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Italian regional econometric model☆

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A B S T R A C T

This paper shifts studies on macroeconomic models from a national to a regional scope. Regions, indeed, often follow growth trajectories that dif- fer greatly from others within the same country. In this study we propose a macroeconometric model for 20 economies corresponding to the Italian administrative Regions. We called it: IREM (Italian Regional Econometric Model). We illustrate the general structure and properties of IREM, especially with regard to the economy's response to changes in regional fiscal policy, technological advances and other dimensions of the economic environment. One of the model's key features is the joint representation of the economy on both the demand and the supply side with a multiple estimating equations system calibrated at regional level. Public finance is designed in great detail, with multiple specific equations for local government expenses and revenues, using the Italian database CPT (Conti Pubblici Territoriali). After documenting the model structure and the estimation results with an in-sample simulation, we turn to illustrate the model properties through the study of its response functions to multiple shocks.

1. Introduction

Nowadays, governments are expected to respond quickly to environmental changes. Forthcoming economic trends need to be anticipated to set the policy which fits best. Therefore, the success or insuccess of macroeconomic policies is highly dependent on the efficiency of predicting tools. Adequate forecasting should work well not only during regular time patterns but also in sudden irregular scenarios where little evidence is obtainable from the past. This is true not only at national level, but also at regional one, where local policy-makers are gaining importance (Capello and Caragliu, 2021; OECD, 2018; Wenzel and Wolf, 2013). However, regional macro-econometric models are still little studied.

Data unavailability, low frequency of published data and periodic data revisions are macroscopic challenges that face regional economic forecasting (Billé et al., 2023). In the past decades, these barriers have discouraged scientists from developing such models; however, increased contemporary demand for regional projection tools has reawakened interest in such models among researchers and policymakers. Nevertheless, three striking limits on current models remain. Firstly, previous studies are focused only on the regional labour market (Lehmann and Wohlrabe, 2014). Secondly, the majority of studies often ad- vance models only for a handful of zones that do not include all administrative local areas of a country. Furthermore, current studies often consider only two countries (Germany or the US) (Lehmann and Wohlrabe, 2015; Baltagi et al., 2014). Thirdly, forecasting is accomplished using autoregressive single equation models (Capello and Caragliu, 2021; Lehmann and Wohlrabe, 2014).

Considering new methodological approaches (e.g. spatial panel data models), new databases and renewed academic interest that emerged in the 2010s, a new strand of literature now focuses on regional GDP prevision. Moreover, in some cases, models are expanded for all administrative regions in a country (Baltagi et al., 2014; Wenzel and Wolf, 2013; Girardin and Kholodilin, 2011; Kholodilin et al., 2008). Therefore, the first two limitations are starting to be overcome.

However, current studies still adopt an autoregressive single

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equation model. For example, Wenzel and Wolf (2013) regress the regional GDP of Germany on GDP applying Lag 1 and on firms' confidence index. Girardin and Kholodilin (2011) regress the GDP of all Chinese provinces on GDP at Lag 1 and a spatial

spillover component. Kholodilin et al. (2008) do the same when examining Germany. Unfortunately, autoregressive single equation forecast models have limitations and only multi-equation models can simultaneously predict the effects of demography, transportation, technology, energy prices, labour market and fiscal policies.

To the best of our knowledge, and according to the contribution of Lehmann and Wohlrabe (2014) and Billé et al. (2023), no studies employ a complete multi-equation macro-economic model at a regional level. In particular, a com- plete regional macro-economic model for Italian regions is still not developed. The paper aims to describe the Italian Regional Econometric Model (henceforth, IREM.).[1] IREM divides the Italian territory into 20 different regions corresponding to the nation's 20 regional administrations and advances a macroeconometric regional GDP projecting model with a multi-equation system. The model has an annual frequency and includes 116 variables (89 endogenous, 27 exogenous) and 36 national accounts identity referencing accounting definitions and institutional relationships between variables, for each of the 20 Italian regions. As a medium-sized econometric model, IREM is suitable for explaining and predicting the behaviour of a considerable number of macro-economic re- gional aggregates in each Italian economic region. The remainder of this paper is organised as follows. Section 2 discusses the general features of our model. Sections 3 and 4 respectively examine demand and supply sides. Section 5 details the validation of model's forecasting ability. Section 6 presents the reactions to shocks implemented for several endogenous variables and the general properties of the model. Section 7 draws relevant conclusions from our findings.

2. General features of IREM

Why do we construct a macro-econometric model for Italy's regional economies? More in general, the current economic scenario in Europe can be characterised by two major trends (Wang and Sun, 2021; Kholodilin et al., 2008). First, globalisation is integrating the economies of several countries at the international level. Second, some regions within nations are gaining autonomy. Therefore, an urgent need arises for reliable prevision tools to support decision-making pro-cesses at the regional level. This is particularly true for Italy, where regional heterogeneity is primarily manifested at the legislative level, where the Italian Constitution recognises a 'special statute' that guarantees particular forms of autonomy for five of the nation's 20 Regions (Sicily, Sardinia, Valle d'Aosta, Friuli-Venezia Giulia and Trentino-Alto Adige). A second form of heterogeneity concerns the substantial differences in each region's economic structure that is related to specific historical and geographical conditions of Italian Regions. This implies that regional forecasts may diverge from those made by national models; hence, the IREM can serve as a meaningful guide for decision-making at the regional level.

The IREM expands the research concerning regional econometric models promoted in Italy by the SVIMEZ association for industrial development in south- ern Italy.[2] Historically, beginning with the first Italian national econometric model (Banca d'Italia, 1970), SVIMEZ has reproduced calculations for the same functional relationships between the economic variables used at the national level for two regional macro-areas of the centre-north and southern Italy. The implicit theoretical hypothesis in this type of approach assumes the existence of an overarching law of development for the two areas that is characterised by an analogous structure of interdependence between economic variables. However, the Damiani et al. (1987) model advanced by SVIMEZ and expanded by Padovani et al. (2000), must partially discard the hypothesis of assuming the equations developed for the national model as a reference for regional investigations because some strategic variables in the empirical validation disregarded the previous hypothesis. A number of SVIMEZ equations are established using a bottom-up approach. We follow the same method, first using the Italian Treasury Econometric Model (ITEM) (Cicinelli et al., 2010) as our national reference model. Second, we introduced new independent variables into the model where the specification of ITEM equations did not fit well for regional economies, re-scaling the model to the regional dimension. Therefore, in constructing an econometric model on a national scale, the ITEM is attentive to the specifications of typical territories, which inevitably get lost in the process of aggregating the variables such as that of the MEF.

We compute GDP accounting identities using net regional imports as the difference between absorption plus inventory changes and regional GDP by the supply side. Treating net imports as a residual component, rather than a variable determined by a behavioural equation, is a novel feature of our model in contrast to the ITEM and its previous versions (Favero et al., 2000; Fiorito, 2003; Cicinelli et al., 2010). The exogenous variables in the IREM are associated with the following: variations in Information and Communication Technology (ICT) investments that alter technological progress; tax rates set by central or regional governments; interest rates, since monetary policies are not controlled by regional economies; international variables such as crude oil price, stock markets indices, international prices, the euro/dollar exchange rate and international shocks on close nations' GDP.

Moreover, since we design the IREM to meet the needs of regional governments, the public finance section is developed with great detail. Expenditure and revenue items are modelled according to the breakdown provided by the National Italian Statistical Institute for Regional Sciences (CPT), consistent with the accounting identities provided by the Italian Statistical Institute (ISTAT).[3] Each expenditure and revenue item is divided into two variables; one at the regional government level (from the CPT database) and one at the central government level (from ISTAT), with an estimating equation for each variable. The primary expenditure items are public consumption of goods, public investments and the cost of regional debt. The main revenue items include direct taxes on income (IRPEF), regional tax on production activities (IRAP) and indirect taxes (value added tax (IVA) and excises on fuel production). Transfers to households and firms are exogenous variables, and other residual variables, which are very small in magnitude, are aggregated while the regional balance sheet is closed using regional debt, which is calculated as the difference between total regional revenue and expenditure.

