MODELING OF MONETARY FINANCIAL FLOWS IN SYSTEM DYNAMICS

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ABSTRACT

Using the stock-flow consistent (SFC) approach, I model advanced interactions between households (1), firms (2), banks (3), the central bank (4), the treasury (4), and the foreign sector (5) within the system dynamics software Ravel. Different calibrations of model parameters demonstrate steady macro-financial dynamics and support post-Keynesian conclusions regarding the instrumental role of public debt in generating private sector profits. However, a well-calibrated foreign sector inflow can help keep public debt under greater control.

keywords : system dynamics, SCF modeling, postkeynesian economics, public debt

THEORY

The stock-flow consistent (SFC) model is grounded in accounting continuity, where every liability corresponds to an asset in another sector, and vice versa. The model tracks changes in the aggregated balance sheets of interacting sectors, based on a system of fundamental accounting equations.

1. Assets(A) = Liabilities(L)+Equity(E) ➡ At−Lt=Et ➡ At−Lt-Et=0

therefore

2. $$\sum_{s=1}^{N} B_{s,j} = 0 \quad \forall j$$

where $\sum_{s=1}^{N} B_{s,j}$ is the sum of all holdings (positive if asset, negative if liability) of instrument j by sector s.

! Final changes in sectoral balance sheets can be interpreted as a theoretical "competition" among sectors. The outcome of this process reveals which sectors have increased their equity and which have experienced a decline. In this sense, the model allows us to identify relative "winners" and "losers" in terms of net financial positions over time!

THEORY

A common dilemma in any stock-flow model revolves around the distinction between stock and flow. Theoretical framework for monetary modeling is provided by Godley and Lavoie (2007), where **stock** refers to a **balance sheet item** and **flow** represents the corresponding transaction (**debits and credits**) that alters the stock level over time.

Other key theoretical points of the model approach :

SCF approach uses **non-linear, differential equations** and time lags to capture dynamic changes in flows and stocks

Follows Pos-tkeynesian and consensual (McLeay, Radia, 2014) approach of **endogenous money creation**

Minimizes normative approach, but still uses some Post-keynesian undertakings (non-equilibrium, long-term non-neutrality of money etc.)

McLEAY, Michael, RADIA, Amar a RYLANDS, Ryland. *Money creation in the modern economy* [online]. London: Bank of England, 2014 Available from: https://www.bankofengland.co.uk/quarterly-bulletin/2014/q1/money-creation-in-the-modern-economy

GODLEY, Wynne a LAVOIE, Marc. *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth* [online]. Basingstoke: Palgrave Macmillan, 2007 [ISBN 978-1-4039-1346-0. Avialbe from: https://link.springer.com/book/10.1057/9780230626546

MODELING

System dynamics (*Forrester, 1961*) frame for SCF monetary model additionally works with the following setup :

*Simulation time: Simulating different scenarios within the different time frames

*Feedback loops: Dynamic feedback to specific flows using chosen logic

*Flows are computed in a sequence determined by causal structure (e.g. consumption → income → tax), allowing **real-time propagation of effects**

! Software used : Ravel (*former Minsky*). Allows system dynamics modelling with in-built accounting continuity tables (*so-called Godley tables, named after Wynn Godley*). The same results and the same model could be achieved also in the most popular SD models, PowerSim and Stella

FORRESTER, Jay Wright. *Industrial Dynamics* [online]. Cambridge, MA: The MIT Press, 1961. ISBN 978-0-262-56089-4. Available from: https://doi.org/10.7551/mitpress/11841.001.0001

MODELING

SECTORS : First, using the Godley Tables, we define all balance sheet items for A,L and E, and all the debits and credits for each sector.

The model simulates monetary flows, focusing on money (i.e., components of broad monetary aggregates, including foreign currency holdings) and reserves (central bank liabilities). These flows are subsequently decomposed into sector-specific monetary stock categories to reflect balance sheet structures of individual institutional sectors. The table below presents the structure of the central bank's balance sheet as represented in the model.

