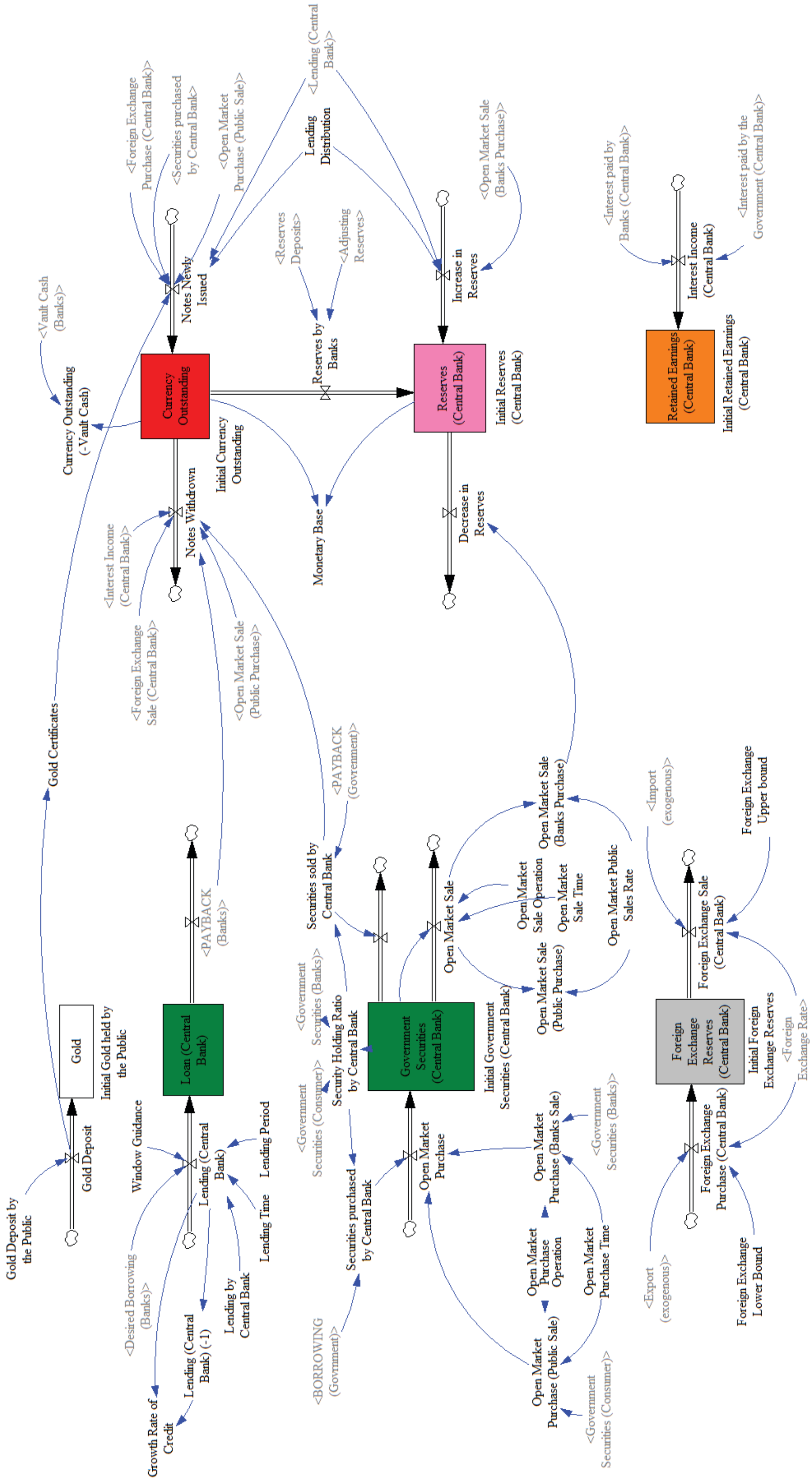
Figure 8 illustrates the central bank sector in the model.

2.9. Model calibration

Model calibration (or optimization of parameters) was done using an optimization algorithm available in *Vensim DLL* modelling software, by the fitting of simulated (endogenously modelled) data with the real (historical) time series data. For the parameters optimization an efficient *Powell's hill climbing* algorithm was used for searching through the space of parameters (or constants) looking for the largest cumulative payoff function, e.g. once we have chosen the constants and their range for optimization, then the chosen optimizer tried to find (within about 1000 iterations) the values for those parameters (constants) that make the chosen payoff as large as possible. In the default case of an ordinary calibration payoff (with only one variable in the payoff definition, without Kalman filtering and assuming normally distributed Gaussian errors), the payoff is calculated as weighted sum of squares of the difference (errors) between the data and the model. Further, the calibration was done in a step-by-step process using switch variables to isolate a part of the model. For example, we isolated consumption by holding all other variables exogenous. Later we gradually expanded the number of variables that are modelled endogenously. The model was completed when the majority of variables were simultaneously modelled endogenously.

In our model we have endogenously modelled the following variables: GDP (nominal/real/full capacity/potential), inventory, investment, consumption, government expenditure/tax revenues, interest rate (nominal/real), wage rate, wages, fiscal deficit/surplus, prices/inflation rate. In the current version of the model, external variables (the variables from the Croatian balance of payments, e.g. export, import, foreign direct investment, domestic direct investment abroad, and income from abroad), the money multiplier and the harmonized index of consumer prices (HICP) of the Eurozone were treated exogenously.

Figure 8. Central bank sector model.