The IREM is not a dynamic stochastic general equilibrium model (DSGE), which has become increasingly popular (Smets, Raf, 2003; Albonico et al., 2017); however, we reference the ITEM from Cicinelli et al. (2010). Therefore, the relationships between variables and the spillover effects of any impulse are not derived from a forward-looking model with the agents' inter-temporal optimisation. DSGE models are too parsimoniously parametrised in relation to our model, which is less theory-dependent and more data-driven. For example, the IREM allows us to break fiscal variables down into a large number of equations, and the same is true for demographic variables, which makes our model more informative. DSGE models do not allow for variable coverage as large as the one featured in the IREM.

[1] The actual development of the project at Regione Liguria started in 2021. This is the last version of the model and the name of IREM (Italian Regional Econometric Model) was assigned to it

[2] SVIMEZ is an Italian association whose name is the acronym that states for: Associazione per lo SVIluppo dell'Industria nel MEZzogiorno (Association for the Development of Industry in the South of Italy). This institution has historically been involved in studying the regional economies of southern Italy.

[3] For CPT data:https://www.agenziacoesione.gov.it/sistema-conti-pubblici-territoriali/dati/for ISTAT: http://dati.istat.it/

The IREM behavioural equations are estimated over a panel sample across 21 year (2000–2020) and 20 cross-sectional variables (corresponding to the 20 Administrative Italian Regions). Each equation employs the autoregressive distributed lag model, which functions as the major workhorse in dynamic single equation regressions (Wickens and Breush, 1988; Hassler and Wolters, 2006). Therefore, our specifications examine long-term equilibrium relationships between variables at the (log) level, lagged dependent variables and some regressors. We ensure the adequacy of the statistical model implicit in the estimated structure, systematically verifying each estimated equation using appropriate statistical tests, confirming that residuals do not exhibit autocorrelation, the absence of endogeneity and the normality of distributions.

After documenting the primary supply and demand side features of the model, we assess its properties by first conducting an in-sample dynamic simulation of the model using the estimated coefficients of the behavioural equations to examine the model's ability to replicate observed data for each aggregate. We then theoretically test the model calculating the GDP elasticities respect to several endogenous and exogenous variables. After that we determine the stationary state (baseline) values for each endogenous variable. Finally, we introduce multiple single shocks that subsequently change several values on demand and supply sides (particularly policy variables). We determine regional economic systems' dynamic responses to policy impulses by comparing the variations in endogenous variables' proportions that are induced by shocks to the previously determined baselines. Our simulation horizon has a length of 50 steps, allowing us to distinguish between short- and long-term effects. The aim of this study is to construct the IREM and provide a detailed description of the model. In doing so, we illustrate its general structure and properties, particularly concerning the simulation outcomes and regional economies' response to local policy changes and the central government policies.

3. The characterization of the demand side

In this section we define the demand side, which has specific features in the IREM that are usually not found in existing regional macro-models. The IREM's demand variables reference the standard accounting definition of GDP (household consumption, investments and government) as in the System of National Accounts (UN, 2009), introducing net imports; a variable that we obtain as a residual after determining real GDP on the supply side using the following accounting identity that closes the model:

$$NX_{j,t} = ABS_{j,t} + SC_{j,t} - VA_{j,t} - INDN_{j,t} \tag{1}$$

Where $NX_{j,t}$ denotes net imports at time t for region j; $ABS_{j,t}$ indicates the absorption (public consumption, household consumption, gross fixed capital for- mation); $SC_{j,t}$ represents inventory changes; $VA_{j,t}$ is the regional economy's added value and $INDN_{j,t}$ denotes indirect net taxes. We cannot estimate im- ports and exports with two separate equations since ISTAT and EUROSTAT do not include these data, only providing net imports.

3.1. Private consumption

Economic theory indicates that consumers maximise utility under budget con- straints of disposable income, net financial assets and expectations of future income (Busetti et al., 2005; Bacchini et al., 2013; Albonico et al., 2017). Therefore, the primary variables for determining what affects private consumption include disposable income, net financial assets and a consumer confidence index. Disposable income is defined, in the SNA, as labour income plus gross operating result and capital income, net taxes and social contributions, plus social and welfare benefits (Eq. 2). The model is distinguished from previous estimation equations by including self-employed labour income (gross operating result) and capital income. Household disposable income is also subject to direct taxation (IRPEF and social contributions) and social benefits; therefore, regional economies' household disposable income is obtained as follows:

$$YD_{j,t} = W_{j,t} + RLGH_{j,t} + RK_{j,t} - I\_D_{j,t} - CS_{j,t} + PREST_{j,t} \tag{2}$$

Where $YD_{j,t}$ is the disposable income in the economy at time t for region j; $W_{j,t}$ is the wage bill; $RLGH_{j,t}$ is gross operating income of household; $RK_{j,t}$ is capital income; $I\_D_{j,t}$ is the fiscal pressure on household income; $CS_{j,t}$ are social contribution; $PREST_{j,t}$ are the social and welfare benefits.

Similarly, as in Cicinelli et al. (2010), the equation for household consumption C_t captures a long-run relationship between real household disposable income and real household net financial assets. The short-run behavior of consumption is modeled by the lagged values of C and by the consumer confidence index, which captures the influence of future income expectations on present consumption. Household consumption has been disaggregated in 6 categories of goods and services.[4] The estimating equation, expressed in logarithms, is:

$$C_{k,j,t} = \alpha + \beta_1 YD_{j,t} + \beta_2 A_{j,t} + \beta_3 FC_{j,t} + \beta_4 C_{k,j,t} + e_t \tag{3}$$

Where $C_{j,t}$ is the household consumption of good/service k at time t for region j; $FC_{j,t}$ is the consumer confidence index; $A_{j,t}$ is net financial assets owned by households; $e_{j,t}$ is the error term. A consumption deflator is applied to deflate disposable income and net financial assets.

The net financial assets variable, according to accounting definition, is the difference between household financial assets and liabilities:

$$A_{j,t} = FA_{j,t} - FL_{j,t} \tag{4}$$

Where FA_t are household financial assets at time t for region j and $FL_{j,t}$ are household financial liabilities. The source of data for these two variables is the Bank of Italy. The appreciation of financial assets ($FA_{j,t}$) is a function of Italian stock exchange price index (FTSEMIB), interest rates on 10 years Italian government bonds and the dollar/euro exchange rate. By contrast, household financial liabilities ($FL_{j,t}$) are assumed to evolve over time in accordance with the dynamics of Regional GDP and interest rates on firm's loans.

Demand for capital goods is determined by examining the long-term relationship between investments and the enterprise confidence index, private consumption expenditure, public investment, investment in transportation and in the real estate market (Bacchini et al., 2013).

3.2. Public consumption

Previous regional macro-economic models rarely establish behavioural equations when examining public finance. In contrast, this model uses the CPT database to estimate equations for public revenue and expenditure, broadly extending the econometric model of Beqiraj and Tancioni (2014) for the Italian Region Lazio.