	Assets	Liabilities		Equity
Flows ↓ / Stock Vars →		*Reserves*	*Government*	*CBequity*
Initial Conditions	150000	40000	100000	10000
Government sells Bonds		$-Bonds$	$Bonds$	0
Government pays interest		$Interest_{gov}$	$-Interest_{gov}$	0
Government Spending		$Spend_{gov}$	$-Spend_{gov}$	0
Taxation		$-Tax$	Tax	0

For example, reserves (*interbank liquidity and government account at Central Bank*) is a **stock**, and **flows** changing it are proceedings from selling government bonds (CB decreases the reserves of banking sector (-) and increases the government account (+) as a result of bonds sell), interest, that government pays on the bonds to the banking sector, spending by the government and taxation.

MODELING

Similarly, we define all the items and operations for all other sectors balance sheets.

FIRMS

	Assets				Liabilities		Equity
Flows ↓ / Stock Vars →	$Reserves$	$Nostro-account$	$Debt_{firms}$	$Debt_{gov}$	$Households$	$Firms^{Stock}$	$Banks$
Initial Conditions	40000	5000	600000	300000	400000	200000	45000
$Firms\ borrow$			$Borrow$			$Borrow$	0
$Firms\ pay\ interest$			$-Interest_{firms}$			$-Interest_{firms}$	
$Firms\ hire\ workers$					$Wages$	$-Wages$	0
$Households\ consume$					$-Consume$	$Consume$	0
$Households\ pay\ bank\ fees$					$-Fee$		Fee
$Banks\ spend$						$SPENDbanks$	$-SPENDbanks$
$Taxation$	$-Tax$				$-Tax$		0
$Government\ Spending$	$Spend_{gov}$					$Spend_{gov}$	0
$Government\ sells\ Bonds$	$-Bonds$			$Bonds$			0
$Government\ pays\ interest$	$Interest_{gov}$			$-Interest_{gov}$			
$Imports_{households}$		$-Foreign_{claims-hh}$			$-Foreign_{claims-hh}$		
$Exports$		$Foreign_{claims}$				$Foreign_{claims}$	
$Imports_{firms}$		$-Foreign_{claims-firm}$				$-Foreign_{claims-firm}$	
$FirmsDividends_{received}$		$-Dividends_{firms}$				$-Dividends_{firms}$	
$BankDividends_{received}$		$-Dividends_{bank}$					$-Dividends_{bank}$

MODELING

HOUSEHOLDS

	Assets	Liabilities	Equity
Flows ↓ / Stock Vars →	$Households$		$Householdsequ$
Initial Conditions	400000		400000
$Firms\ hire\ workers$	$Wages$		$Wages$
$Households\ consume$	$-Consume$		$-Consume$
$Households\ pay\ bank\ fees$	$-Fee$		$-Fee$
$Taxation$	$-Tax$		$-Tax$
$Imports_{households}$	$-Foreign_{claims-hh}$		$-Foreign_{claims-hh}$

TREASURY

	Assets	Liabilities	Equity
Flows ↓ / Stock Vars →	$Government$	$DEBTgov$	$TREASURY$
Initial Conditions	100000	300000	-200000
$Taxation$	Tax		Tax
$Government\ Spending$	$-Spend_{gov}$		$-Spend_{gov}$
$Government\ sells\ Bonds$	$Bonds$	$Bonds$	
$Government\ pays\ interes$	$-Interest_{gov}$		$-Interest_{gov}$

FOREIGN SECTOR

	Assets	Liabilities	Equity
Flows ↓ / Stock Vars →	$Payment_{claims}$	$Payment_{debts}$	$Saldo_{net}$
Initial Conditions	0	0	0
$Exports$	$-Foreign_{claims}$		$-Foreign_{claims}$
$Imports_{firms}$	$Foreign_{claims-firms}$		$Foreign_{claims-firms}$
$BankDividends_{received}$	$Dividends_{bank}$		$Dividends_{bank}$
$FirmsDividends_{received}$	$Dividends_{firms}$		$Dividends_{firms}$
$Imports_{households}$	$Foreign_{claims-hh}$		$Foreign_{claims-hh}$

Foreign sector is defined by exports, imports, imports directly consumed by the households, firms paying dividends, and banks paying dividends to foreign shareholders. For the sake of simplicity, those operations are defined as having direct impact on an aggregated Equity of Foreign Sector.