3. Results

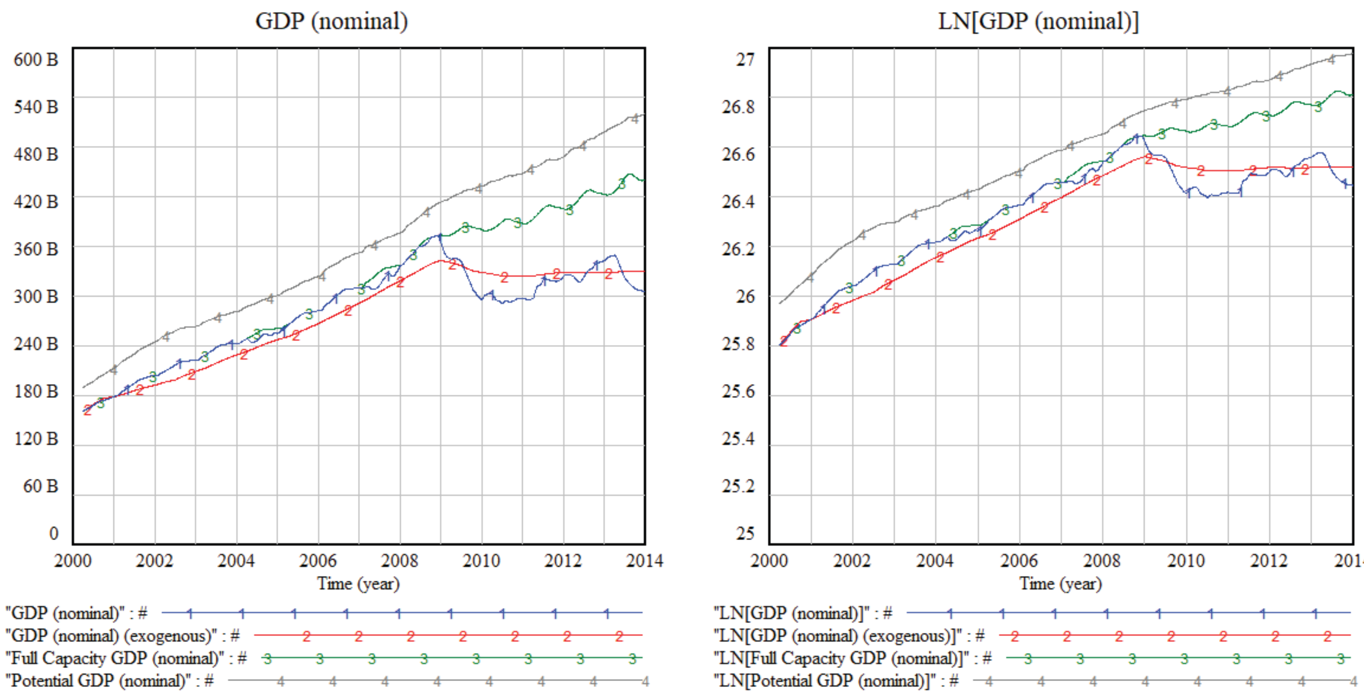
3.1. Model validation

In the baseline results we present simulations from our model obtained for main macroeconomic variables: GDP, interest rate, investment, consumption, inventory, government revenue and expenditure, fiscal deficit, public debt, wages, and prices. In addition, the model can be used to validate economic behaviour in past scenarios, or to estimate future paths of key macroeconomic variables one or more quarter ahead. Furthermore, regarding structural validity, the model was tested and conforms with basic physical realities (all relevant stocks do not become negative), the model was tested using automated dimensional analysis (there are no any strange combination of units or non-dimensional parameters), several extreme values such as zero or infinity (for prices, labour and capital) were tested and the model is robust under these extreme conditions, and lastly we tested the model sensitivity using Monte-Carlo simulations, primarily focusing on the impact of value added tax (VAT) rate, the parameter we consider highly influential in our economy and fiscal policy.

Figure 9 illustrates the results of simulated (modelled, endogenous) data in comparison to the historical data for nominal GDP, achieving a coefficient of determination or R-square (R^2) of 0.907 indicating very good fit between the simulated model data and actual historical data, while comparable goodness of fit was reached in other time series as well (Figures 9 - 18). In addition to nominal GDP Y, full capacity GDP Y_{full} and potential GDP $Y_{potential}$ are also plotted.

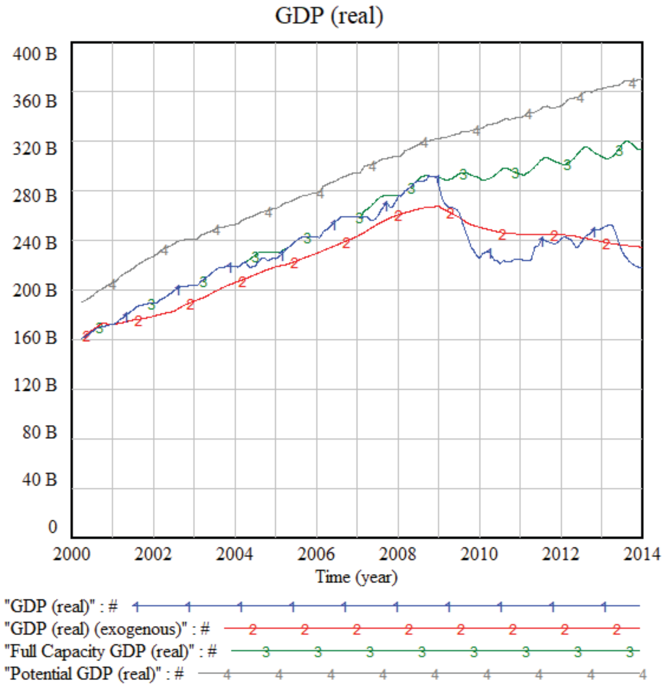
We also simulate GDP time series in real terms. Figure 10 illustrates the results of the simulated data in comparison to the historical data for real GDP. In addition to real GDP ($Y_{real}=Y / P$), full capacity real GDP (Y_{full} / P) and potential real GDP ($Y_{potential} / P$) are also plotted. Simulation results show that modelled real GDP follows full capacity real GDP and historical real GDP very well up to the last quarter of 2008 (just after the collapse of Lehman Brothers and the spread of the financial crisis to the global economy) and then it falls more abruptly than the historical real GDP. Moreover, while historical real GDP stagnates in 2011 and in 2012, our simulation points to a temporary recovery followed by another downturn as of the second quarter of 2013. The model shows no signs of recovery by the end of 2013 implying that real GDP growth rate was negative in 2013.

Figure 9. Simulated (modelled, endogenous) time series and historical time series for nominal GDP, full capacity GDP and potential GDP. Two representations are available: in absolute values (left figure) and in logarithmic values (right figure).



Note: Blue lines (also labelled with marker "1") represent simulated (endogenous) data from the model and red lines (also labelled with marker "2") represent historical (exogenous) data given exogenously for comparison.

Figure 10. Simulated (modelled, endogenous) time series and historical (exogenous) time series for real GDP, full capacity real GDP and potential real GDP. Two representations are available: in absolute values (left figure) and in logarithmic values (right figure).