The CPT database provides information on public revenue and expenditure, which are differentiated into five levels, including Central Administration, Regional Administration, Municipal Administration, Local Public Enterprises and National Public Enterprises, which separates public accounting items into re- gional and central categories. This makes it possible to treat each region as a small state, with individual revenue and expenses, considering revenue and expenditure, respectively, to and from the central state, as transfers from or to abroad, where abroad indicates to and from the Central Government of Italy. The two main aggregates of regional public revenue provided in the CPT are indirect (IRAP) and direct (municipal additional IRPEF) taxes. The residual components, which are extremely small compared with the total revenue, are aggregated into a single item that is estimated using a

[4] The 6 categories are: agriculture, manifacturing, commercial services, financial and real estate services, education and health, arts.

simple autoregressive equation. The main items on the expenditure side include consumption (almost all of which is devoted to healthcare) and public investments. We also collect the residual portions of expenditure in a single item that is estimated using an autoregressive equation. The difference between the revenue and expenditure indicates the regional fiscal deficit/surplus as follows.

Total Regional revenues, according to the accounting definition in SNA, are:

$$E_{j,t} = I\_INDR_{j,t} + I\_DR_{j,t} + TRe_{j,t} + VE_{j,t} \quad (5)$$

Where $E_{j,t}$ is Regional revenue at time t for region j; $I\_INDR_{j,t}$ and $I\_DR_{j,t}$ are regional tax on production and regional tax on income, respectively, both of which remain within the regional economy. $TRe_{j,t}$ represents transfers from households and private firms received by European Union and other foreign in- stitutions. $VE_{j,t}$ denotes goods, services and capital goods sold by the regional administration. Both $TRe_{j,t}$ and $VE_{j,t}$ are exogenous variables in this model as they reflect choices that are strictly set by the policymaker.

The accounting definition of public expenditure in SNA, is:

$$U_{j,t} = GR_{j,t} + TR_{j,t} + INVR_{j,t} + INT_{j,t} \quad (6)$$

Where U_t is public regional expenditure at time t for region j;, $GR_{j,t}$ is the regional administration's consumption of goods and services plus administrative personnel expenses at time t for region j (predominantly devoted to local healthcare); $INVR_{j,t}$ is the gross fixed capital formation of the regional administration[5] and $TR_{j,t}$ denotes regional administration transfers to households and private firms, which is an exogenous variable since it is strictly linked to policymakers' choices. Finally, $INT_{j,t}$ represents the interests paid by regional administrations for debts. The regional fiscal deficit is the difference between $E_{j,t}$ and $U_{j,t}$. The three variables for revenue and expenditure are estimated using specific equations. No estimating equation is needed for the current fis- cal deficit since it is simply determined as the difference between *Uj, t* and *Ej, t*.

We obtain total public expenditure (*G*) by adding the central government's consumption expenditure on the regional territory to the public consumption of the regional government (*GR*) from the ISTAT database. By adding regional investments ($INVR_t$) to investments made by private entities and the central government, we obtain the total value of the gross fixed capital formation as found in ISTAT. We determine the total indirect taxes by adding the indirect taxes received by the central government (such as value added tax (VAT)) to regional indirect taxes (I_INDR_t). Finally, by adding the direct taxes received by the central government (such as IRPEF) to the regional direct taxes (I_DR_t), we obtain the total direct taxes from ISTAT.[6]

In the IREM, interest rate is exogenous because monetary policy is issued by the European Central Bank and not regional governments. We model several deflators in the IREM, including investment, government expenditure, household consumption, added value and GDP deflators. Raw material and energy import prices have a strong and positive relationship to the investment and household consumption deflators, and the interest rate on firms' loans negatively affects the investment deflator, while the interest rate on households' loans negatively affects the consumption deflator. Unit labour cost has a positive relationship with the added value deflator, while it is reduced by the interest rate on firms' loans. The GDP deflator combines households' loan interest rate and consumption. The government expenditure deflator is positively affected by the private consumption deflator and the magnitude of nominal government expenditure. The euro/dollar exchange rate increases the added value and household con- sumption deflators since it affects the cost of foreign and consumer goods.

Finally, the accounting identity of GDP on the income side, according to SNA, is:

$$GDP_{j,t} = W_{j,t} + RLG_{j,t} + I\_IND_{j,t} \quad (7)$$

Where $W_{j,t}$ is the amount of wages at time t for region j; $RLG_{j,t}$ is gross operating income and $I\_IND_{j,t}$ represents indirect net taxes. In the model, this identity is closed through the variable $RLG_{j,t}$, which is obtained as a residual after determining the supply side GDP, $W_{j,t}$ and $I\_IND_{j,t}$, with specific equations. The wage equation references the theoretical model of wage bargaining (Layard and Nickell, 1986) also referencing Cicinelli et al. (2010).

4. The characterization of supply side

The added value is not directly estimated by a specific equation but it is defined as the product of the added value per hours worked times hours worked. ISTAT provides both data. The added value is therefore:

$$AV_{k,j,t} = P_{k,j,t}\Lambda_{k,j,t}H_{k,j,t} \quad (8)$$

Where $AV_{k,j,t}$ is the aded value of sector k, at time t in region j; $P_{k,j,t}$ is the price level of sector k at time t for region j; $\Lambda_{k,j,t}$ is the hourly productivity; $H_{k,j,t}$ are the total hours worked in the economy in the sector j at time t.

Added value per hour worked is the most accurate measure of productivity (Bick et al., 2018). Hourly productivity is the key variable for long-term per capita economic growth; an accurate estimation of this variable is therefore crucial to provide reasonable forecast scenarios. In the literature, hourly pro- ductivity depends on several factors. First, investments in the ICT (Information and Communication Technologies) increase productivity; microprocessors, computers, and recent developments in artificial intelligence drastically reduce the number of hours worked keeping constant the added value, leading, by defi- nition, to positive shocks on hourly productivity (Pieri et al., 2018). Second, imports of goods also have a positive impact; the import of advanced technology from abroad introduces positive shocks on the economy's hourly productivity as spillover effects (Pieri et al., 2018). Finally, hours worked by employees nega- tively impact hourly productivity, as highlighted by Shepard and Clifton (2000) and Bick et al. (2018). More recently, Gibbs et al., (2021), studied hourly productivity during the Covid-19 pandemic lockdowns showing that when employees had more time to work, since they stayed at home, their productivity decreased since they had less time to work in a focused or uninterrupted manner.

Instead, the number of hours worked depends on private consumption, the number of employees hired and technology (investments in ICT).[7] The number of hours worked also depends on the economic performance of other Italian regions. From an economic point of view, the meaning of a global spatial spillover effect in our case is that the added value in one region tends to rise its value due to the increased added values (i.e., hourly productivity or the number of hours worked) in neighboring regions. Since GDP reflects the value generated by any hour of work engaged producing goods and services, it is reasonable that

[5] In CPT database we aggregated three items to form this variable: the purchase and realization of real estate, other capital goods, purchase of shareholdings.

[6] The equations for each of these four variables (direct and indirect taxes, public consump- tion, investments) are therefore 8: four at regional level of administration and 4 at central level of administration. The items of these four aggregates referring only to central adminis- trations are found as a simple difference between the total aggregate provided by ISTAT and that provided by the CPT database

[7] An increase in private consumption also involves a positive shock on the total hours worked, which in turn have a positive impact on the added value in the economy. The economic intuition is the following: if consumption increases but the hourly productivity of the economy remains the same, production can increase, to satisfy the increased consumption, only by employing a greater number of hours worked.