MODELING

After defining the conditions for the balance sheets, we need to define the **flows logic**. Doing so is a creative task, that cannot be done without some input from the normative *economic schools*. Below are some of the key value definitions :

$$GDP = \frac{Firms}{Turnover_{firms}}$$

GDP is defined by the ***Firms stock*** (asset side of the Firms sector) divided by the*times, which is an additional parameter.

$$\frac{d\,TREASURYequity}{dt} = Tax - \left(Spend_{gov} + Interest_{gov}\right)$$

Dynamics of the government equity is defined by the difference between the taxes collected and the sum of government spending and interest paid on issued bonds

$$Bonds = INTERESTgov + SPENDgov - Tax$$

If government spends and pay on interest more, than it collects on taxes, it must issue the bonds to finance it's deficit

$$Consume = Households \times Spendrate_{hh}$$

Consumption of households is defined by the exogenous parameter

Profits in the firms sector is given by the difference between the income and the cost items.

$$Firms_{profit} = Consume + SPENDbanks + SPENDgov + Foreign_{claims} - \left(Wages + Interestfirms + Foreign_{claims\text{-}firms}\right)$$

MODELING

$$Intrate = Intrate_{cb} + Intrate_{market}$$

First, we define interest rate as a sum of actual market rate markup and the initial central bank's key rate

Based on the actual rate, we then define the borrow offer of the firms sector, using two difference between the two additional parameters, multiplied by the interest rate. Those parameters could be calibrated to change the conjuncture of the firms sector and firms desire to borrow.

$$BorrowOffer = Firms^{Stock} \times \left(BorrowFrac_{MAX} - BorrowFrac_{slope} \times Intrate\right)$$

At the same time, borrow offer by the firms sector is met by the lending offer from the banks sector, which is simply defined as the banks sector aggregated equity level multiplied by the leverage parameter. This parameter could be changed to reflect the corresponding capital adequancy regulatory ratios and/or average total loans to equity.

$$LendOffer = Banks \times Leverage_{ratio}$$

Finally, we define the rate of change of the interest rate, using complex logic. First, we multiply the slope of change of exchange rate (exogenous parameter, which controls the sensitivity of the interest rate to changes in other parameters) by the difference between the sum of borrow offers (including the government bonds) and the lend offer, divided by the GDP.

$$\Delta INTrate = \frac{\left(BorrowOffer + Bonds - LendOffer\right) \times \Delta IntRate_{Slope}}{GDP}$$

MODELING

PARAMETERS

The model includes 18 exogenous parameters, each designed to control or influence specific monetary flows. Their purpose is to enable proper calibration of the model. The table below presents an overview of these parameters.

Parameter	Description
`BankFee_rate`	Fee rate applied by banks on transactions or balances
`Banks_dividend-ratio`	Share of bank profits distributed as dividends
`BorrowFrac_cmax`	Maximum share of credit demand banks are willing to finance
`BorrowFrac_slope`	Sensitivity of borrowing fraction to credit conditions
`Exports_ratio`	Share of output sold abroad (export rate)
`Firms_divratio`	Share of firms' profits distributed as dividends
`Import_firms-ratio`	Share of firms' purchases that are imported
`Import_hh-ratio`	Share of households' consumption that is imported
`IntRate_market`	Effective market interest rate
`IntRate_cb`	Policy rate set by the central bank
`Leverage_ratio`	Target ratio of bank assets to equity (financial leverage)
`Spendrate_gov`	Government consumption rate relative to GDP or income
`Spendrate_hh`	Household propensity to consume from disposable income
`Tax_rate`	Flat tax rate applied to income or value added
`Turnover_firms`	Average turnover rate of firm revenues
`Wage_share`	Share of output paid as wages
`ΔIntRate_slope`	Change rate of interest rate in response to market conditions

MODELING

Further relationships in the model are defined by the complex non-linear differential equations. Depending on the settings of the simulation, equations dynamically recalculate the values in every new step of the simulation. For example, asset side (Stock) of the firms sector is defined dynamically by the value of inflows and outflows (debits and credits) in time.

$$\frac{dFirms}{dt} = Borrow + Consume + SPENDbanks + SPENDgov + Foreign_{claims} - (Interestfirms + Wages + Dividends_{firms} + Foreign_{claims\text{-}firms})$$

GDP growth is driven by the rate of change in total firm assets, scaled inversely by the turnover ratio.

$$dGDP/dt = \frac{(Turnover_{firms} \times 1 \times (dFirms/dt \times 1 + 0) - Firms \times 1 \times (0 \times 1 + 0))}{Turnover_{firms} \times 1 \times Turnover_{firms} \times 1}$$

Similarly, other dynamic values are calculated using similar non-linear logic.