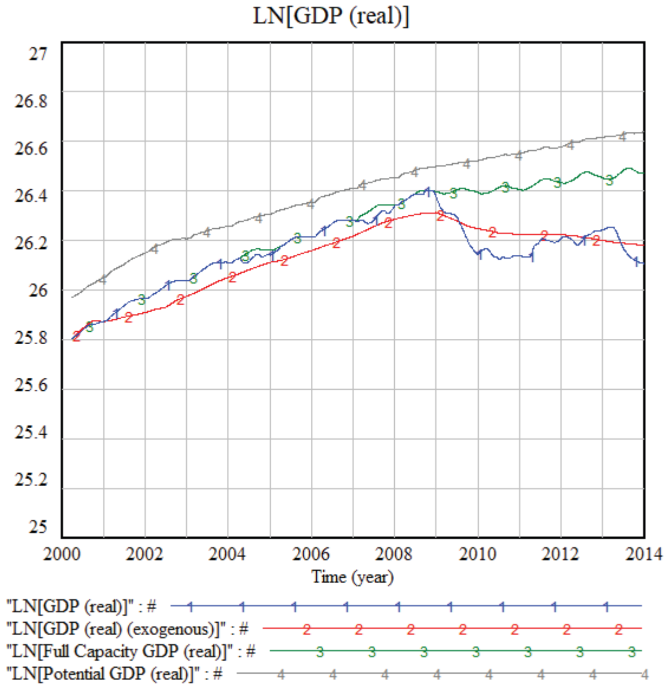
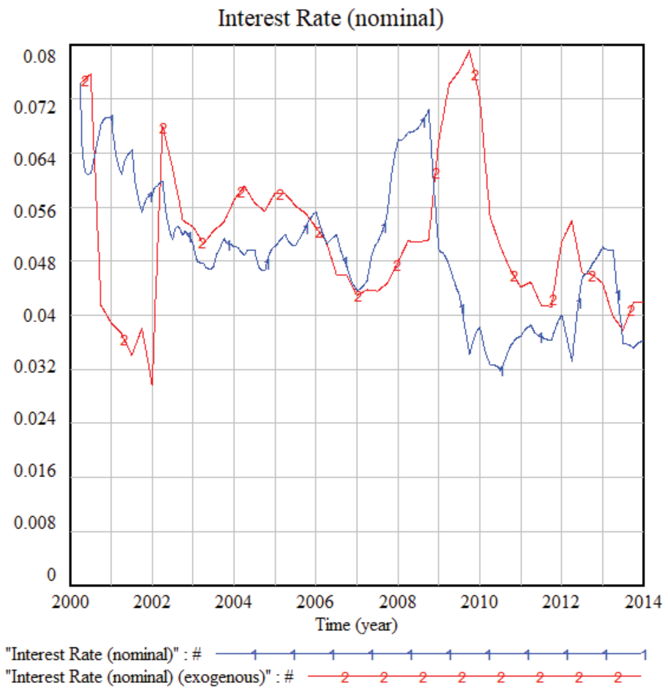


Figure 11 illustrates the results of the simulated data in comparison to the historical data for the nominal interest rate *i* and the real interest rate *r*. As a benchmark nominal interest rate does not exist in Croatia, we use a proxy - the nominal interest rate on short-term Croatian *kuna* enterprise credits not indexed to foreign currency less bank's prime rate premium which is 2.5 percent on average. The (real) benchmark interest rate is calculated by subtracting the exogenous change in prices (measured by the consumer price index, CPI) from the proxied nominal benchmark rate. In this model, the real and the nominal benchmark interest rates were used only for comparison, not for modelling. Both nominal and real interest rate obtained by the simulation follow the historical trend very well, although the historical time series are much more volatile. Understandably, the model cannot capture events, such as the one-time interest rate spike from the first quarter of 2009 when rates jumped due to the central bank decision to withdraw local currency liquidity from the money market in order to contain the HRK/EUR (Croatian *kuna* vis-à-vis the *euro*) depreciatory pressures caused by the sudden capital outflow.

Figure 12 illustrates the results of the simulated data in comparison to the historical data for investment. We allow for two different investment specifications. One obtained through the investment base formulation, and the other based on desired capital investment function. Although these two simulations are fairly similar, investment obtained on the basis of desired capital investment function provides a somewhat better fit to historical data. An even better fit is obtained when we compare the simulation with investment composed of both domestic and foreign investment, although our model still cannot explain total investment. The blue (simulation) line is always below the historical (green), probably because we treat the foreign sector, an important source of investment, as exogenous in the model.

Figure 11. Simulated (modelled, endogenous) time series and historical (exogenous) time series for the nominal interest rate *i* (left figure) and for the real interest rate r (right figure).



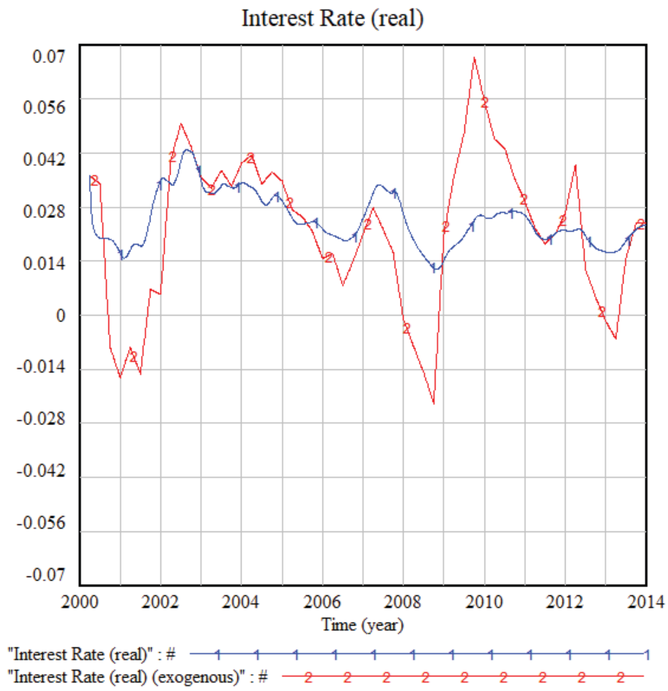
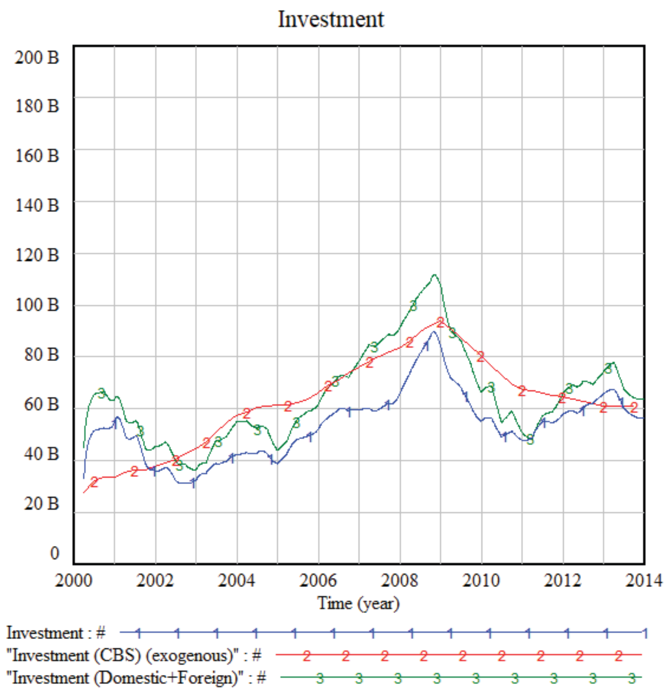


Figure 12. Simulated (modelled, endogenous) time series and historical (exogenous) time series for investment *I*. Two representations are available in which investment is either defined through the investment base formulation in equation 9 (left figure) or through the desired capital investment function in equation 9 (right figure).



