3 FUNCTIONAL RECIPROCITY OF THE MACROECONOMIC VARIABLES

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Abstract

This paper's objective is to evaluate the intensity of the connection between two economic time series – x and y - by the degree in which they are representing a linear interdependent pair. This intensity is measured by the product of the slope coefficients of separate regressions y=f(x) and x=f(y), and will be called hereafter "the functional reciprocity" (rec_{xy}) of the respective variables. The closer to unity is rec_{xy}, the higher will be the intensity of the said functional reciprocity i, and vice versa. A high functional reciprocity is a solid argument for utilizing the orthogonal regression, however the converse reasoning is not valid: there is not certain that the estimator obtained by this econometric technique would reflect the actual intensity of the connected variables.

The bundle of macroeconomic indicators involved into monetary processes is a good empirical platform for testing the proposed methodology. The USA experience during the junction of the last two centuries (1960-2022) was chosen as study case, with the focus on relationships among the global output, inflation, broad money M3, money velocity, and interest rate. Quarterly frequency was preferred, the statistical series thus obtained being not only reliable enough, but also able to provide consistent econometric estimations.

The main problem identified by this paper was a pronounced instability of the functional reciprocities resulted from statistical data. By itself, the randomly resampling procedure did not allow surpassing this inconvenience. The VAR technique proved to be a more proper tool to transform volatile series into more stable ones; it was applied on both statistical and resampled series.

Comparison of the results of the post-sample simulations to the averages of initial database has brought up two remarks: i) it seems reasonable to assign more credibility to the steady state approximations, since they yield from a considerably longer series of iterations; ii) whenever there are cases when the steady state estimations themselves are contradictory, they dictate the necessity to improve the proposed algorithm, for example by involving a great number of resampled series - a question requiring further research.

Keywords: functional reciprocity, longest stable VAR, post-sample simulations

JEL Classification: C15, C32, C53

I. Introduction

1. The manifold network of interdependencies among the production factors and global output, the primary and redistributive income processes, the typical monetary and financial phenomena and the international relationships has established itself as a prominent mainstream theme of the modern macroeconomics. Terminologically, this issue was consecrated as i) the mutual or

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contemporaneous causality (Hicks 1980, p. 19), and ii) the interconnectedness or interconnectivity, these syntagms circulating in various linguistic forms. Time series of the corresponding indicators offered a rich empirical material for quantitative researches.

1.1. Causal approach covered a huge diversity of such interdependencies. Illustratively, we shall mention (almost randomly) some of the papers on this topic, published at beginning of the 21-th century. Many of them concerned the interactions of the economic growth with: trade and foreign direct investment (Dritsaki et al. 2004, Gupta and Singh 2016); stock and credit market (Dritsaki and Dritsaki-Bargiota 2005); exports (Kónya 2006, Kang et al. 2009, Georgantopoulos and Tsamis 2011); higher education (Erdem and Tugcu 2010); financial development (Adamopoulos 2010, Vazakidis and Adamopoulos 2010, Garefalakis et al. 2022); savings-led (Tang 2010); school education (Dănăcică 2011); research (Guloglu and Tekin 2012); tax rates (Karagianni et al. 2013); insurance development (Su et al. 2013); energy (Xiangdong et al. 2019, Bachman 2023); human capital (Khan et al. 2015); debt (Gómez-Puig and Sosvilla-Rivero 2015, De Vita et al. 2018, Dawood et al. 2021); environmental quality (Saidi et al. 2017); structural changes (Olczyk and Kordalska 2018); money supply and inflation (Hicham 2020); transaction fees (Ante and Saggu 2023). An extended area of causal analysis is represented by the prices and inflation (Hall et al. 2009, Hoxha 2010, Shirvani et al. 2012. Lai et al. 2017, Xu et al. 2018, Khan 2020). The monetary and financial markets should be added, as well (Hong et al. 2009, Kapounek 2011, Wilcox and Gebbie 2015, Subrata 2020). As should be expected, the sectoral problems appear frequently enough: foreign trade (Tang 2008. Liu 2009, Steingress 2018), energy (Huseynli 2023), infrastructure (Iqbal and Khurram 2006, Beyzatlar et al. 2012), education and health (Naurin and Pourpourides 2023, Amiri and Ventelou 2010, Chen et al. 2012); policy and public governance (Barro and Redlick 2009, Olanipekun et al. 2019, Boţa-Avram et al. 2021, Xiong et al. 2022, Trofimov 2023). The behavioral implications of causal misperceptions should be mentioned, too (Spiegler 2020).

1.2. Interconnectedness emerges rather suddenly in international economics: Dudley 2012, OECD 2013, Lagarde 2013, KPMG 2013, Greenwood-Nimmo et al. 2015, Raddant and Kenett 2016, Liow and Yuting 2017, Robinson 2018, Levite and Jinghua 2020, Delabarre 2021, Khemraj and Pasha 2024, Penzin et al. 2023. Sometimes, this notion is used in relation with the banking and financial system: Moghadam and Viñals 2010, Peltonen et al. 2015, Chen and Iftekhar 2016, Alonso and Stupariu 2019, Ellul and Kim 2021.

2. The afore-mentioned references are only a drop in a veritable ocean of studies, which analyze the relationships among various macroeconomic indicators. This bibliographical torrent stems above all from the growing interest of society (business world, scientific centers, Government institutions, social media, public opinion) for identifying the regularities dominating the economic life – whose understanding would improve the micro and macro decisional mechanisms. At the same time, several factors of conceptual-technical type also favored such a trend.