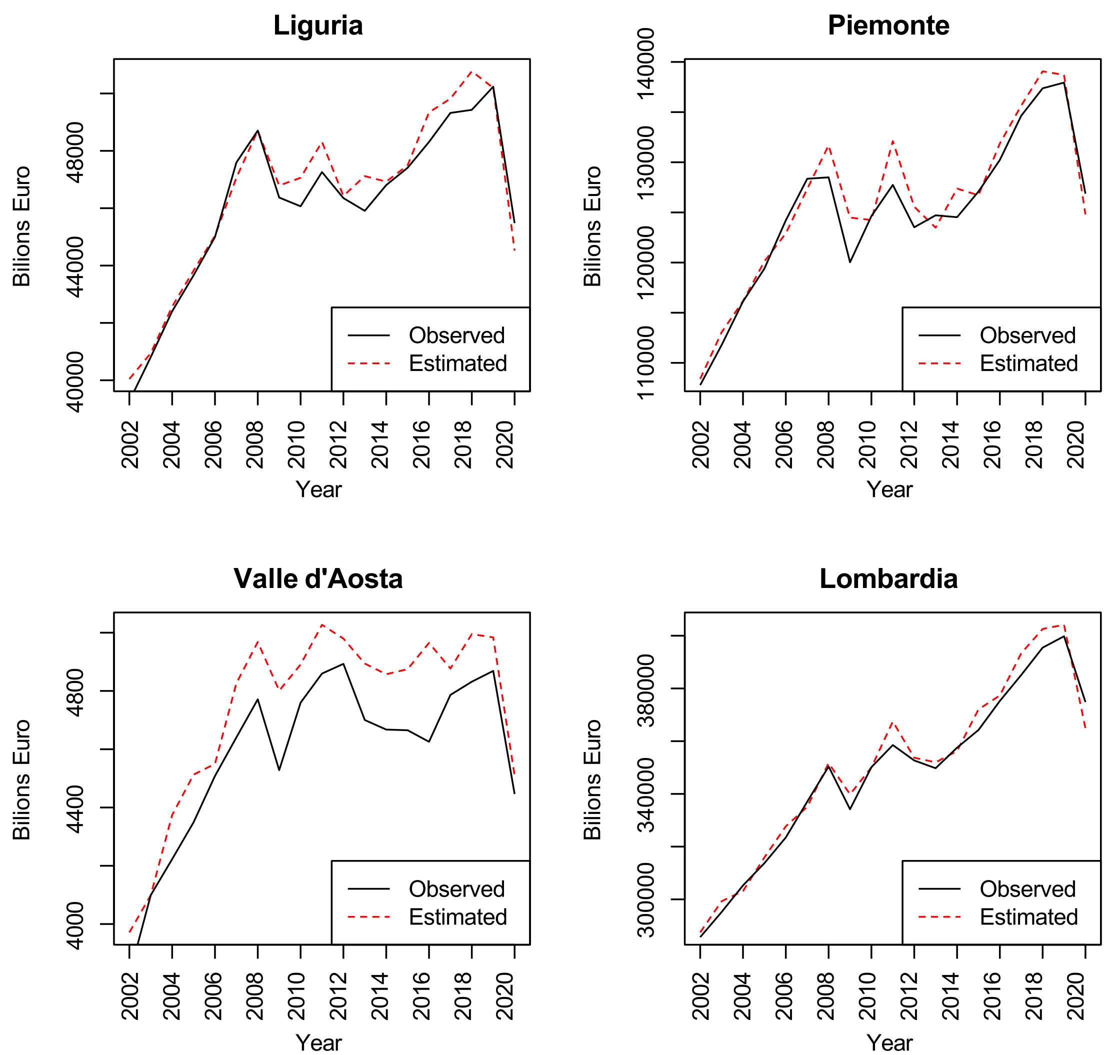

Fig. 1. Estimated GDP vs observed GDP: in-sample simulation.

the increased demand for goods and services in one region helps to raise neighboring production of goods and services (Billé et al., 2023). When household demand increases in one region, its imports tend to grow; these imports are satisfied, in part, by the neighboring regions, in part by the foreign supply. This is the channel that links the aggregate private demand of the neighboring regions to the hours worked by the region considered. Regions' exposure to national/international shocks is positively correlated to their openness to trade, and the spatial effects are measured by geographic distance (Servén and Abate, 2020). This is the case for Italian regional economies (World Bank, 2018; Billé et al. 2023, IRPET, 2024).

The best way to study this spatial correlation would be to use input-output matrices at the regional level to account for inter-regional exchanges. Unfortunately, only a few regional statistical offices (Tuscany) produce this type of data, only for a few non-consecutive years, and not always easily available. However, in literature, there are other tools to account for spatial effects. Kosfeld and Dreger (2019) study unemployment spillovers among economic regions of East Germany, assigning a weight of 1 if the regions share a common border and 0 otherwise. They use a spatial square weight matrix W, where each region is usually assumed not to be a neighbor of itself (elements on the main diagonal are 0) and assign different values to the other regions, normalizing the spatial weights so that the sum of each row is equal to 1. We follow a similar approach. We consider the spillover effects among Italian regions as a matrix W, which is a time-invariant $n \times n$, where n is the number of regions (20). We model the dependence between regions assigning to the cells of W values which are a function of the geographical distance between them (Long et al., 2019; Fingleton, 2019).[8] The matrix W is multiplied by the matrix Q which contains by row the household consumption for the region i at time j so that it is a 20 $\times$ 21 matrix (20 regions times 21 periods). The product $W \times Q$ provides a variable that captures the influence on region i of household consumption of the regions j, weighted to their geographical distance with respect to i. This variable has been proven in Appendix 2 to be highly statistically significant, having a substantial impact on regional GDP, as also shown in paragraph 5.3.

5. The model properties

5.1. Model simulations: exogenous variables projections and policy rules

This work endeavours to construct a statistically adequate empirical model that satisfies the assumptions of a classical linear regression

[8] Region which share at least a border in common to region i are assigned value 1; regions that have a border in common to a region that has at least a border in common to the region i, but none direct border in common to Region i, are assigned 1/2 and so on (1/3,1/4,…). After that, we sum the elements of W by row. Finally we divide each cell by the sum by row of W