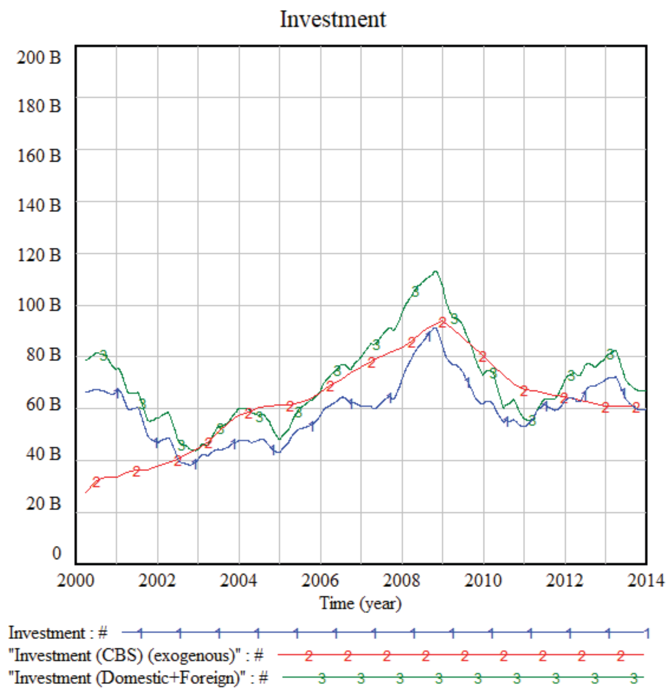
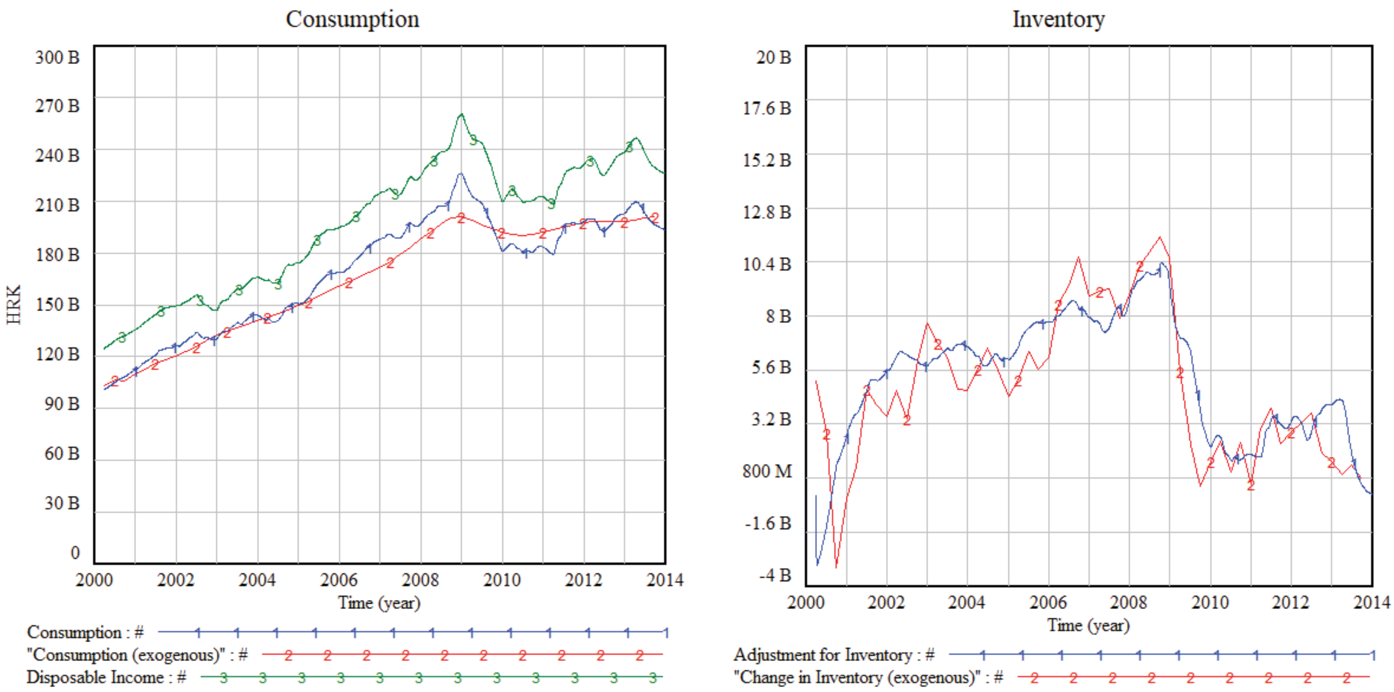
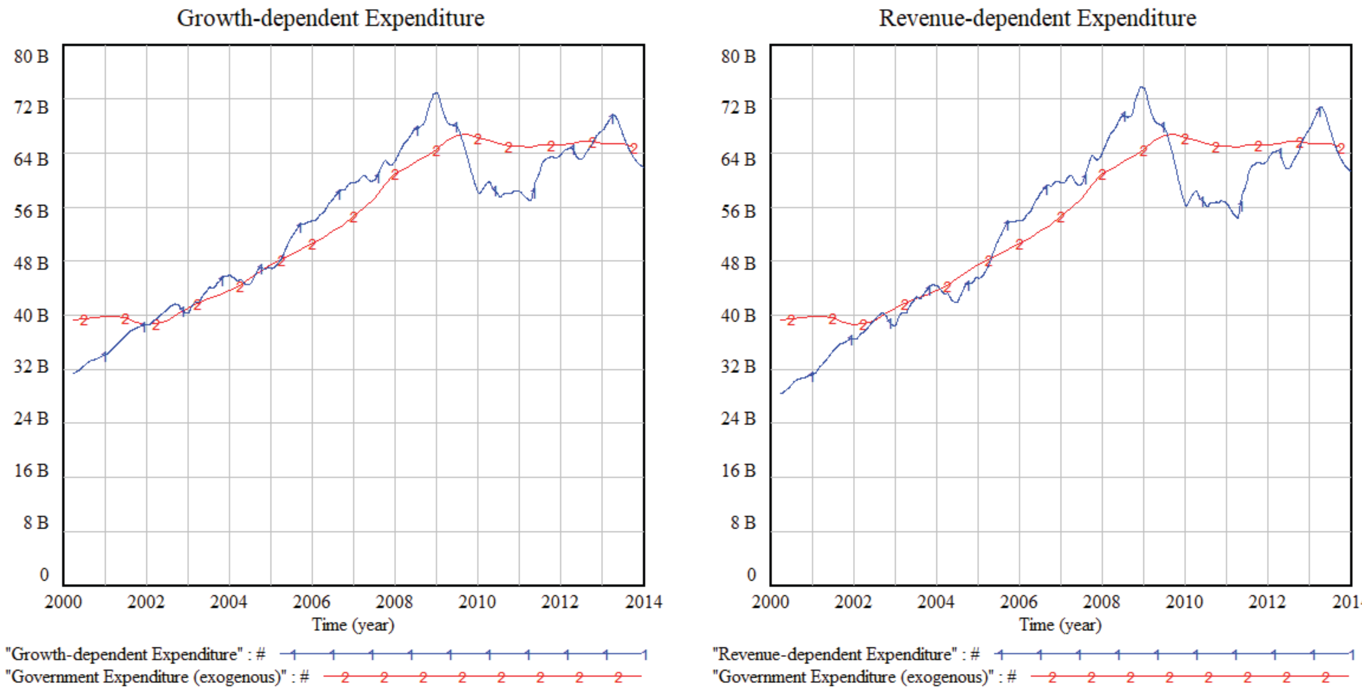


Figure 13. Simulated (modelled, endogenous) time series and real (historical, exogenous) time series for consumption C (left figure) and for inventory I_{nv} (right figure).