2.1. Debates concerning the epistemological problems of the causality in economics (Hicks 1980, Leamer 1985, Pearl 2003, Guisan 2003, Moneta 2005, Heckman 2005 and 2008, Angrist and Pischke 2010, Zaman 2010, Smith 2016, Henschen 2018) reveal an increasingly diversified interpretation of this issue. In his monograph "The Philosophy of Causality in Economics - Causal Inferences and Policy Proposals" (2020), Maziarz – arguing that "economists, as a group, are moderate causal pluralists" - pointed out (p. 196-197) five main approaches to causality: ▪ the theory-driven econometrics, as in structural-equation modeling, developed by the Cowles Commission; ▪ the probabilistic view - causality that locates itself – as in Granger's definition and the vector autoregressive technique; ▪ the ideal counterfactual claim (what would happen if an intervention were introduced; ▪ the axiomatic, deductive (theoretical) path as DSGE models (special case of this class); ▪ the quasi-experimental research designs and experiments, which allow for uncovering relations that are invariant under intervention. Naturally, such a polysemantic interpretation of causality has stimulated the expansion of empirical research to broader areas of

economic life. The above presented examples confirm this pluralistic trend.

2.2. In our opinion, it was greatly facilitated by the changes occurring in the informational sources themselves.

i) During the 20th century, the ever-increasing number of economic entities (especially the ones in advanced countries) adopted the modern accounting systems, whose core principle is the double-entry bookkeeping. The notable advantage of such systems is a more accurate description of the interdependencies established among economic indicators.

ii) Another informational mutation was the considerable expansion of aggregative operations on primary data. The switch, in many cases, from the customary annual frequency to quarterly, monthly, weekly, daily and even in real time frequencies opened new threads in empirical research. These changes allowed, on one hand, a more substantial apprehension of the so-called sequential causality (Hicks 1980), and, on another hand, a multiplication of the investigated data (resulting in a growing consistency of the econometric estimations).

iii) Such an evolution would have not been possible without the spectacular development of computational techniques, currently capable to process the constantly augmenting databases.

3. Our proposal is to evaluate the intensity of the connection between two economic time series –say x and y – by the degree in which they are representing a linear interdependent pair.

3.1. This intensity is to be measured by the product of the slope coefficients of separate regressions y=f(x) and x=f(y), and will be called the "functional reciprocity" (rec_{xy}) of the respective variables; inter alia, the Granger causality test is based just on similar logics. Hence, from the equations:

$$y = a_0 + a_1 * x + \varepsilon_y \quad (1), \text{ and}$$

$$x = b_0 + b_1 * y + \varepsilon_x, \quad (1a),$$

the product $a_1 * b_1$ approximates the functional reciprocity between x and y, as a quantitative expression of their susceptibility to impart one's changes to the other.

3.2. Functional reciprocity is strongly linked to the Galtung-Pearson correlation. By introducing the standard deviations of x (s_x) and of y (s_y), and the correlation coefficient between x and y (r_{xy}), in univariate regression the following equalities are valid:

$$a1 = r_{xy} * (s_y / s_x) \quad (2), \text{ and}$$

$$b1 = r_{xy} * (s_x / s_y) \quad (2a)$$

from which the functional reciprocity becomes:

$$rec_{xy} = r_{xy} * ((s_y / s_x)) * (r_{xy} * (s_x / s_y)) = r_{xy}^2 \quad (3)$$

The widely used coefficient of determination (R^2) is a particular case of the functional reciprocity, respectively when the statistical series y is compared to its values estimated by the regressor x.

From (3) it automatically yields $0 < rec_{xy} < 1$; hence, the closer to unity is rec_{xy}, the higher is the intensity of the respective functional reciprocity, and vice versa.

3.3. To estimate the relative impact of each of the pair's components (x and y) on the forming of their functional reciprocity, the following weights could be used:

$$sh\_x \rightarrow y = |a_1| / (|a_1| + |b1|) \quad (4)$$

$$sh\_y \rightarrow x = |b_1| / (|a_1| + |b1|) \quad (4a)$$

Obviously, $sh\_x \rightarrow y + sh\_y \rightarrow x = 1$.

4. The bundle of macroeconomic indicators involved into monetary processes is a good empirical platform for experimenting the previously described methodology.

4.1. Starting from the monetary conceptual thesaurus inherited from John Stuart Mill 1848, Knut

Wicksell 1898, Irving Fisher 2011, Ludwig von Mises 1912 and John Maynard Keynes 1936, this topic has been intensively investigated by modern economics. Some general topics were developed, for example, in Friedman 1956, Friedman and Schwartz 1963 and 1970, Lucas 1972, Sims 1972 and 1977, Humphrey 1974, Thornton and Batten 1985, Cagan 1989, Johnson et al. 2001, Stock and Watson 2003, Wennerlind 2005, Bernanke 2006, Fuerst 2010, Cerdeiro 2010, Hoover 2023. Analyses of the money market interferences with the dynamics of the global output, income, and inflation can be found in Sims 1972 and 1980, Green 1982, Rhee and Rich 1995, Coleman 1996, Rolnick and Weber 1998, King 2001, Haug and Dewald 2010, Hasanovz and Omay 2010, Ryczkowski 2021, Lu et al. 2022, Mathai 2023, Gorton 2023, Schnabel 2023, Deb et al. 2023, Ari et al. 2023, Hall et al. 2023, Steinsson 2024. Debates around the quantitative monetary theory were provided by a large body of literature on money velocity, such as Friedman and Meiselman 1963, Isard and Rojas-Suarez 1986, Wen and Arias 2014, Shirvani and Delcoure 2014, Nunes et al. 2018, Chen and Tillmann 2020, Berk and van den End 2022, Faria and McAdam 2023. More recently, researching efforts in this field have been concentrated on the quantitative easing hypothesis: Graff 2015, Hendrickson 2022, Ruderweis et al. 2023, Vyletelka 2023, Webster 2023, Tanaka 2023, Shi 2023. Monetary policy transmission mechanisms also constituted a frequent researching target, a special attention being paid to the interest rate: Friedman and Schwartz 1982, Muscatelli et al. 1998, Zhang 2021.

4.2. Statistically, the relationships characterizing the monetary processes developed in USA during the junction of the last two centuries were chosen as study case. Due to its dimensions and experience in practicing the market mechanisms, the American economy is probably one of the most appropriate examples for such an endeavor. The chosen interval – years from 1960 to 2022 - covers nine successive cycles (NBER 2023), many international shocks, plus the Covid 19 pandemic crisis, being highly relevant in examining the relationships among the global output, money supply, and inflation. A quarterly frequency was preferred, to obtain statistical series not only reliable enough, but furthermore able to provide consistent estimations. Five macroeconomic indicators have been considered crucial for this econometric exercise:

- global output, represented by the real gross domestic product, in billions of chained 2017 dollars (GDPc);
- inflation, approximated by the implicit price deflator (PGDP), to reflect all segments of economic transactions;
- money supply, through the broad money M3, US dollar;
- money velocity (V), as a ratio of nominal GDP to money supply;
- regarding interest (IR), there were retained long-term Government bond yields, 10-Year: Main (including benchmark).