MODELING

CALIBRATION: MONETARY MODEL FOR THE CZECH REPUBLIC (2024, APPROXIMATE)

Calibrating parameters and values for a small open economy requires accurate completion of balance sheet entries, proper setting of weights and behavioral parameters, and correct specification of the foreign sector shares. **Naturally, this model is a monetary-only simplification, and this limitation should be kept in mind when interpreting the results**.

FIRMS SECTOR

Parameter / Stock	Aproximate 2024 Czech Value*
Firms (total assets)	~6–7 trillion CZK (aggregate corporate assets)
Turnover_firms	~1.3 (yearly turnover rate)
Wage_share	~0.5 (adjust for wage bill vs. gross value)
Firms_divratio	~0.25 (dividend payout ratio)

HOUSEHOLDS

Parameter / Stock	Aproximate 2024 Czech Value*
Spendrate_hh	~0.85 (MPC close to empirical data)
Import_hh-ratio	~0.2 (household import content estimate)
BankFee_rate	~0.01 (banking service cost)

MODELING

CALIBRATING THE MODEL FOR THE CZECH REPUBLIC

GOVERNMENT / TREASURY

Parameter / Stock	Aproximate 2024 Czech Value*
Tax_rate	~0.35 (aggregate effective tax rate)
Spendrate_gov	~0.2–0.25 (gov. expenditure share)
Gov Bonds	~2.5 trillion CZK
Treasury_equity	Adjust to ensure A=L+E balance

BANKS

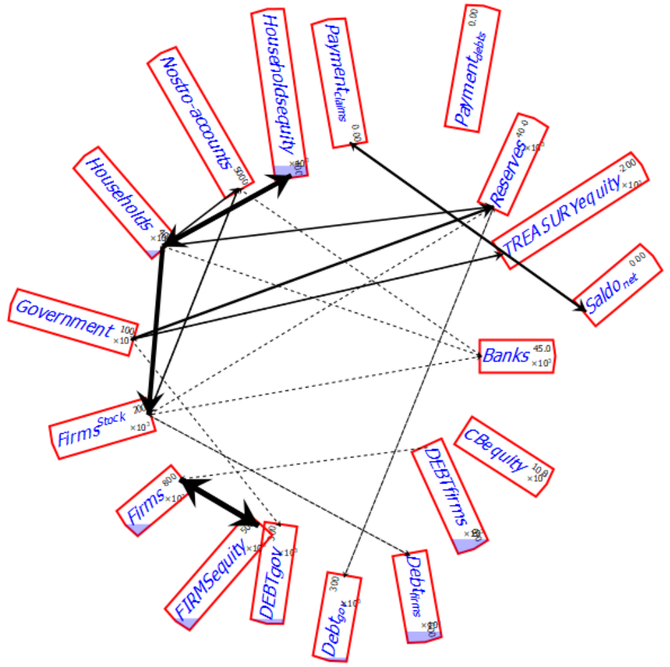
Parameter / Stock	Value
Leverage_ratio	~8 (assets to equity)
Banks_dividend-ratio	~0.3
Interest_rate_market	~6% (2024 avg lending)
IntRate_cb	~5.75% (CNB base rate 2024)

FOREIGN SECTOR

Parameter / Stock	Value
Exports_ratio	~0.7 (exports to GDP)
Import_firms-ratio	~0.25–0.3
Foreign Transfers	(~1% GDP)

SIMULATION

- Once all values are defined and calibrated, we can run a simulation, using the defined parameters. Below is the casual diagram for the whole model. Ravel does not support classical casual loop representation (like Vensim etc.), but it gives the idea of how the monetary flows are defined between the stocks.



We are going to run different simulation scenarios, based on the calibrated model. First we will test the modest, **normal scenario** with no exogenous or endogenous shocks for the time period of **60 years**.