Simulated and historical time series for consumption and inventory are presented in Figure 13. Since we define consumption as proportional to disposable income, our simulation closely follows disposable income (consumption follows from below, because we assume that consumers save a part of their income or they invest in government securities), while historical data follow only the trend in disposable income, appearing to be much smoother and a bit below our simulation. It could be the case that official statistics do not record all transactions and that there is a part of consumption that stays in the shadow economy. Regarding inventory, our model manages to completely describe the trend in historical data and even most of the variability. Inventory is the crucial part of our model because it describes the discrepancy between production and sales, therefore reflecting the business cycle.

Figure 14. Simulated (modelled, endogenous) time series and historical (exogenous) time series for government expenditure G. According to (11), two representations are available: growth-dependent expenditure (left figure) and revenue-dependent expenditure (right figure).



We present in Figure 14 both growth-dependent and the revenue-dependent government expenditure. From the figures we can see that both definitions provide very similar fits, which closely follow the revenues trend. Both simulations tend to exaggerate the decrease in expenditures as of 2009, stemming from the fact that this version of the model does not allow for borrowing abroad. Since in reality the government had access to international markets, this allowed more or less constant level of expenditures in the period from 2010-2013.

According to the simulation, the deficit/GDP ratio somewhat underestimates the severity of the poor fiscal position. This is probably so because it overvalues tax revenues due to existence of shadow economy (Figure 15).

Figure 15. Simulated (modelled, endogenous) and historical (exogenous) time series for government revenues T collected through production $T_{production}$, income T_{income}, and corporate $T_{corporate}$ taxes.

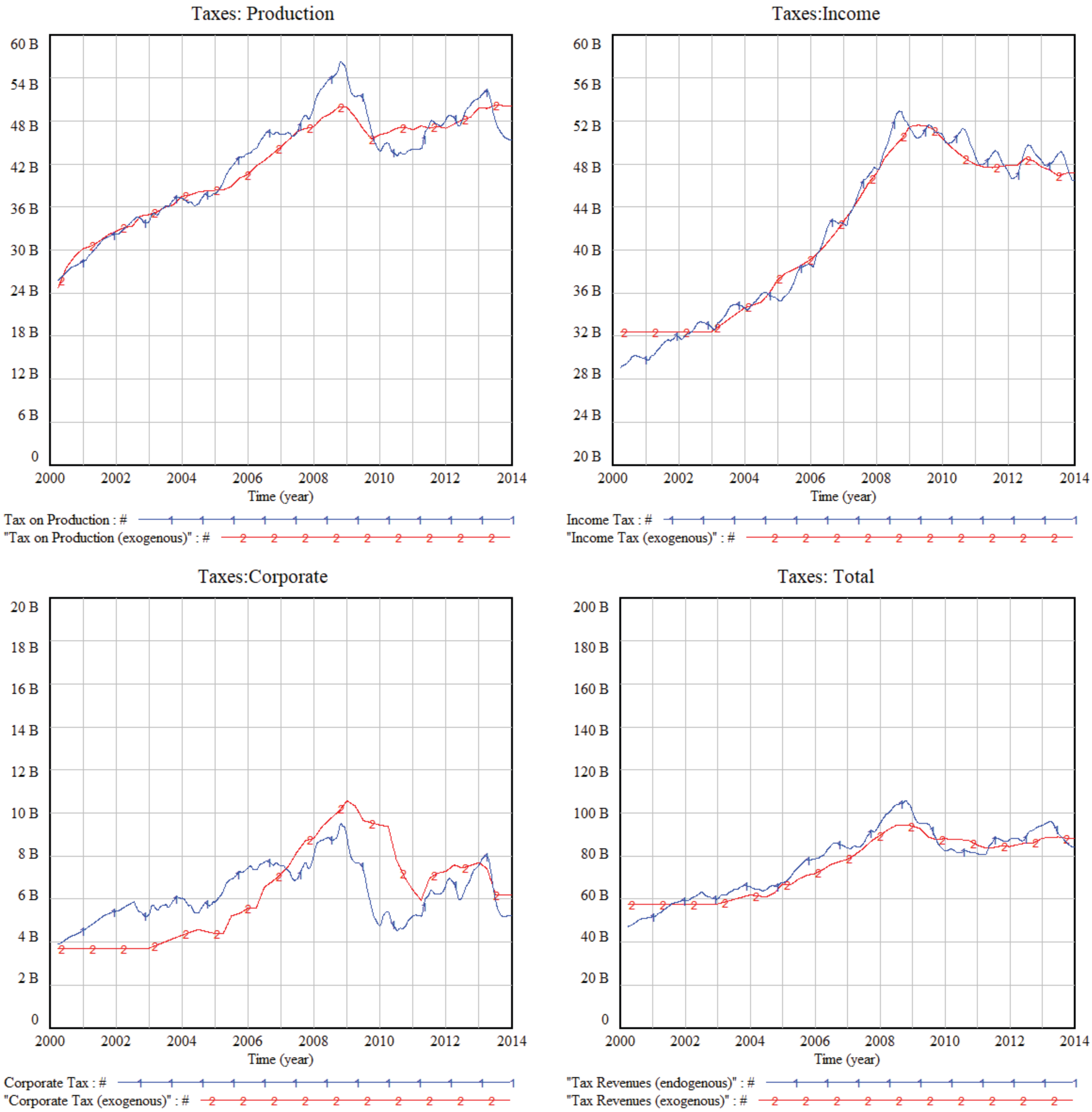
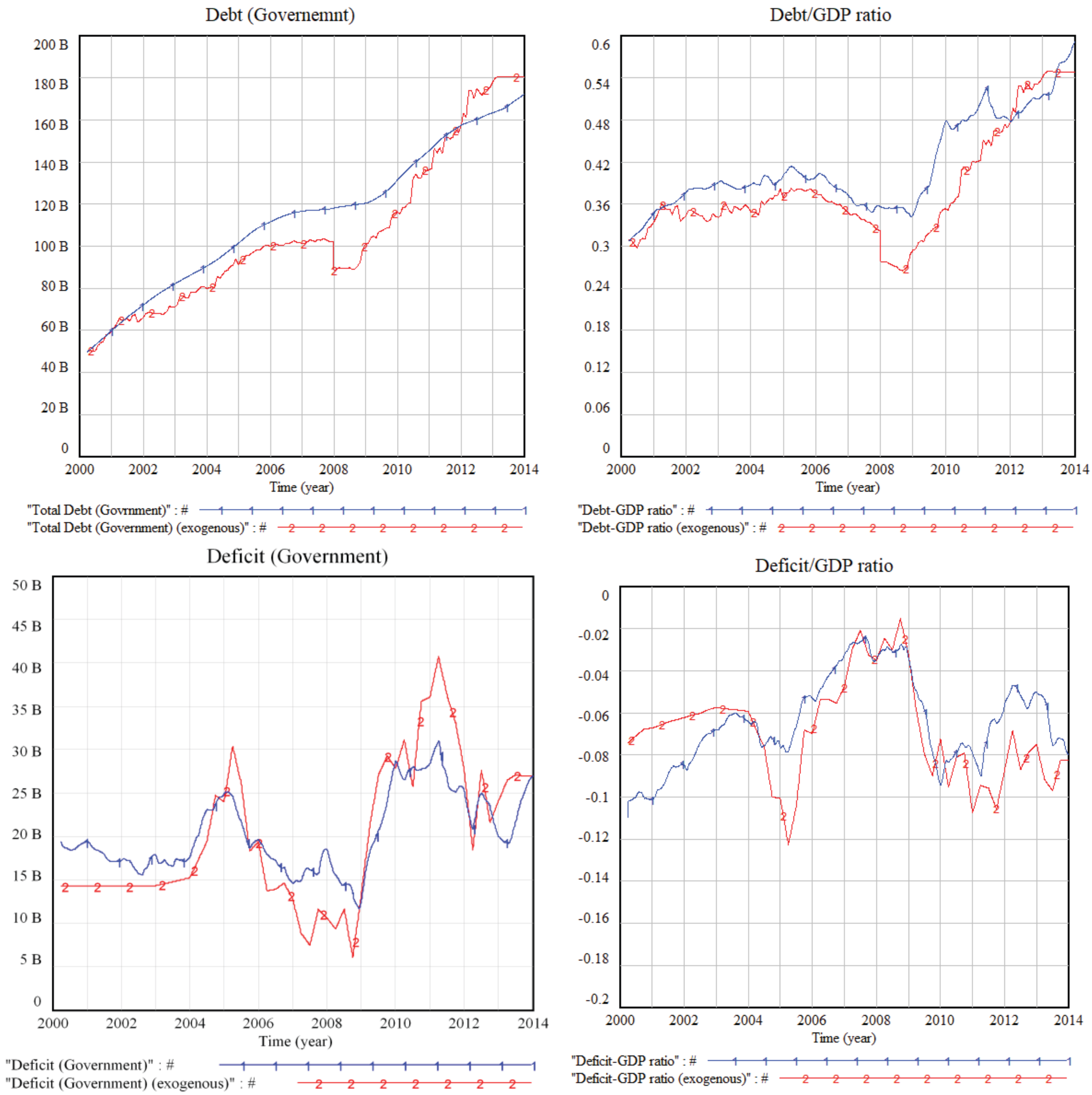