The symbols of macroeconomic indicators are completed with the prefix qI, representing the quarterly data expressed as chain indices; in case of inflation, "I", being redundant, is omitted.

5. Apart from the database analysis (stationarity and Granger causality tests), the second chapter of this paper discusses empirical estimations – for the time span 1960-2022 – of the functional reciprocity in the American economy, for ten pairs of indicators: qIGDPc↔qPGDP, qIGDPc↔qIM3, qIGDPc↔qIVM3, qIGDPc↔qIIR, qPGDP↔qIM3, qPGDP↔qIV, qPGDP↔qIIR, qIM3↔qIV, qIM3↔qIIR, and qIV↔qIIR. The main problem identified in this chapter is a pronounced instability registered by the functional reciprocity of the monetary variables during the chosen statistical interval.

6. The third chapter extends the empirical analysis, involving facilities provided by the VAR technique and resampling procedure to obtain – by simulations – some series congenitally derived from the primary ones, whereas more stable than those. Our proposed hypothesis is that such series could reflect the causal structure of the examined process for a time span longer than the sampling one. Some conclusions concerning the interaction between the global output of economy and the main monetary variables are exposed in the last chapter of this paper.

II. Functional reciprocity estimations for USA economy years 1960-2022

IIA. Statistical data

1. Using the sources provided by the Federal Reserve Bank of St. Louis 1-5 (2023), completed – in the very few cases of information gaps – with the author's approximations, there were computed series of quarterly chain indexes (1960Q1-2022Q4, that is 252 observations) of *i)* the real gross domestic product (qIGDPc), *ii)* the GDP deflator (qPGDP), *iii)* the broad money M3 (qIM3), *iv)* the money velocity (qIV), and *v)* the interest rate (qIIR). It is worth noticing that the money velocity index was approximated as:

$$qIV = qIGDPc*qPGDP/qIM0 \quad (5),$$

where M0 is the monetary base. The constituted database is detailed in the Appendix 1a (statistical data are mentioned with the postfix _s).

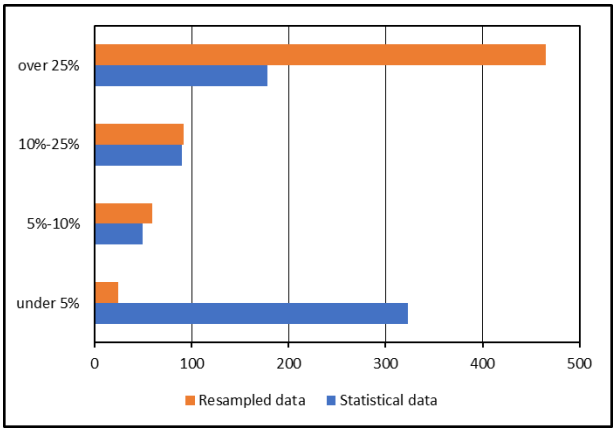
2. Technically, the involvement of quarterly chain indexes has proved advantageous from the econometric viewpoint.

2.1. All the statistical series are stationary in level (with intercept). Relating to statistical series, the probability of ADF null hypothesis (the series has a unit root) is situated, in all cases, significantly under the critical value of 5%. (Table1, online appendix).

2.2. Some useful information is offered also by the standard Granger causality test, applied on statistical data. For example, it indicates the presence of dependences (in Granger sense) among many of the examined variables. This test was applied in 32 variants of lags (1, 2, …, 32). Depending on the probability of the null hypothesis, the obtained results were grouped into four categories: under 5%, 5-10%, 10-25%, and over 25% (Figure 1).

In case of statistical data, a probability lower than 5% appears in 50.5% of tests; together with those of 5%-10% probability, therefore, in more than 58% of cases the Granger test rejects the null hypothesis, which infers a consistent presence of interdependences among the time series.

Figure 1 Number of Granger causality tests with probability of the null hypothesis situated between thresholds



3. The functional reciprocity maybe estimated for various lengths of the analyzed series. In this matter, our option was guided by the information concerning the short-medium cyclicity of the

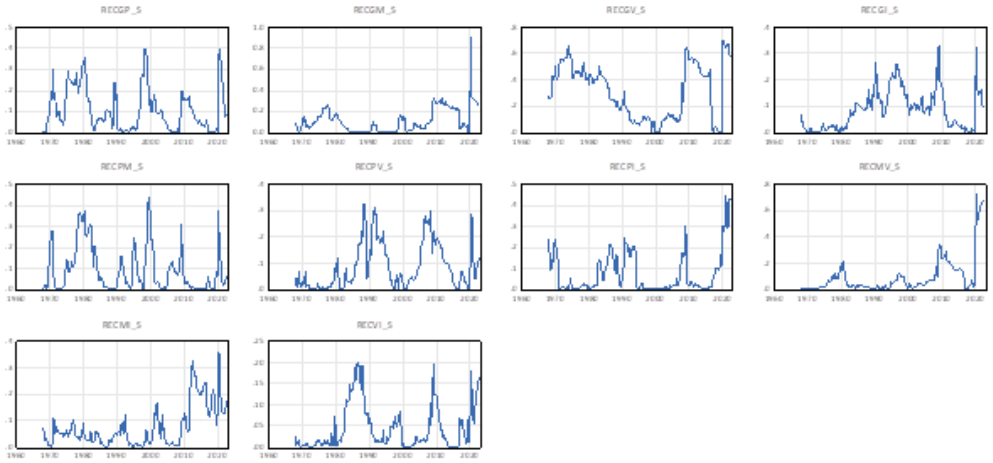
American economy. According to NBER data (2023) about the distances between successive peaks, the average duration of business cycles produced during 1960q1-2022q4 was 30.375 quarters; on the other hand, a double President mandate covers eight years. Consequently, our option for the present application was to estimate the functional reciprocity using the moving time series of 32 consecutive quarters. The following ten pairs of series were considered proper for this analysis: recGP for the interaction qIGDPc↔qPGDP, recGM for qIGDPc↔qIM3, recGV for qIGDPc↔qIV, recGI for qIGDPc↔qIIR, recPM for qPGDP↔qIM3, recPV for qPGDP↔qIV, recPI for qPGDP↔qIIR, recMV for qIM3↔qIV, recM I for qIM3↔qIIR, and recVI for qIV↔qIIR (for statistical data see Appendix 2a, online).