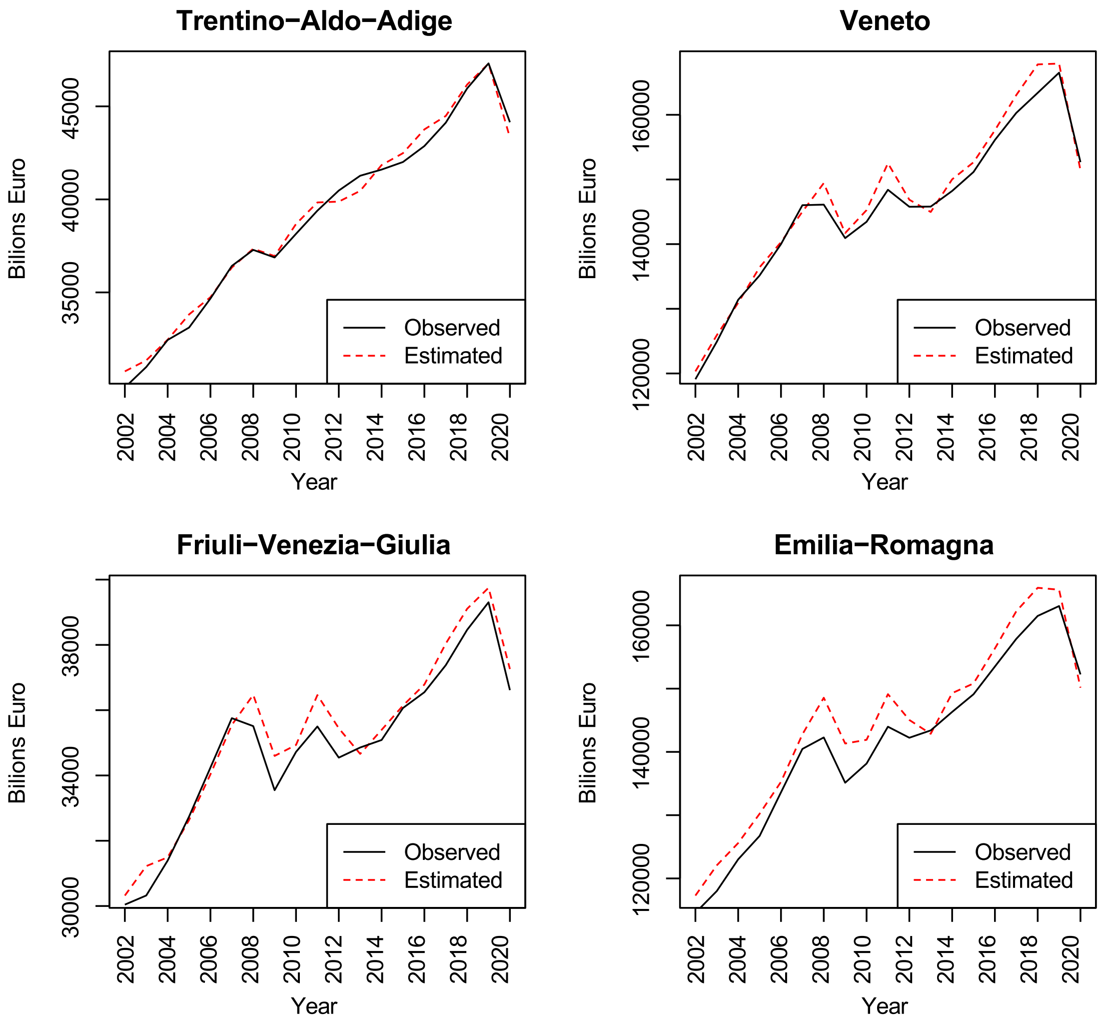

Fig. 2. Estimated GDP vs observed GDP: in-sample simulation.

model (CLRM) (i.e. that it is parsimonious) that complies with standard theoretical interpretation that all signs of the estimated coefficients are correct and all dimensions of the esti- mated coefficients are correct. A common approach to constructing such a model is the general-to-specific methodology (GETS), which is associated with Hendry and Doornik (1994) and Brooks (2008). Starting from the complex model of the ITEM for the national economy, the approach is progressively simplified (where statistically possible) by replacing some equations, modifying some regressors and adding some behavioural equations that are absent in the ITEM and specific to using the CPT data. The initial general unrestricted model contained four lags, and those that were statistically insignificant or did not significantly improve the Akaike information criterion were progressively excluded. According to previous simulation studies (Mazzoli, 1998) this is an appropriate dynamic structure from which to start to capture the dynamic properties of the model. For clarity of exposition, we only list the final estimation equations as they emerged from the GETS estimation process in Appendix.

The model equations are estimated on a large panel-type dataset that con- siders the 20 Italian regions from 2000 to 2020, with 420 observations (20 × 21) for each variable. We apply the regional fixed effects estimation method for all the equations, which captures the general relationships that hold for all regions (collected from the estimation regressors) and the typical characteristics of regions' economic systems, which flow into a different regression constant for each region in the same estimation equation. The Hausmann test on each estimated equation indicates that the fixed effects estimation method is more appropriate than the random effects approach.

We group exogenous variables into three categories: a) those referring to the international economic environment such as the exchange rate (euro/dollar), the international crude oil price, the importation price index, firms' average interest rate (from BCE and BI) and the Dow Jones Index; b) Italian Central

government variables, including national tax and contribution rates (such as VAT), interest rates on central government bonds and other public expenditure aggregates; and c) other regional exogenous variables such as demographics (life expectancy at birth), ICT investments, tax rate on production and family income (IRAP and Addizionale IRPEF).

We next run a one-step dynamic in-sample simulation to test the model's capability to replicate observed values. The 89 behavioural equations estimated by the IREM are combined in a source code written on R software. Using a numerical method with repeated iterations, we run the IREM system of non-linear equations, annually and by region. The in-sample simulation is run for the years 2002–2020, excluding the years 2000 and 2001 because of variables with Lag 1 and Lag 2. All the exogenous variables enter the simulation with historical values such as tax rates, stock market indices and firm and consumer confidence indices. The purpose of this exercise is not to determine how fiscal policy affects the properties of the model, but to verify the accuracy of the model's predictions. Dynamic, in-sample simulations provide a real set of consecutive predictions (OECD, 2016). The following figures illustrate the comparison between actual and estimated regional GDP time

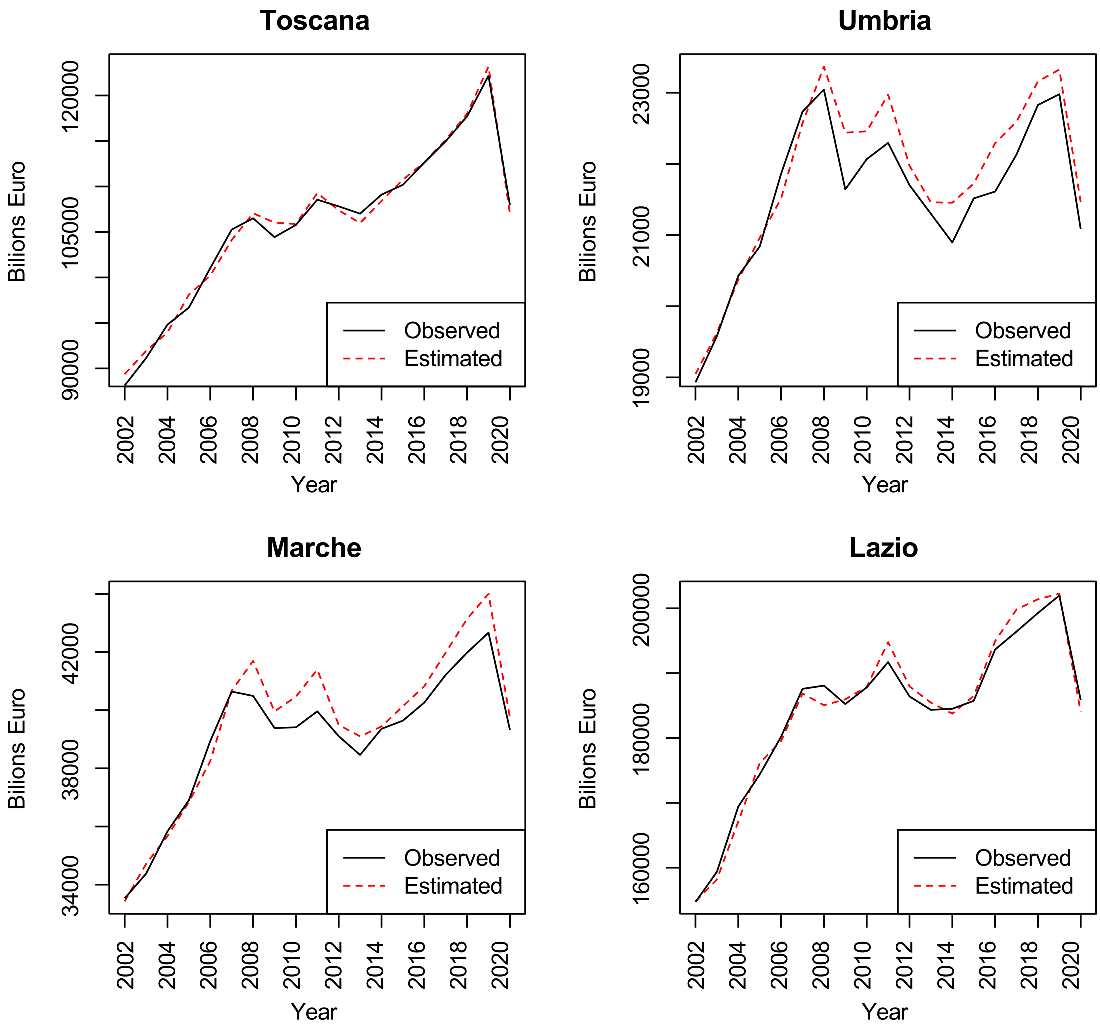

Fig. 3. Estimated GDP vs observed GDP: in-sample simulation.

series. Despite the turbulences over the last 20 years, a visual inspection of the figures indicates good model accuracy in forecasting regional GDP of the next year.