Figure 16. Simulated (modelled, endogenous) time series and historical (exogenous) time series for accumulated government debt *D* (upper left figure) and annual government *Deficit* (lower left figure). *Debt/GDP* ratio is given in the upper right figure, and *Deficit/GDP* ratio in the lower right figure. All series are obtained for the general government (which includes central and local government).



Government debt and deficit together with their shares in GDP are presented in Figure 16. Simulation of government debt follows the trend and more or less the level in government debt up to 2012. However, the model does not manage to pick up a spike in government debt that occurred at the beginning of 2012, but in terms of debt level, the simulation does fairly well. The relative indicator, debt/GDP, mirrors the dynamics in the indicator much better. Moreover, our simulation suggests that in the last quarter of 2013, debt/GDP continued to grow very close to 60 percent of GDP. Our simulation of government deficit follows historical data satisfactorily. Especially encouraging is the fact that our deficit/GDP simulation coincides with the trend in historical data.

The real wage rate is presented in Figure 17. According to (23), there are two possible representations for wages; one through the exogenously obtained employed labour and wage rate dynamics, and the other through GDP and fixed distribution of wages. Simulation shows that the former definition provides a better fit. This is so because the latter definition provides a more cyclical simulation, and having in mind that wages are rather sticky, i.e. they do

Figure 17. Simulated (modelled, endogenous) time series and historical (exogenous) time series for the nominal and real wage rate *w* (upper figure). According to (23), two representations are available for wages: through employed labour that is taken to be exogenous and wage rate dynamics (lower left figure), or through GDP and fixed distribution of wages (lower right figure).