Table 2. Functional reciprocity in USA economy, during 1960-2022 (average, statistical data)

recGP_s	**recGM_s**	**recGV_s**	**recGI_s**	**recPM_s**
0.1085292	0.1081461	0.3101377	0.0851196	0.0928939
recPV_s	**recPI_s**	**recMV_s**	**recMI_s**	**recVI_s**
0.0862167	0.0751534	0.0944855	0.0738252	0.0443003

Over the entire period, the statistical data display weak enough functional reciprocities, excepting relationships between the global output and the money velocity. This is, however, just the average picture.

Figure 2 Evolution of the functional reciprocity estimated from statistical data



Contrary to the previous image, Figure 2 reveals a highly agitated dynamics, the levels of the functional reciprocity alternating frequently and in significant proportion.

4. The relative impact of the paired variables on the corresponding functional reciprocity is described in Figure 3 (online appendix) as the average for the sample period.

Excepting the relationship between broad money and global output, all the other dependences are unilateral, as an average for the whole period. Shorter intervals exhibit, however, more diverse situations.

5. Volatility of the rec series has been evaluated by the coefficient of variation (calculated as ratio

of the standard deviation to average) during the sample period (Figure 4, online appendix).

Almost in all cases, the coefficient of variation is worrisomely high, weakening the cognitive reliability of the functional reciprocity estimations themselves.

IIB. Resampled data

1. Resampling procedure has also been involved, the benefits of this technique being often evoked in literature (Efron 1982, Sitter 1992, Yu 2002, Good 2006, Sinharay 2010, Arya 2023, Soni 2023). With this aim, we opted for the algorithm developed by Econometric Views 13; the outcomes are displayed in Appendix 1b.

2. As a result, the dynamic properties of the examined indicators are relatively changed.

2.1. New series remain, however, stationary (see Table 1).

2.2. Instead, the share of Granger causality tests with probability under 5% decreases to 3.75% and represent, together with those of 5-10% probability, only 13% (Figure 1). The Granger causality test is, therefore, less favorable to the hypothesis of presence of interdependences among the resampled series.

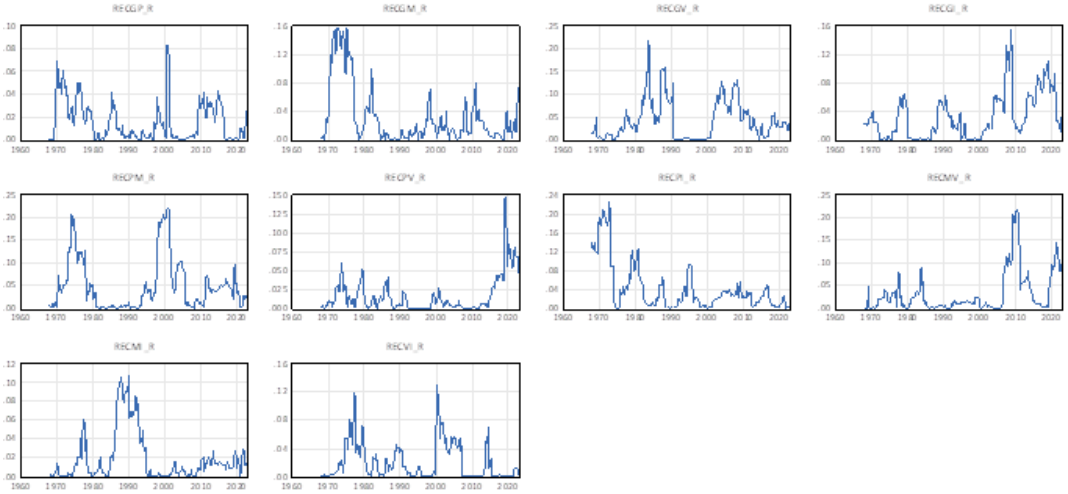
3. Calculated using the same methodology as the one applied for statistical data, the functional reciprocity for resampled data is detailed in Appendix 2b; Table 3 summarizes the estimations for the whole interval.

Table 3. Functional reciprocity in USA economy, during 1960-2022 (resampled data)

recGP_r	**recGM_r**	**recGV_r**	**recGI_r**	**recPM_r**
0.0155416	0.0315288	0.042758	0.0320962	0.0501561
recPV_r	**recPI_r**	**recMV_r**	**recMI_r**	**recVI_r**
0.0162198	0.040786	0.032399	0.0187895	0.0208203

This time, the functional reciprocity over the entire period is very low for all pairs of variables. Even in this case, however, the intermediary sub-samples register many variations (Figure 5).

Figure 5. Evolution of the functional reciprocity estimated from resampled data



4. For integral series, the relative impact of the paired variables on their functional reciprocity is characterized in Figure 6 (online appendix).

Overall, therefore, the differences resulted from the resampling procedures are (comparatively with the statistical data) small enough, excepting the binomial global output – inflation. It is easy to notice that the picture is more nuanced when shorter sub-intervals are taken into consideration.

5. Assessed again by the coefficient of variation, the volatility of the functional reciprocity of resampled series is displayed in Figure 7(online appendix).

In most cases, the resampling operation mitigates the estimated coefficients of variation. However, irrespective of the type of series used – statistical or resampled – the high volatility of the resulted functional reciprocity of the examined macroeconomic variables remains a significant problem. Consequently, the identification of computational algorithms better suited to generate more stable series is particularly important. For the present application, we opted for the vector-autoregression technique.