SIMULATION

NORMAL SCENARIO : SETTINGS FOR 60 YEARS SIMULATION

Setting	Value
Time unit	Year
Start time	0
Run until time	60
Min step size	0.01
Max step size	1
Steps per iteration	1
Solver order	4 (Runge–Kutta)
Absolute error	0.001
Relative error	0.01
Implicit solver	No

SIMULATION RESULTS

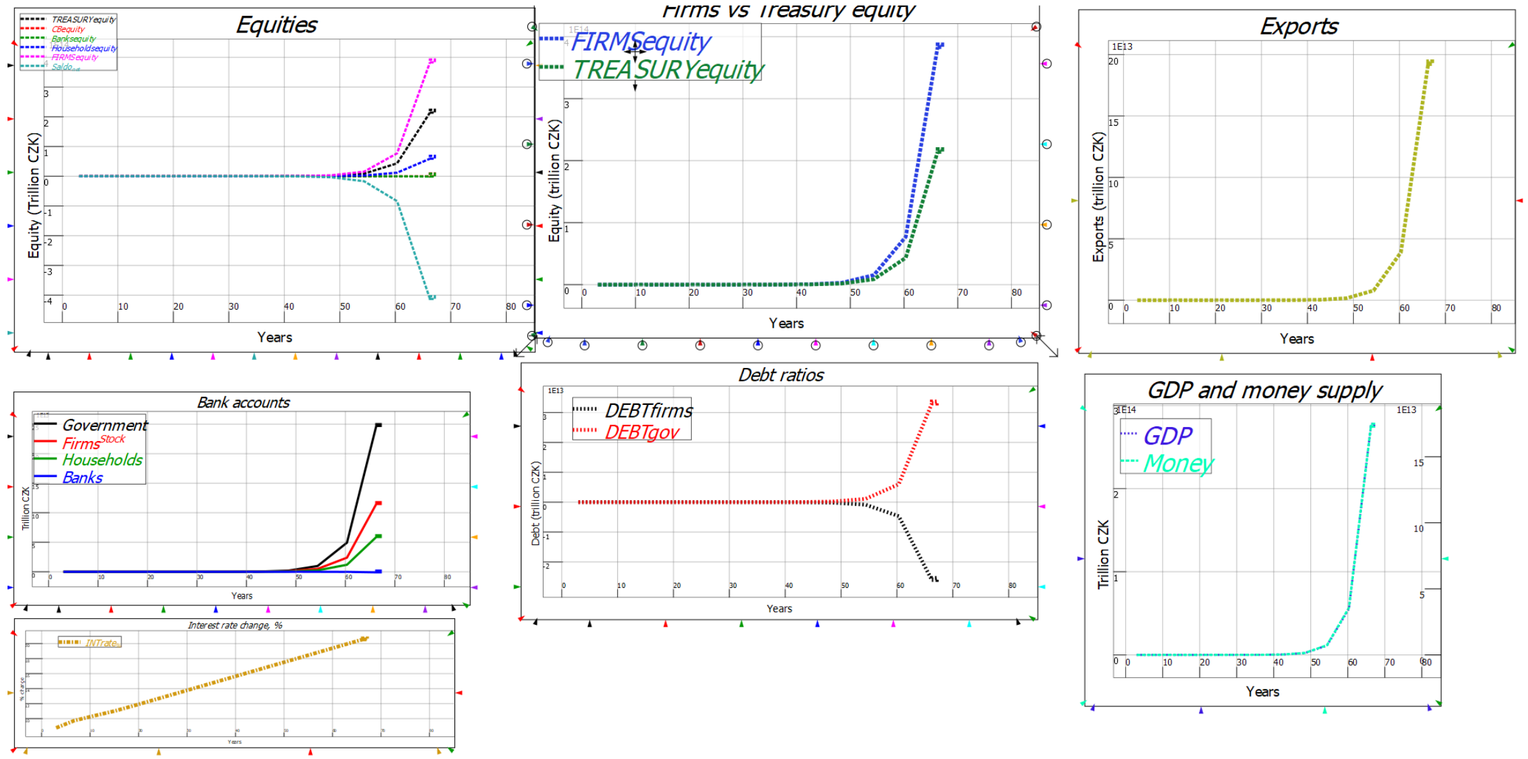
POSITIVE SCENARIO

With a well-calibrated parameter set — including long-term export surplus, moderate government spending, and effective taxation — and under conditions of stability (no shocks, mild interest rate growth, steady GDP and money supply expansion), government debt remains more controlled while the firm sector maintains positive equity. Although public debt still increases, the government effectively leverages foreign capital in this scenario.