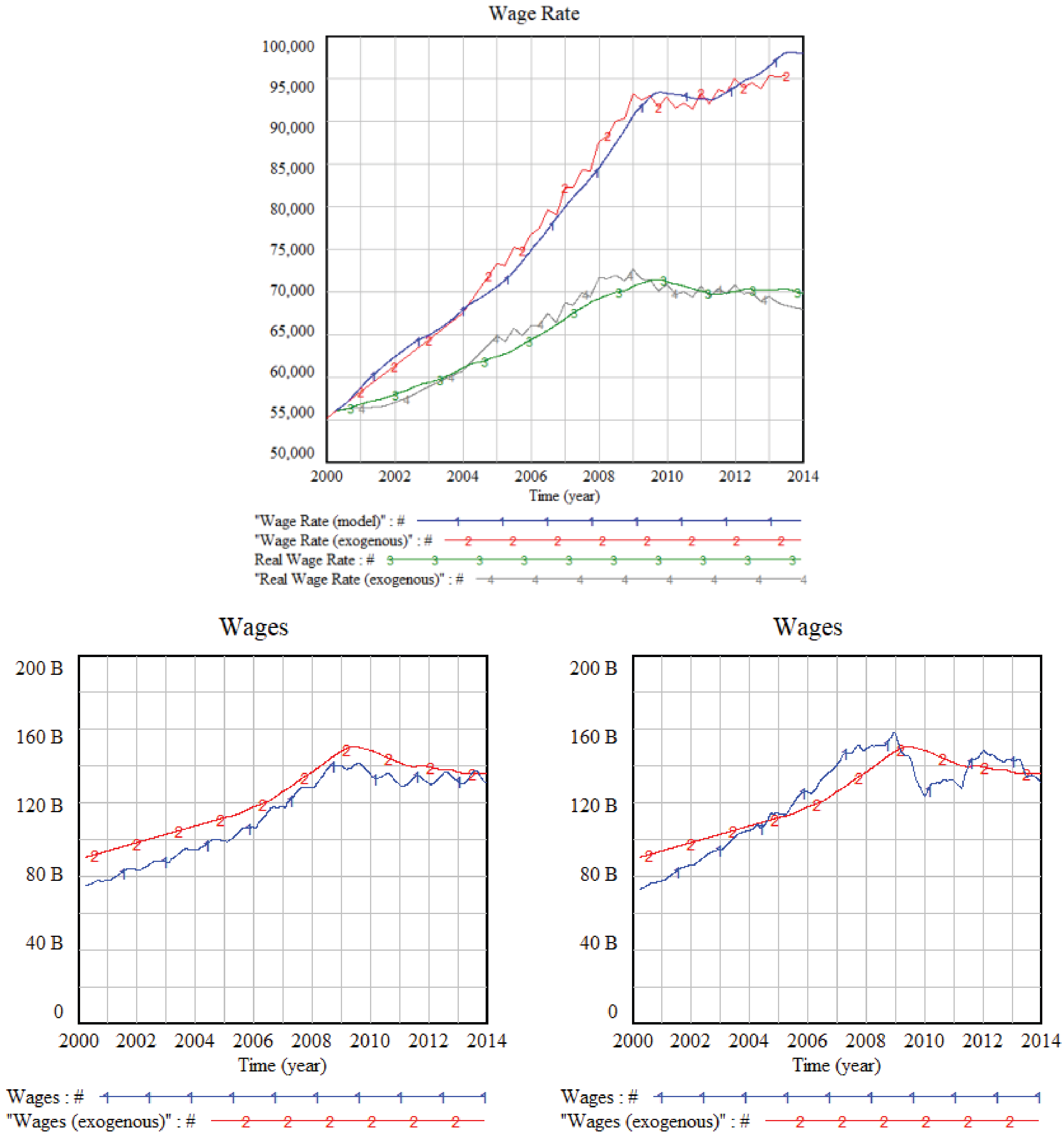


Figure 18. Simulated (modelled, endogenous) time series and historical (exogenous) time series for prices P (left figure) and for the inflation rate (change in price) π (right figure).

not tend to decrease easily, it is hard to expect that wages will exhibit such variability as obtained by the simulation.

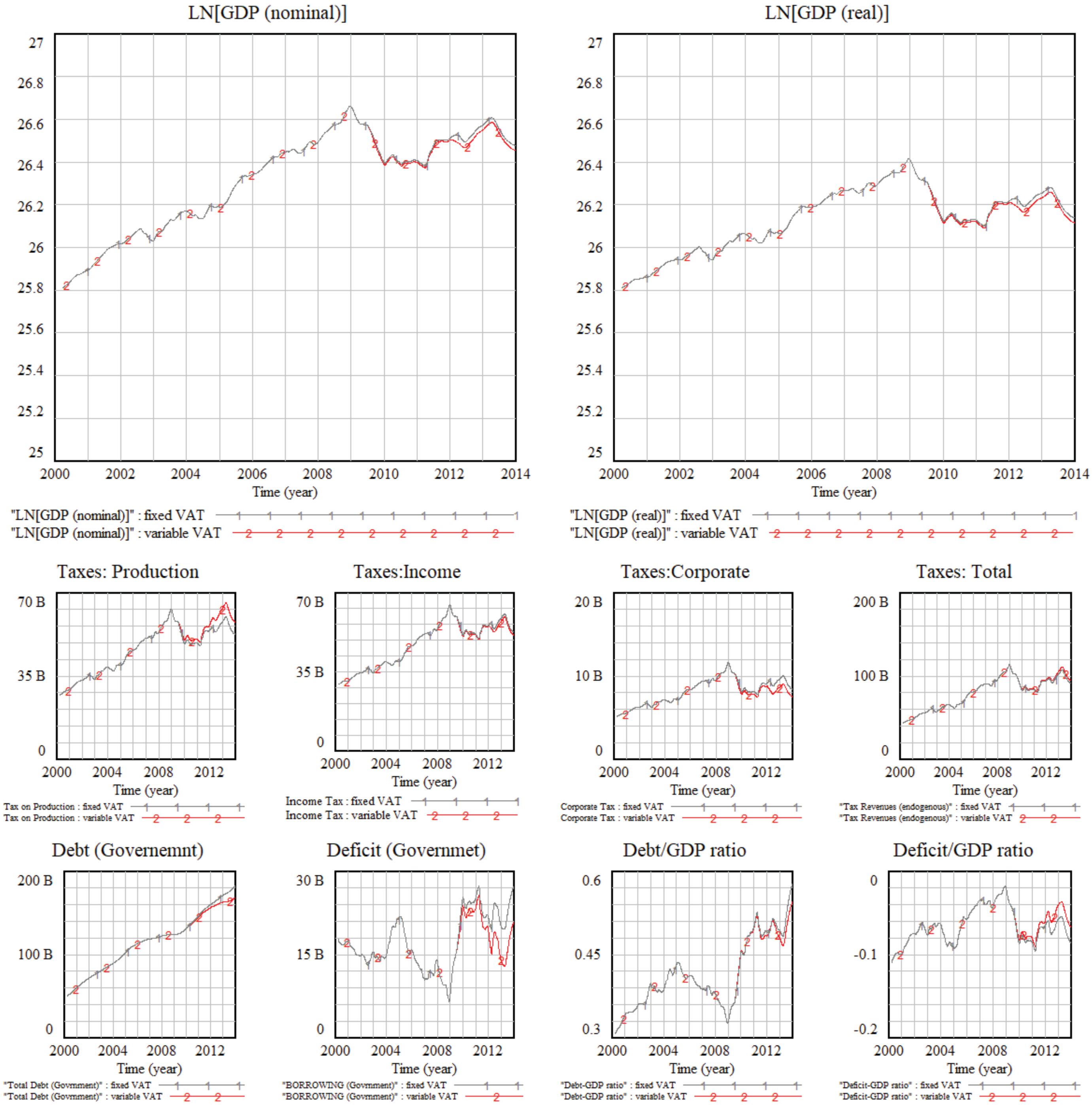
Prices and the inflation rate are shown in Figure 18. We can observe that our simulation provides an almost perfect fit in the case of prices. However, although our simulation of inflation does follow the trend in historical data very well, it cannot reproduce some significant spikes in inflation. For example, the simulation undervalues a spike in the second half of 2008 that was completely caused by a rise in global oil prices or inflation caused by administrative price hikes in 2012 and 2013. As our model does not and cannot account for all possible causes of a price increase (global price shocks or political decisions), we do not expect to get a perfect fit for inflation, but only a good approximation for the trend.

3.2. Economic policy scenarios

To test a possible application of our model to simulate effects of economic policy actions, we examined an actual discretionary fiscal policy measure that was introduced in Croatia. Before the Great Recession, Croatian value added tax rate was set at 22%, but in the third quarter of 2009 it was hiked to 23% and then again in the first quarter of 2012 to 25%. Using model, we examined two scenarios, as presented by Figure 19. First, the hypothetical scenario in which the VAT rate remained at the historical 22% (scenario 1 or "*fixed VAT*"). Second, the scenario of the actual fiscal intervention in which VAT rate was gradually increased to 25% (scenario 2 or "*variable VAT*").

Our results imply that an increase in the VAT rate raises tax revenues from this specific tax, but at the same time, it drives down revenues from income tax and especially from corporate tax, because a VAT rate hike causes an increase in consumer prices. This means consumers can afford fewer products with the same income level, which causes the contraction of aggregate demand. Producers respond to the drop in aggregate demand by decreasing production. Lower production translates into lower profit and lower corporate tax revenues for the Government. In addition, producers need to lay off some workers due to a cut in production, which adversely affects the personal income tax revenues.