Below, from Fig. 1 to Fig. 5, we present the regional GDP estimates for the 20 Italian Regions from 2001 to 2020. The 2007–2008 financial crisis of and the economic crisis induced by the lockdowns of the COVID-19 pandemic occurred during this time. Despite these significant macroeconomic shocks, the model accurately estimates the GDP, even in the years when the strongest shocks occurred. This is possible because all the exogenous variables are set to historical values at each step referencing by Cicinelli et al. (2010). A prevision model must produce accurate estimations for endogenous variables, once the value of exogenous variables is set at its actual value, which is the case for the IREM.[9]

Let us now analyze the elasticity of GDP with respect to the main endogenous and exogenous variables.[10] The analysis of elasticities reveals how these variables affect regional GDP, constituting a theoretical test of the model.

In Table (1) we report the effect on GDP from 1 to 5 years, of a 1 % shock implemented on the main endogenous variables. Those with the most significant impact on GDP are hours worked, household consumption, and employment. The results shown in Table (1) reflects the theory underlying our model. In fact, the IREM is a macroeconomic model in which consumption is linked to production, but production is also linked to consumption. Therefore, when hours worked increase, household consumption also increases, contributing to the growth of

[9] For example, the Regional GDP estimated for 2020 is close to the actual value and this could seem a quite surprising because nobody could anticipate the COVID-19 pandemic and the effects on GDP of the policies applied in Italy. Actually, setting, for example, the observed values in 2020 for FTSEMIB index, firms confidence index, consumer confidence index, import prices for energy and raw material we indirectly capture the economic effect of COVID-19 pandemic. Therefore the accuracy of model forecasts rely on the ability to set the correct value for the future exogenous variables.

[10] For the easy of exposition, we refer Tables (1) and (2) only to the elasticity of Ligurian GDP; however elasticities tables for the other 19 regions can be easily deduced. The consistency of elasticities signs to the economic theory is observed also for the other regions.

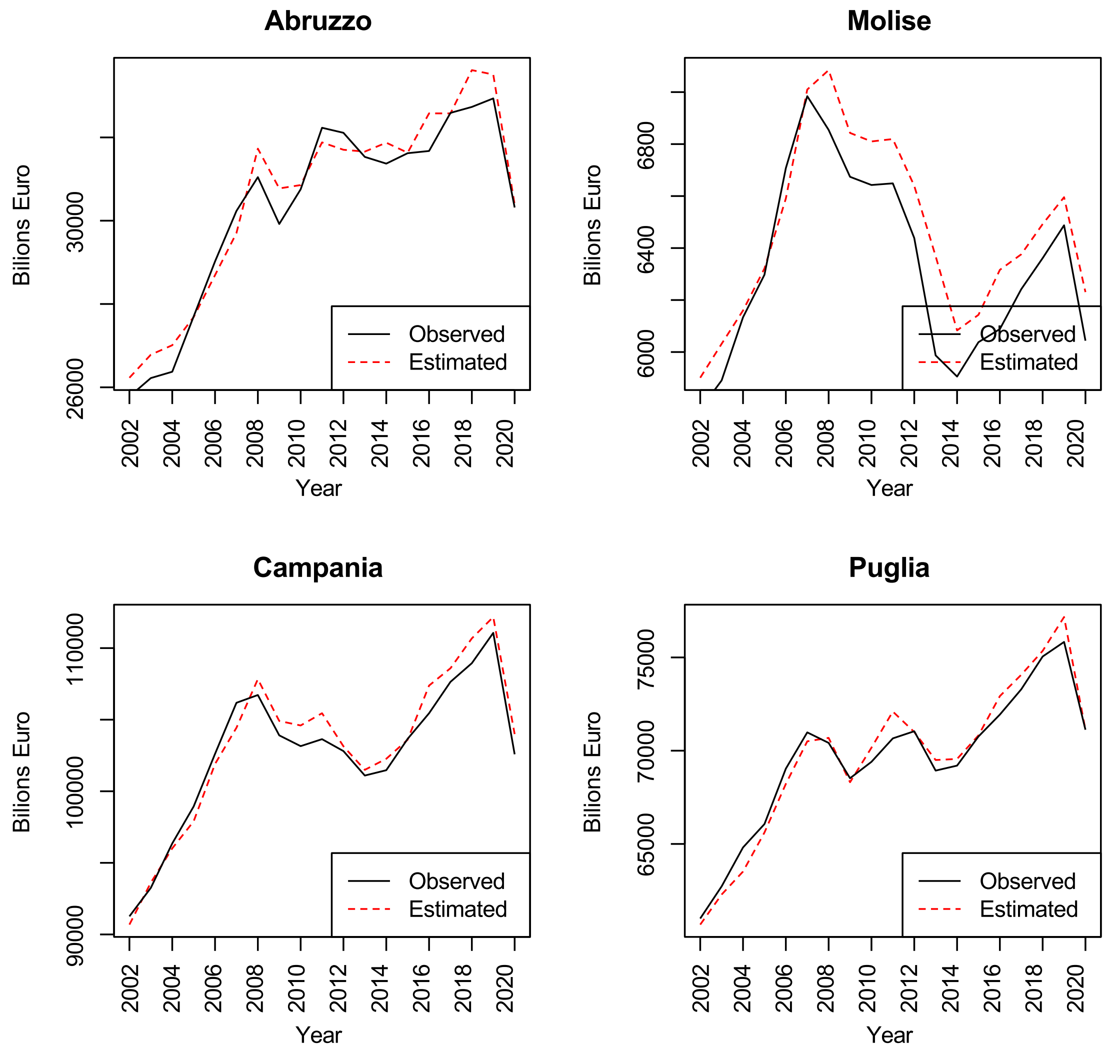

Fig. 4. Estimated GDP vs observed GDP: in-sample simulation.

production and, therefore, GDP; in turn, employment have a substantial impact due to the increases in wages, i.e. household consumption, that they bring. Taxation, on the other hand, has, consistently with economic logic, a recessive effect on GDP. Finally, we observe that all signs are "correct" according to the economic theory.

Table (2) shows the elasticity of Ligurian GDP to shocks introduced on the main exogenous variables. We start from the stationary state (see paragraph 5.3) and show the percentage effects on GDP in the five years after introducing the shock (1 %). As for interest rates and tax rates, we raised these rates by one percentage point instead of applying a variation corresponding to 1 % of the rate. A first general consideration in Table (2) is that the elasticities of the exogenous variables on GDP are lower than those observed for the endogenous variables. This aspect is generally found in the literature and is confirmed by empirical analyses. A second fact that can be deduced from Table (2) is the general coherence of the model with the expectations of economic theory. The signs are "correct" and magnitude reasonable. Moreover, the exogenous variables that exhibit the greatest (negative) effect on GDP are the VAT rate, the IRAP rate, and the interest rate the banking system applied to household loans. Among the strongest positive shocks, we found the business confidence index, the consumer confidence index, and the spillover effects coming from the GDP growth of the other regional economies.