Parameters for the positive foreign scenario

Parameter	Value
BankFee_rate	0.002
Banks_dividend-ratio	0.2
BorrowFrac_max	0.6
BorrowFrac_slope	0.02
Exports_ratio	0.7
Firms_divratio	0.2
Import_firms-ratio	0.1
Import_hh-ratio	0.1
IntRate_market	0.045
IntRate_cb	0.04
Leverage_ratio	8
Spendrate_banks	0.03
Spendrate_gov	0.22
Spendrate_hh	0.85
Tax_rate	0.21
Turnover_firms	1.3
Wage_share	0.55
ΔIntRate_slope	0.006

Simulation results – positive foreign scenario



SIMULATION RESULTS

POSITIVE SCENARIO : RESULTS

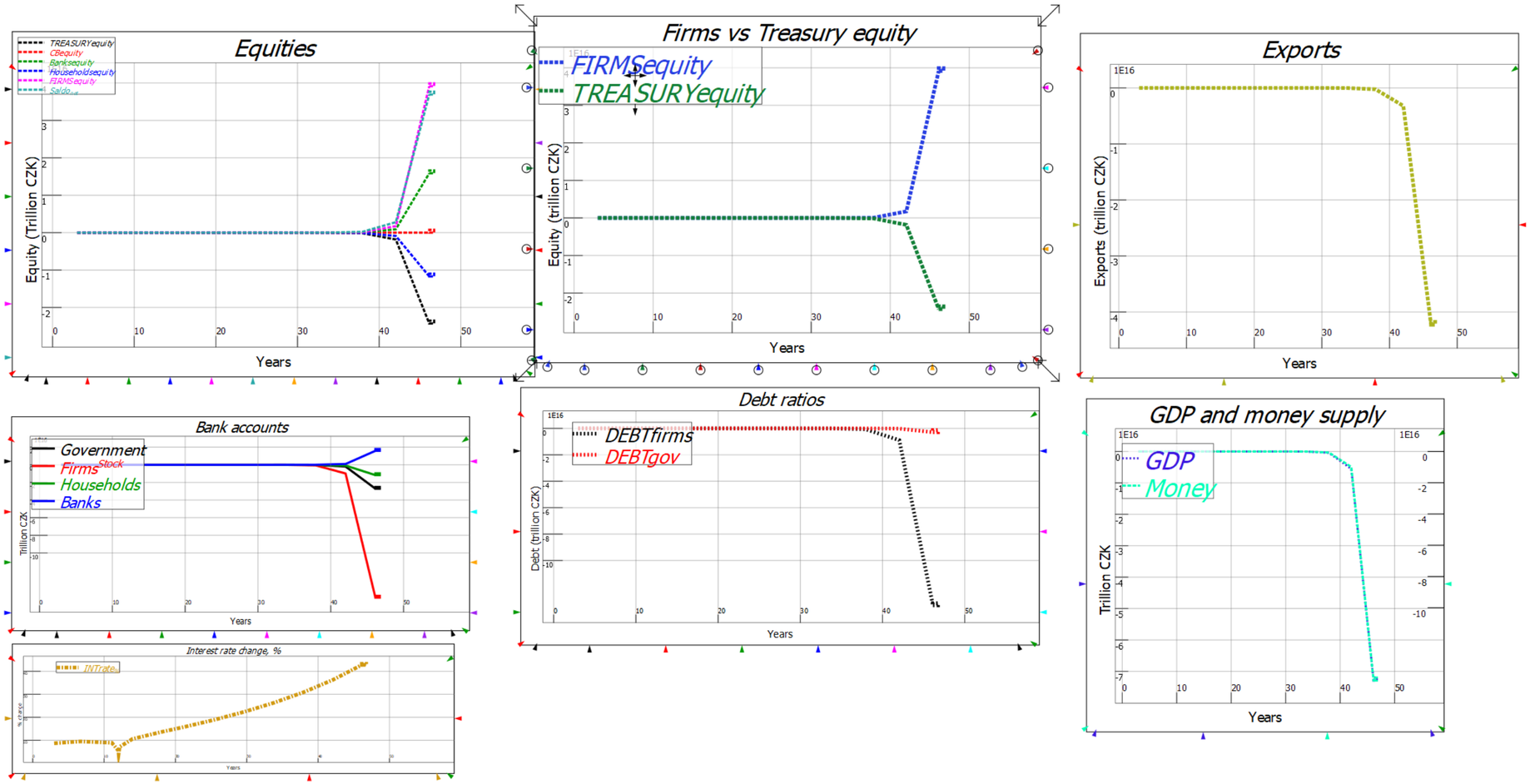
Value	Description
Equities	Firms, households, and banks accumulate equity; treasury drops then stabilizes.
Firms vs Treasury equity	Private equity rises; government equity improves via tax revenue and inflows.
Exports	Strong late-stage export boom drives foreign inflow and GDP growth.
Bank accounts	Government and firms hold increasing CZK balances; banks remain steady
Debt ratios	Gov debt grows; firm debt flattens → indicates deleveraging under strong profits.
GDP and money supply	Steady growth, accelerating after export boom → monetary base expands.
Interest rate change	Gradual increase over time; no sharp monetary shocks.