Figure 19. Comparison of two scenarios: (1) hypothetical, "fixed VAT" scenario (grey line marked with "1") and (2) "variable VAT" scenario that actually occurred (red line marked with "2"). For comparison we have also plotted nominal and real GDP, production, income, corporate, and total taxes, and debt, deficit, debt/GDP ratio, and deficit/GDP ratio of the general government.



Nominal and real GDP both decrease because of VAT rate hike, due to a fall in aggregate demand caused by rising consumer prices, and then further due to the second-round increase in unemployment and related reduction of disposable income, which further suppresses aggregate demand. Regarding aggregate fiscal indicators, total tax revenues slightly increase, as VAT takes the biggest share of total tax revenues. As a result, government deficit and debt decrease in absolute terms, and relative fiscal indicators (debt/GDP and the deficit/GDP) mildly decrease because the fall in GDP is not large enough to offset the decrease in public debt and deficit, at least not when exogenous data up to 2012 are considered.

4. Discussion

Building on the previous and only theoretical work of Yamaguchi (2013), in this paper we presented for the first time the practical use of the national system dynamics model, calibrated for the case of the Croatian economy. Our contribution is in the structural adaptation of the model to the Croatian economy (mainly how the consolidated general government revenues / expenditures, transactions / liabilities and debt are specifically organized, as well as how the central bank assets / liabilities and balance of payments are explicitly structured) and the latter contribution is the calibration of the model to the actual historical time series of the Croatian economy.

The model is holistic in the sense that the whole is more than the sum because the parts of the model are interrelated and interdependent, and the model has plenty of feedback loops. The model is also dynamic and nonlinear due to numerous cash flows described by nonlinear differential equations that are solved by numerical integration in time, spanning from 2000 to 2014, using the Euler method.

The following time series have been treated exogenously in the model: money multiplier (needed to model the money supply endogenously), balance of payments (export/import, foreign direct investment, income from abroad), and labour market (population/employment) dynamics. We see this current version of the model as a proof of concept showing that the simulated data fit the historical data fairly well meaning that, by capturing the dynamics of the main economic variables in a satisfactory way, the model is validated.

The main limitation regarding the assessment of the future path (short-term and long-term) of key macroeconomic variables is the partial openness of the model and the use of several exogenous variables. In the future versions of the model, we plan to endogenize labour market dynamics and money multiplication. Endogenizing the remaining external sector would require development and calibration of a separate model of the foreign sector (e.g. European Union as Croatia's biggest trading partner).

For now, to carry out a one-quarter-ahead forecast by extending the numerical time integration for endogenously modelled variables, a naïve forecasting approach for the exogenous variables can be employed, using the last known value of the previous quarter. This approach could be significantly improved by using econometrically obtained forecasts of exogenous variables.

5. Conclusion

This paper is focused on the modelling of the national economic system, using the system dynamics approach and the practical application of the model calibrated on the real historical data. As this study is based on many system dynamics information feedbacks, it can provide holistic insight into the effects of the economic policy actions. To illustrate this feature of the model, we have demonstrated an application of the model to the analysis of fiscal policy intervention. Our results imply that an increase in the VAT rate raises tax revenues, but at the same time, decreases nominal and real GDP due to a fall in aggregate demand caused by consumer prices inflation, and additionally, by rising unemployment which aggravates disposable income and thereby further erodes aggregate demand.

We have also identified the advantages and possible further practical applications of the model. We assume that the future versions of the improved model could be used for: (1) forecasting and nowcasting paths of GDP, investment, consumption, government expenditure, inventory, interest rates, inflation, fiscal deficit, public debt, etc.; (2) calibration of other similar South East European economies (such as Bosnia and Herzegovina, Serbia, Slovenia, Macedonia, etc.)[1]; (3) programming project frameworks of EU funds for sectors with largest investment or financial gaps and analysis of their multiplication potentials; (4) scientific research, publications, and commercial projects including (a) stress tests on different economic sectors, spill-over effects estimation, non-performing loans forecasting, estimation of linkages between monetary and real economy; (b) research on multiplication effects on a sectoral basis (agriculture, construction, industry, services, public, etc.), where an added value would be to include dynamics in the analysis of multiplication potentials; (c) estimating the size of shadow economy.

Endnotes

1 For the copy of the model please contact the first author: https://www.linkedin.com/in/ssovilj/

Acknowledgements

This work has been supported in part by Croatian Science Foundation under the project UIP-2017-05-9066.

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Appendix

Table 1. Names of the variables and constants with belonging symbols and values.

Name	Symbol	Value
Potential GDP	$Y_{potential}$	-
Full production GDP	Y_{full}	-
Factor of Technological Change	A	-
Capital (property, plant, and equipment)	K	-
Employed labour force	L	-
Total labour force	LF	-
Exponent on capital	α	0.33
Exponent on labour	β	0.67
Technological change	κ	0.015
Initial GDP	Y_0	190B (in 2000)
Initial capital (property, plant, and equipment)	K_0	250B (in 2000)
Initial employed labour	L_0	1.342M (in 2000)
Initial total labour force	LF_0	1.7M (in 2000)
Forecasting adjustment time	-	0.25 years
Desired production	Y^D	-
Inventory	I_{nv}	-
Desired inventory	I_{nv}^*	-
Normal inventory coverage	-	0.50
Time to adjust inventory	-	5 years
Aggregate demand	AD	-
Consumption	C	-
Investment	I	-
Government expenditure	G	-
Export	X	-
Import	M	-
Basic consumption	C_0	20B
Marginal propensity to consume	c	0.65
Disposable income	Y_d	-
Income (GDP)	Y	-
Income tax rate (social contributions included)	t_{income}	0.40
Tax on production (value added tax)	$t_{production}$	0.22 (or variable)
Corporate tax	$t_{corporate}$	0.20
Tax revenues	T	-
Lump-sum taxes (e.g. property taxes)	T_0	-
Government transfers (e.g. subsidies and social benefits)	T_r	-
(Nominal) interest rate	i	-

Desired interest rate	i^*	-
(Real) interest rate	r	-
Premium rate spread	-	0.025
Desired capital	K^*	-
Desired labour	L^*	-
Labour supply	L^S	-
Depreciation rate	δ	0.03
Investment base	I_0	500B
Interest sensitivity	α_I	0.1
Growth rate	g	-
Initial government expenditure	G_0	33B (in 2000)
Primary balance ratio	β_{PB}	0.7
Money supply (nominal)	M^S	-
Money demand (nominal)	M^D	-
Money velocity	V	0.52
Inflation rate (change in price)	π	-
Price level	P	-
Desired price level	P^*	-
Weight ratio for inventory and GDP gap	ω	0.5
Delay time (price adjustment)	-	5 years
Delay time (interest adjustment)	-	0.25 years
Income fraction for transaction	a	0.52
Interest sensitivity of money demand	b	1250B
Ratio elasticity (effect on interest rate)	e	1
Money demand (real)	m_d	-
Money supply (real)	m_s	-
Foreign direct investment	I_{FDI}	-
Domestic direct investment	I_{DDI}	-
Wage rate	w	-
Wages	W	-
Distribution ratio of wages	-	0.45