III. VAR framework

1. VAR algorithm allows generating post-sample simulations, under the assumption of multicausal interdependence among the studied variables (Sims 1972, 1980; Leamer 1985; Cooley and Leroy 1985; Bernanke and Mihov 1997; Rudebush 1998; Bagliano and Favero 1998, 1999; Brüggemann 2003). To capture in the greatest possible extent the properties of the initial database, this approach is structured as follows:

i) VAR specification comprises all the five variables of interest;

ii) it is tested for stability condition under a different number of lags;

iii) for the post-sample simulations, it is chosen such a specification which – observing the stability condition – involves the largest number of lags (LsVAR).

This methodology will be tested on both statistical and resampled data.

2. Statistical time series qIGDPc, qPGDP, qIM3, qIV, and qIIR are integrated into model VAR5_0, whose full description can be found in Appendix 3, online.

2.1. As expected, the accuracy of estimations (Table 4) is not very high. It is acceptable enough, however, the main goal of our research being not to predict the future evolution of the mentioned indicators, but only to create a computational framework for simulating their stability.

Table 4. Accuracy of the Model VAR5_0 estimations

	qIGDPc	qPGDP	qIM3	qIV	qIIR
R-squared	0.4130054	0.8509193	0.5053136	0.3777753	0.5330057
Sum sq. resids	0.0163795	0.0012667	0.0158371	0.2930321	1.273458

2.2. The Model VAR5_0 residuals were submitted to BDS test, applied into five dimensions (2, 3, 4, 5, and 6) and three distance options, used in testing the proximity of data points (fraction of pairs, standard deviations, and fraction of range). Table 5 (online appendix) exposes the BDS null hypothesis resulted from the sample data as such.

Values assigned to the residuals qIGDPc, qIV, and qIIR clearly confirm the BDS null hypothesis. Those of "fraction of pairs" and "standard deviation" reject it for resqPGDP and resqIM3; it is worth noting, however, that even in this case the BDS null hypothesis is agreed by most of the tests in "fraction of range". The BDS null hypothesis probability was approximated not only for sample data, but also for the bootstrapped residual series (Table 6, online appendix).

Therefore, the conclusions extracted from the Table 5 are supported by the information provided in Table 6.

3. Resampled time series of qIGDPc, qPGDP, qIM3, qIV, and qIIR were also structured as model VAR5_1, its full specifications being displayed in Appendix 3, online.

3.1. The accuracy of estimations (Table 7) appears to be improved comparatively with VAR5_0.

Table 7. Accuracy of the Model VAR5_1estimations

	qIGDPc	qPGDP	qIM3	qIV	qIIR
R-squared	0.734368	0.744671	0.685621	0.701446	0.726082
Sum sq. resids	0.004282	0.001649	0.009562	0.140596	0.678002

3.2. BDS test was applied on the residuals of Model VAR5_1, following the same procedural pattern as it was. The proportion of the probabilities of the BDS null hypothesis surpassing 0.05 represents, therefore, approximately 75% when following the normal procedure, and 95% for the bootstrap one.

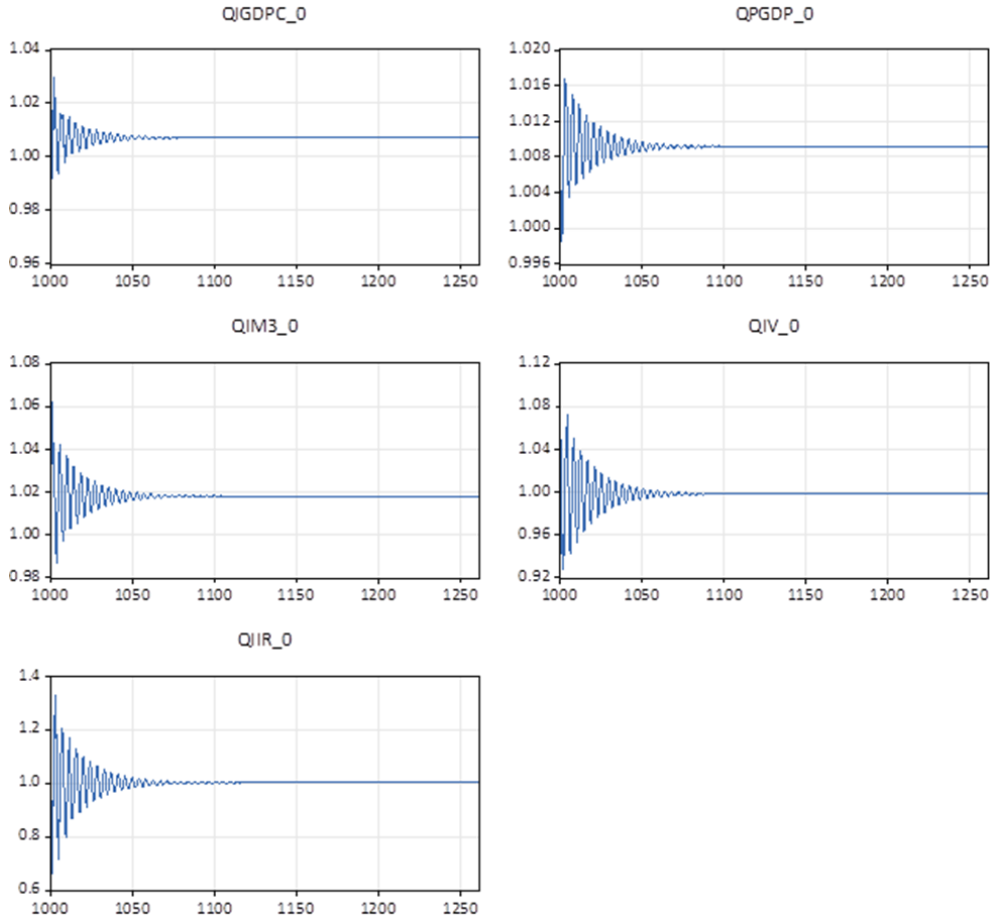
IV. Post-sample simulations and discussion

Post-sample simulations of models VAR5_0 and VAR5_1 have as a main objective to verify if, in so doing, more stable series of the involved macroeconomic indicators can, or cannot be obtained, which reverberates as well on the functional reciprocity derived from them. Our exercise focuses on the results of 1.260 successive iterations, corresponding to a length five times higher than the one of the initial database (252 quarters).