5.2. *Forecast validation*

We next validate forecasting properties of the IREM. In addition to using goodness of fit and regression diagnostics measures for each equation in the Appendix, we dynamically simulate the model from 2015 to 2019, excluding the pandemic year, setting all exogenous variables at historically observed values. This dynamic simulation, common in literature to test forecast accuracy (Cicinelli et al., 2010), provides multi-step projections for each region of Italy. In Table (3) we only show the average of outcomes for the 20 regions. The aim of this exercise is to confirm the model's goodness of fit and forecasting accuracy. In Table (3) we compare the statistics for simulated and actual series for a subset of endogenous variables, reporting the ratio between the standard deviation of the simulated and actual series (column 1). In column 3, we also show the ratio between the standard deviation of some endogenous variables and the GDP for the actual and simulated series (column 2). Finally, always in Table (3), we present the contemporaneous GDP cross correlation of the endogenous variables (Cicinelli et al., 2010, Agresti and Mojon, 2003). Comparison of the standard deviations in columns 1 and 2 is a relevant criterion of evaluation because it explains the individual volatility of each endogenous variable's provision. The results appear to be generally satisfactory. Column 3 indicates the model's ability to replicate the main features of the regional business cycle, and the contemporaneous, lag and lead correlations of the simulated variables with GDP align with actual figures.

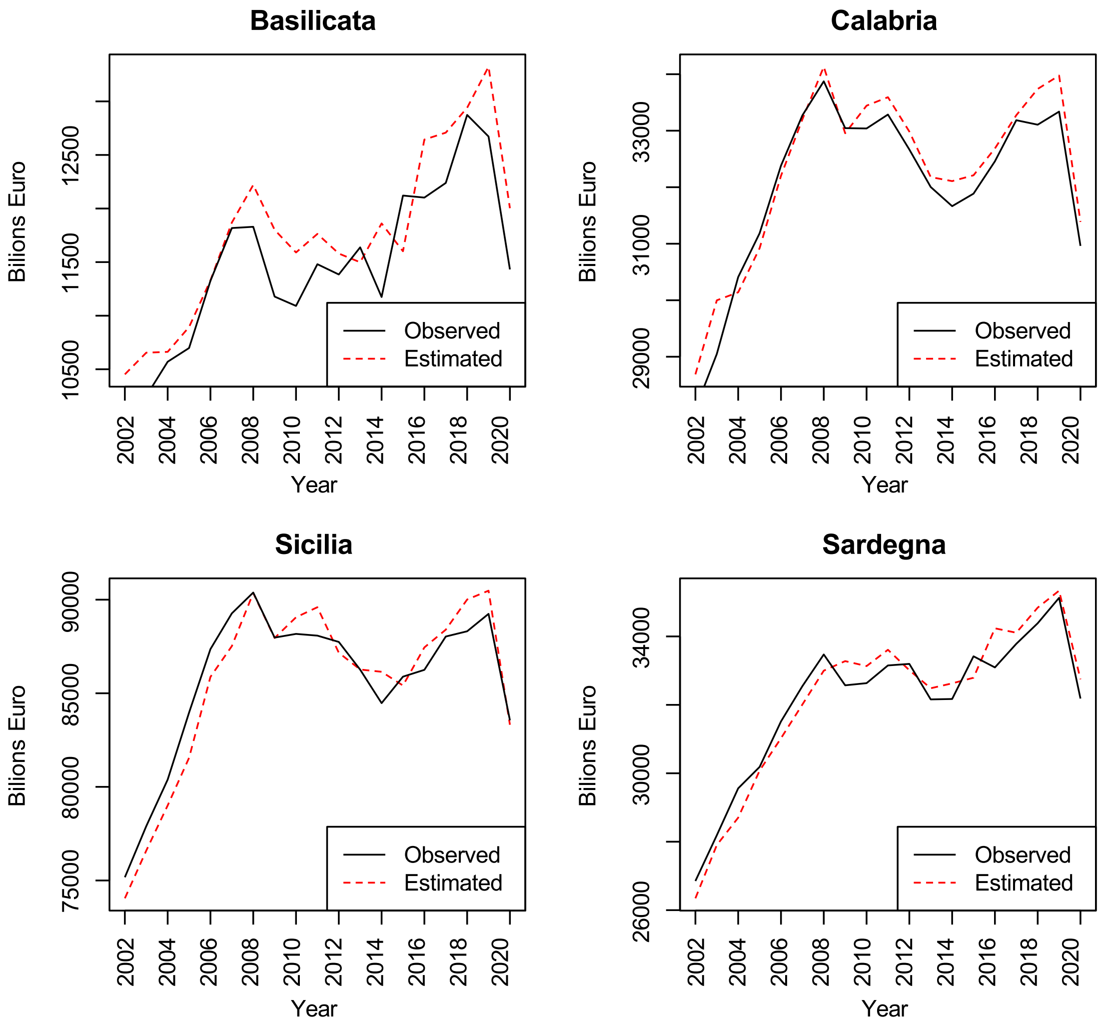

Fig. 5. Estimated GDP vs observed GDP: in-sample simulation.

For example, simulated value added exhibits the highest correlation with GDP at time t (approximately 0.999). Moreover, the degree of correlation declines as the number of lags decreases, and this pattern mirrors that observed for historical data. Furthermore, the simulated pattern of real net indirect taxes on products, which has a contemporaneous correlation with GDP of approximately 0.980, is very close to actual behaviour. More cautious interpretation is necessary for some patterns on the supply side. In particular, the degree of correlation to GDP for the first lead is higher than that observed in actual data for added value and real net indirect taxes on products and wages. Nevertheless, this outcome aligns with findings of Cicinelli et al. (2010) and reflects the general limit of estimations as forecasted variables may be more strongly correlated with past values than actual values, since each estimation is adaptive.

5.3. Multiplier analysis

The distinctive properties of the model can be verified by studying the responses to different shocks. First of all, we found the steady state of this model that is a balanced growth path with zero growth (Barnett and Ghosh, 2013). The steady state is calculated for each Region and it is used as the baseline sce- nario to compute the percentage change of a variable in a perturbed simulation. The system of equations we used in the previous paragraph to run the dynamic in-sample simulation, is now repeated thousands of times (3500) on software R.[11] After thousands of iterations, the model converges to a stationary equilib- rium that has the following set of common restrictions to the long run properties:

1) Capital depreciation equals gross fixed investments (zero capital growth)
2) New births equal deaths (zero population growth, i.e. zero labour force growth)[12]
3) Employed people converge to labour force (i.e., from 2, zero workers growth)

Conditions 1) and 3), together to the assumption of no technology shocks on productivity, imply an added value zero growth (we recall that added value is realized through the product of hours worked and hourly productivity). A steady state of a dynamic model is a stationary solution to the fundamental differential equation(s) of the model. In general, a balanced growth path is a path $(Y; K; L)_{t=0}^{\infty}$ along which the quantities Y (GDP), K (Capital), and L (Labour force) are positive and grow at constant rates; in our case these rates are equal to zero. The

[11] The starting value of each variable is the one observed in 2020, while the exogenous variables are fixed at the value observed in 2020

[12] Immigrated people and emigrated people converge to zero.

Table 1
GDP elasticity with respect to the main endogenous variables.

Variabili	Var.% PIL (t+k) 1	2	3	4	5
ADDED VALUE	0.836	0.713	0.595	0.490	0.395
DISPOSABLE INCOME	0.374	0.429	0.516	0.597	0.664
NET INDIRECT TAXES ON PRODUCTS	−0.300	−0.375	−0.388	−0.387	−0.379
INDIRECT TAXES - ADM. REG.	−0.115	−0.168	−0.197	−0.216	−0.227
PUBLIC CONSUMPTION	0.401	0.524	0.590	0.624	0.636
PUBLIC CONSUMPTION ADM. REG.	0.043	0.060	0.062	0.057	0.051
WAGES	0.305	0.430	0.514	0.578	0.624
HOUSEHOLDS CONSUMPTION	0.600	0.691	0.633	0.560	0.487
GROSS FIXED INVESTMENTS	0.033	0.046	0.052	0.054	0.053
INVESTMENTS ADM. REG.	0.0007	0.0014	0.0019	0.0022	0.0024
CAPITAL INCOME	0.115	0.167	0.197	0.217	0.229
DIRECT TAXES	−0.069	−0.093	−0.104	−0.110	−0.113
DIRECT TAXES - ADM. REG.	−0.013	−0.016	−0.017	−0.018	−0.018
SOCIAL CONTRIBUTIONS	−0.082	−0.108	−0.115	−0.116	−0.112
SOCIAL TRANSFERMENTS	0.078	0.120	0.148	0.171	0.189
EMPLOYMENT	0.827	0.776	0.633	0.587	0.490
HOURS WORKED	0.837	0.677	0.520	0.388	0.275

Table 2
GDP elasticity with respect to the main exogenous variables.