SIMULATION RESULTS

NEGATIVE SCENARIO – FOREIGN SECTOR SHOCK

A slight drop in the export-to-GDP ratio from 0.7 to 0.58 causes the model to shift drastically. Over 40 simulated years, system changes completely: GDP and money supply shrink, firm activity weakens, and treasury equity turns negative

Simulation results – exports decline to 0.58



SIMULATION RESULTS

FOREIGN SECTOR SHOCK: RESULTS

Value	Description
Equities	Treasury equity falls post-export drop; firms flatten; households/banks modestly rise.
Firms vs Treasury equity	Treasury equity diverges downward sharply after t≈38; firm equity grows but more slowly.
Exports	Sharp collapse around year 38; no recovery — signals lasting foreign sector deterioration.
Bank accounts	Firm and government accounts drop significantly; banks hold capital; households steady.
Debt ratios	Gov debt plateaus; firm debt collapses as credit contracts and deleveraging begins.
GDP and money supply	Both shrink sharply post-export collapse; declining turnover pulls GDP down.
Interest rate change	Smooth rise → reacts slowly; no overshooting or spike.

CONCLUSION

With a well-calibrated parameter set — including long-term export surplus, moderate government spending, and effective taxation — and under conditions of stability (no shocks, mild interest rate growth, steady GDP and money supply expansion), government debt remains more controlled while the firm sector maintains positive equity. Although public debt still increases, the government effectively leverages foreign capital in this scenario. However, even a modest decline in the export-to-GDP ratio (e.g. from 0.7 to 0.58) leads to a rapid deterioration of government equity, contraction of money supply, and eventual GDP decline — highlighting the system's strong sensitivity to foreign sector assumptions

OTHER KEY TAKEAWAYS

> The model captures **core financial and monetary linkages** using an integrated system of balance sheets, stocks, and flows.

> Despite **intentional simplifications**, the internal consistency of the framework allows for rich and non-linear dynamics.

> Small changes in parameters, such as the export-to-GDP ratio, lead to **significant shifts** in equity positions, debt trajectories, and GDP behavior.

> The model demonstrates **path dependency** and sensitivity to external sector assumptions, especially over long-term simulations.

> It reveals that **positive macro outcomes** (e.g. stable GDP and rising firm equity) can emerge even in the absence of active stabilization policies, **if external flows are strong and well-aligned**.

> Conversely, even modest deterioration in trade conditions **triggers fiscal stress** and eventual system-wide imbalances.

> The experiment confirms the usefulness of **system dynamics for macro-financial diagnostics**, though full empirical realism would require more detailed calibration and policy feedbacks.

FUTURE RESEARCH

Integration with core monetary model

Merge the model with the main money supply decomposition model to ensure full accounting consistency and trace capital flows across borders.

Shock-response simulations

Introduce and analyze export shocks, interest rate volatility, and foreign capital reversals to assess system resilience.

Sectoral refinement

Add simplified but meaningful sector decomposition (e.g. tradable vs. non-tradable firms) to test export dependency and fiscal feedbacks more realistically.

Empirical calibration using real data

Aligning export ratios, public finance parameters, and firm turnover with observed macro-financial dynamics from available datasets.

THANK YOU

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