IVA. Model VAR5_0

1. The post-sample simulations operated with Model VAR5_0 which concern the involved macroeconomic indicators can be found in Appendix 4a1, online. All the series are convergent (Figure 8).

Figure 8. VAR5_0 post-sample simulations of the macroeconomic indicators



2. Being derived from these macroeconomic indicators, the corresponding functional reciprocities (Appendix 4a1) are presented in Figure 9.

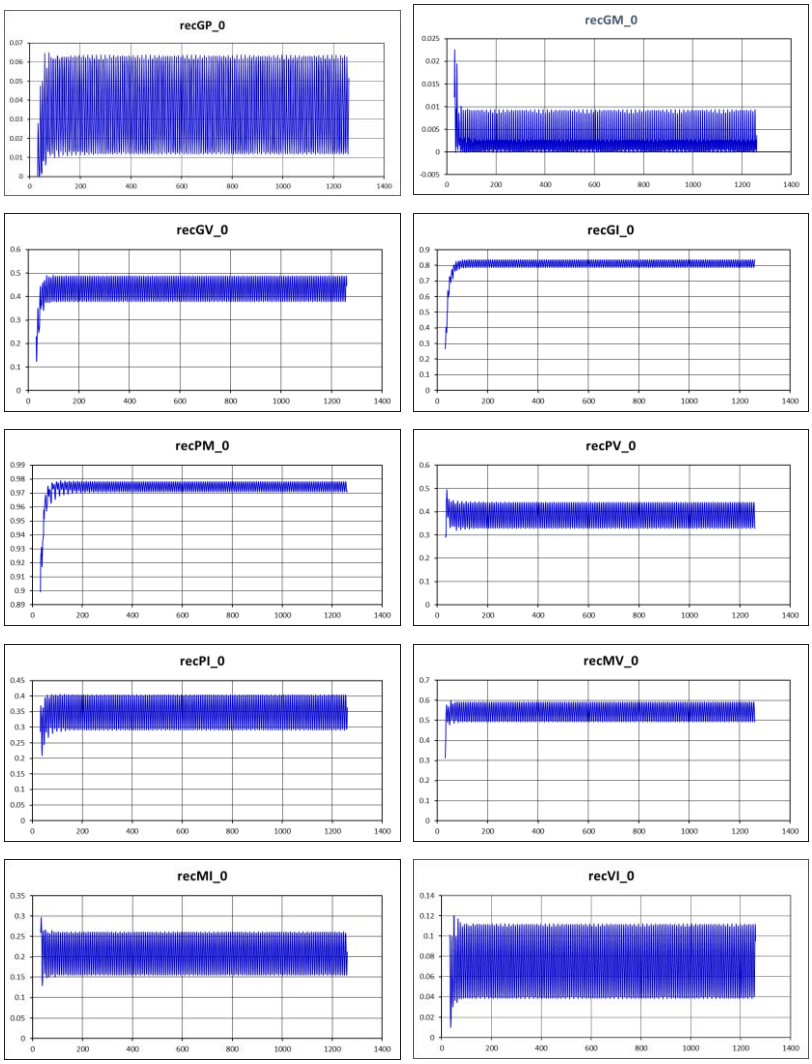
3. Within the convergence process, there was revealed what will be called the "steadiness zone", as a prelude to the steady state. We presume that a series is entering a steadiness zone whenever its relative successive differences in module (rel) remain below 0.00001, at least one hundred times.

$$rel_t=((sim_t/sim_{t-1}-1)^2)^{0.5} \quad (6),$$

where *sim* represents the simulated values.

In the case of macroeconomic indicators, such a brink of steadiness is reached after 452 post-sample iterations for qIGDPc_0, 414 for qPGDP_0, 516 for qIM3_0, 586 for qIV_0, and 675 for qIIR_0. These benchmarks are considered applicable also for the functional reciprocity series, which are only a replica of the first ones.

Figure 9. Functional reciprocity simulated by Model VAR5_0



4. As for the steady state potentially generated by the post-sample simulations, we shall formulate an acceptable enough approximation, starting from the following premises:

i) since the functional reciprocity is derived from the macroeconomic indicators, steady state levels must be determined simultaneously and interdependently for the variables involved;

ii) this means that the iteration after which the steady state is estimated should be identical for all of them, hence the equivalent of the maximal number of iterations registered as brink of steadiness; in our application, it is 675;

iii) the number of subsequent iterations required for the approximation of the steady state levels is, certainly, a pragmatic question; experimentally, one hundred seems a reasonable choice.

Hence, the steady state levels (prefix sts) of the macroeconomic indicators and functional reciprocity are equal with the mean of their estimations along the iterations 675-774. Estimations are displayed in Table 10.

Table 10. Steady state levels of the macroeconomic indicators and the functional reciprocity, estimated by VAR5_0

sts_qIGDPc_0	**sts_qPGDP_0**	**sts_qIM3_0**	**sts_qIV_0**	**sts_qIIR_0**
1.007215691	1.009142741	1.017952203	0.99819857	1.00203101
sts_recGP_0	**sts_recGM_0**	**sts_recGV_0**	**sts_recGI_0**	**sts_recPM_0**
0.034760987	0.003181171	0.43470515	0.81136054	0.974679392
sts_recPV_0	**sts_recPI_0**	**sts_recMV_0**	**sts_recMI_0**	**sts_recVI_0**
0.386462255	0.347172286	0.544473239	0.20633141	0.073816071

5. Comparatively with the statistical data (Table 11), the post-sample simulations induce only minor modifications regarding the macroeconomic indicators. Instead, the functional reciprocity undergoes substantial changes. Whereas statistics assigns a modest intensity to the interaction between the global output and interest rate, between the inflation and money supply, and between the money supply and money velocity, the post-sample simulations induce significant steady state values in all these cases. Conversely, these simulations reveal a weaker functional reciprocity than the statistical data concerning the relationships between the global output and inflation, respectively broad money.

Table 11. Average of the statistical data 1960q1-2022q4

av_IGDPc	**av_PGDP**	**av_IM3**	**av_IV**	**av_IIR**
1.00744704	1.00820965	1.01721114	0.99817899	1.00454869
av_recGP	**av_recGM**	**av_recGV**	**av_recGI**	**av_recPM**
0.10852922	0.10814614	0.31013773	0.0851196	0.09289389
av_recPV	**av_recPI**	**av_recMV**	**av_recMI**	**av_recVI**
0.08621669	0.07515336	0.09448555	0.07382525	0.04430034

6. Steady state does not change the type of causality displayed by the statistical data (Figure 10, online).

7. Calculated for those one hundred VAR5_0 values (included into sts approximation), the coefficient of variation somehow decreases (Figure 11, online), however within a limited enough proportion, due to the cyclically descending estimations' trend.

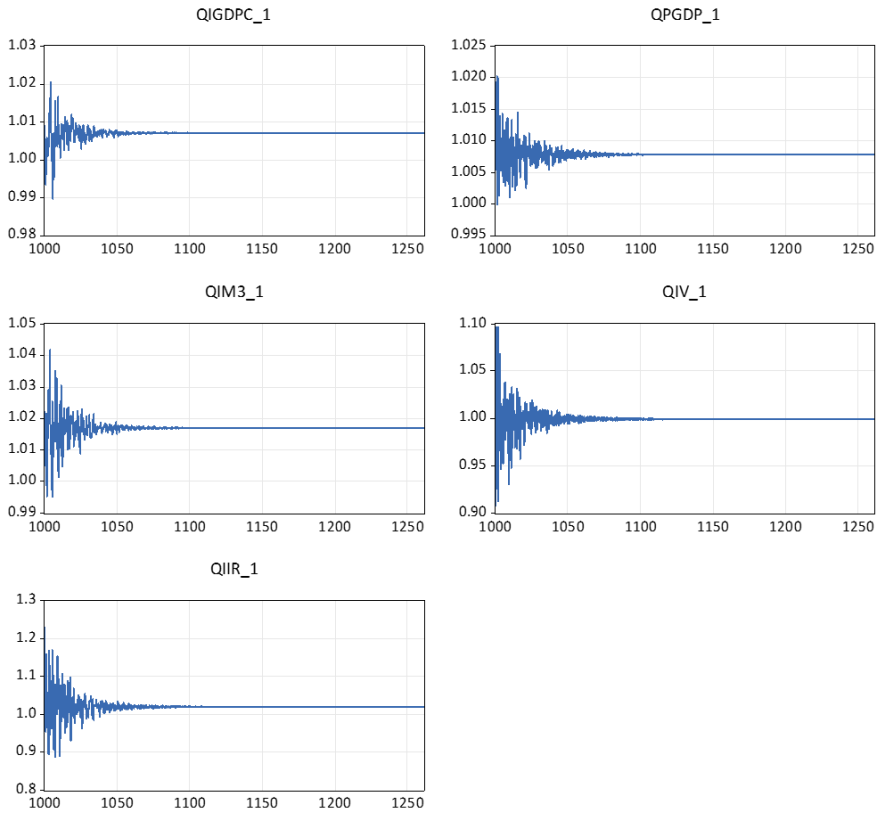
Obviously, a complex socio-economic interpretation of the afore-mentioned differences should need additional research.

IVB. Model VAR5_1

1. The post-sample simulations performed with Model VAR5_1 for the macroeconomic indicators can be found in Appendix 4b1. The resulted series are shown in Figure 12.

In this variant, the brink of steadiness is reached after 455 iterations for qIGDPc_1, 417 for qPGDP_1, 519 for qIM3_1, 589 for qIV_1, and 678 for qIIR_1.

Figure 12. VAR5_1 post-sample simulations of the macroeconomic indicators



2. The corresponding functional reciprocities (Appendix 4b1, online) - they, too, convergent - are plotted on Figure 13.

3. By applying the same methodology as in the previous section, the brink of steadiness of the macroeconomic indicators simulated by VAR5_1 is accomplished after 587 post-sample iterations for qIGDPc_1, 643 for qPGDP_1, 623 for qIM3_1, 833 for qIV_1, and 884 for qIIR_1.

4. Consequently, steady state levels of post-sample simulations in VAR5_1 are to be defined as averages of the 884-983 iterations' results (Table 12).

As for the impact on the macroeconomic indicators, the simulations performed on resampled series induce, again, unsignificant modifications.

Figure 13. Functional reciprocity simulated by Model VAR5_1

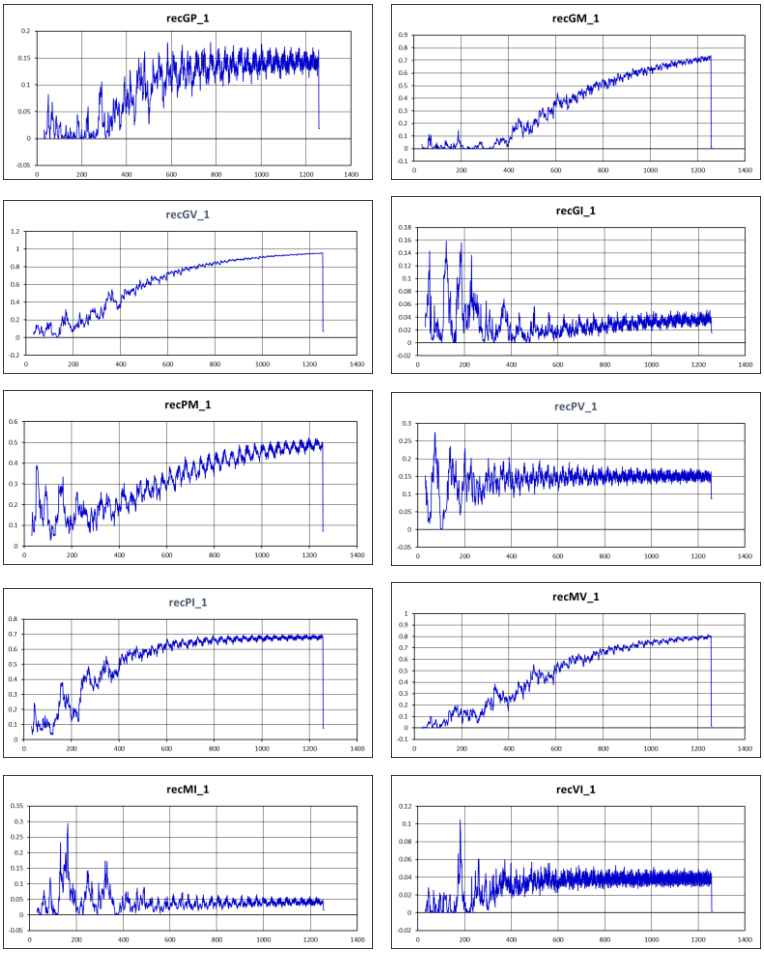


Table 12. Steady state levels of the macroeconomic indicators and the functional reciprocity, estimated by VAR5_1

sts_qIGDPc_1	**sts_qPGDP_1**	**sts_qIM3_1**	**sts_qIV_1**	**sts_qIIR_1**
1.006984884	1.007811443	1.016929992	0.999147073	1.018964151
sts_recGP_1	**sts_recGM_1**	**sts_recGV_1**	**sts_recGI_1**	**sts_recPM_1**
0.138573113	0.595846655	0.887726368	0.030614933	0.437470541
sts_recPV_1	**sts_recPI_1**	**sts_recMV_1**	**sts_recMI_1**	**sts_recVI_1**
0.149897216	0.670089302	0.720415723	0.038805799	0.038199332

5. In the case of functional reciprocity the situation is, however, different (Table 13).

Table 13. Functional reciprocity VAR5_1 (sts_rec…1) comparative to the average of statistical data (av_rec…)

av_recGP	av_recGM	av_recGV	av_recGI	av_recPM	av_recPV	av_recPI	av_recMV	av_recMI	av_recVI
0.10852922	0.108146137	0.31013773	0.085119597	0.09289389	0.086216694	0.075153362	0.094485549	0.073825249	0.044300341
sts_recGP_1	**sts_recGM_1**	**sts_recGV_1**	**sts_recGI_1**	**sts_recPM_1**	**sts_recPV_1**	**sts_recPI_1**	**sts_recMV_1**	**sts_recMI_1**	**sts_recVI_1**
0.138573113	0.595846655	0.887726368	0.030614933	0.437470541	0.149897216	0.670089302	0.720415723	0.038805799	0.038199332

In the case of the binomials global output – broad money, global output – money velocity, inflation – interest rate, and broad money – money velocity, the differences are even greater.

6. The types of causality identified on the initial series of resampled data resurface within VAR5_1 steady state (Figure 14, online appendix).

7. Cyclicity echoes also on the volatility of the functional reciprocity pertaining to the steady state estimation by VAR5_1.

IVC. Some final remarks

The attempt to measure the bilateral causality in macroeconomics through the functional reciprocity proved to be an apt means of providing useful information, especially concerning the intensity of the interdependences among the macroeconomic variables. Of great help was in our endeavor the use of such relevant statistics as those pertaining to the American economy on a large enough time span (1960q1-2022q4).

1. The product of the linear slope coefficients of the time series regressions y=f(x) and x=f(y) provides useful information on the intensity of the existing relationship among the corresponding variables. The closer to unity this product gets, the stronger is the interdependence of the variables. Obviously, a highly functional reciprocity is a solid argument for using the orthogonal regression (ORT), although the converse reasoning is not valid: there is no certainty whatsoever that the estimator obtained by this econometric technique would reflect the actual intensity of connected variables.

2. The volatility of the statistical time series (high CV) is one of the greatest difficulties encountered. A resampling procedure, as such, does not solve it: as Figures 4 and 7 show, the coefficients of variation for resampled series – although somehow smaller in many cases comparatively to the statistical ones – maintain the volatility at a worrisomely high level.

3. The VAR technique proved to be a viable tool in transforming volatile series into more stable ones, which favors the quest for the deeper, presumably hidden interdependences among economic variables. It was applied on both statistical and resampled series. The comparison of the functional reciprocities pertaining to the steady states resulted from post-sample simulations to their averages from the initial database can be summarized as follows:

3.1. The steady state estimations (of both VAR5_0 and VAR5_1) are consistent with the low statistical averages for the relationships global output – inflation, broad money – interest rate, and money velocity – interest rate. The compared estimations for the interaction between global output and money velocity could be considered, as well, congruous (this time at a significant level of intensity).

3.2. In the case of binomials inflation – interest rate and broad money – money velocity, the steady states estimations of both VAR5_0 and VAR5_1 indicate a relatively important functional reciprocity, contrarily to the initial rather low statistical average.

3.3. In two cases (the relationships global output – interest rate and inflation – money velocity) the steady state VAR5_0 tends to indicate them as intense, contrarily to the statistical average and steady state VAR5_1. Conversely, for the interaction global output – broad money, the steady state VAR5_1 estimates a high functional reciprocity, while the statistical average and steady state VAR5_0 suggest the opposite.

4. In what concerns the type of causality characterizing the examined relationships, our paper's estimations seem more coherent (Scheme S1, online).

All estimations, therefore, point out to the same type of causality, except the relationships global output – inflation and inflation – broad money. It is worth noting that the unilateral type of causality is prevalent, which can bear a high importance from the macroeconomic management viewpoint.

5. Ensuing from the chosen VAR framework, our suggestion is to assign more credibility to the steady state approximation, resulted from a considerably longer series of post-sample iterations. Should there emerge any cases when the steady state estimations themselves are contradictory, that would infer the necessity for improving the proposed algorithm. A possible way of improvement could be, for example, performing the computations by involving a great number of resampled series, while also involving some aggregative operators. Further research will explore this matter more extensively.

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