Variabili	Var.% PIL (t+k) 1	2	3	4	5
SPILLOVERS OTHER REGIONS	0.528	0.433	0.329	0.236	0.153
TRANSFERMENTS REG. ADM.	0.0005	0.0007	0.0008	0.0009	0.001
IMPORT PRICE INDEX	−0.108	−0.128	−0.134	−0.136	−0.134
FTSEMIB INDEX	0.006	0.009	0.012	0.014	0.015
CONSUMER CONFIDENCE INDEX	0.058	0.071	0.075	0.077	0.077
BUSINESS CONFIDENCE INDEX	0.037	0.053	0.062	0.68	0.70
PUBBLIC INVESTMENTS	0.033	0.042	0.045	0.045	0.042
ICT CAPITAL	0.104	0.086	0.068	0.051	0.035
IRPEF	−0.063	−0.086	−0.098	−0.104	−0.107
REGIONAL IRPEF ADDITIONAL TAX	−0.175	−0.212	−0.230	−0.243	−0.250
IVA	0.226	0.104	0.038	−0.011	−0.048
IRAP	−0.391	−0.568	−0.664	−0.726	−0.762
IRES	0.014	0.019	0.019	0.019	0.018
INTEREST RATE FOR BUSINESS LOANS	−0.294	−0.229	−0.163	0.105	0.054
INTEREST RATE FOR HOUSEHOLD LOANS	−0.190	−0.191	−0.170	−0.146	−0.123
INTEREST RATE ON TEN-YEAR ITALIAN BONDS	−0.0176	−0.024	−0.027	−0.028	−0.028
DOLLAR/EURO EXCHANGE RATE	−0.009	−0.010	−0.011	−0.010	−0.010

fundamental differential equation of the model is the same of Solow (1956):

$$\dot{k} = sf(k) - (\delta + g + n)k \quad (9)$$

where s is the savings rate, g is the GDP growth rate, n is the population growth rate, δ is the capital depreciation rate and $f(k)$ is the production function in the intensive form. In this model the growth rates of Y, K and L in the steady state is zero, ($\dot{k} = 0, g = 0, n = 0$); therefore, in stationary equilibrium, it holds that $sf(k) = \delta k$. Given the dynamic resource constraint (10), Uzawa's theorem grants that if balanced growth with positive gross savings occurs (as in this model), then the ratios Y/K and C/Y are constant, as it is in this model.

Starting from the model in its steady state, we introduce different shocks to determine the various effects on GDP and other relevant variables in relation to the original steady-state value. The interconnections between different variables' responses can explain how the model settles on the new equilibrium or how it returns to its original steady state. The lines drawn in the following figures (from 6 to 13) refer to Region Liguria, which we have chosen as an exemplary reference. In general, a *permanent* shock shifts the model into a new steady state while a *temporary* shock does not change the steady-state equilibrium.

5.3.1. Demand shock

We first consider the effect on the GDP of Region Liguria caused by a positive shock (+1 %) on household consumption of the other 19 Italian Regions. This shock intends to show the spillover effects of the neighboring economies on the GDP of Liguria. The changes induced by this shock are shown both for demand (Fig. 6) and supply (Fig. 7) sides. Changes to the steady state of workforce and fiscal variables are presented in Figs. 8 and 9.

The positive shock to other regional economies provides an impulse that propagates firstly to GDP. Secondly, the stimulus is transmitted to the other domestic demand components. The maximum value of the GDP multiplier is reached in the first year of the simulation (+0.5 %) (Fig. 6). In the medium-long term, aggregate demand is gradually brought back to base. Less strong, but always positive, the investments growth that follows the GDP path, albeit rescaled, and the same for household consumption.

Growing demand immediately drives input utilisation upwards and production slowly follows the demand positive shock (Fig. 7). The Gross Operating Income and added value gain the highest percentage of growth (respectively, +1.4 % and 0.7 %) while the total wages paid in economy increase, at its peak, only by 0.25 %. The capital income path follows the one of added value but rescaled with a small initial peak at +0.25 %. The employment response to the public spending shock is positive since the increased value added through the production channel also requires a higher number of self-employed workers (Fig. 8). The number of self-employed workers grows to its maximum level (+0.2 %) and then decreases for a few years until a second, smaller and negative peak, finally returning to the baseline scenario. The unemployment follows the economic cycle: initially it drops because the augmented added value (-0.3 %); subsequently, speedily comes back to its stationary state.

Finally, increased GDP of the other 19 Italian Regions leads to more direct taxes because of the subsequent income increase due to the augmented labour and capital income (Fig. 9). Even more noteworthy is the effect on indirect taxes, which rise by more than 0.2 % at their peak. The social contributions of workers undergo a positive impulse (+0.4 %) as a consequence of the increased number of employed people and higher wages. Conversely, social benefits un- dergo an important decline (-0.4 %) since part of the social unease is reduced by improved employment conditions and better services provided by the public administration.

Table 3
Comparing the first and second moments of cyclical compo- nents of the actual and simulated series.

Variables		Std. Dev. (simu- lated/actual)	Std. Dev. relative to GDP	Cross Correlation with GDP(t+k)		
				-1	0	1
VALUE ADDED	1.561	actual	0.899	0.912	0.999	0.920
		simulated	0.908	0.961	0.980	0.987
DISPOSABLE INCOME	0.999	actual	0.566	0.826	0.972	0.881
		simulated	0.366	0.992	0.932	0.979
REAL NET INDIRECT TAXES ON PRODUCTS	1.347	actual	0.105	0.803	0.963	0.670
		simulated	0.092	0.966	0.951	0.966
PUBLIC CONSUMPTION	1.934	actual	0.096	0.996	0.942	0.931
		simulated	0.120	0.963	0.958	0.949
WAGES	0.867	actual	0.564	0.843	0.984	0.922
		simulated	0.316	0.958	0.983	0.981
HOUSEHOLD CONSUMPTION	0.816	actual	0.837	0.901	0.959	0.989
		simulated	0.442	0.977	0.967	0.989
REAL GROSS FIXED INVESTMENTS	2.132	actual	0.913	0.965	0.878	0.709
		simulated	1.259	0.962	0.982	0.975
GROSS OPERATING INCOME	2.274	actual	0.444	0.830	0.884	0.486
		simulated	0.653	0.990	0.957	0.996
DIRECT TAXES	1.654	actual	0.062	0.502	0.637	0.491
		simulated	0.067	0.961	0.992	0.963
SOCIAL CONTRIBUTIONS	2.213	actual	0.175	0.806	0.913	0.967
		simulated	0.251	0.963	0.985	0.983
SOCIAL TRANSFERMENTS	0.249	actual	0.160	0.895	0.862	0.787
		simulated	0.026	0.459	0.794	0.812
TOTAL EMPLOYMENT	0.740	actual	0.003	0.845	0.834	0.975
		simulated	0.002	0.688	0.826	0.998
TOTAL HOURS WORKED	0.575	actual	9.819	0.725	0.925	0.471
		simulated	3.649	0.943	0.932	0.997

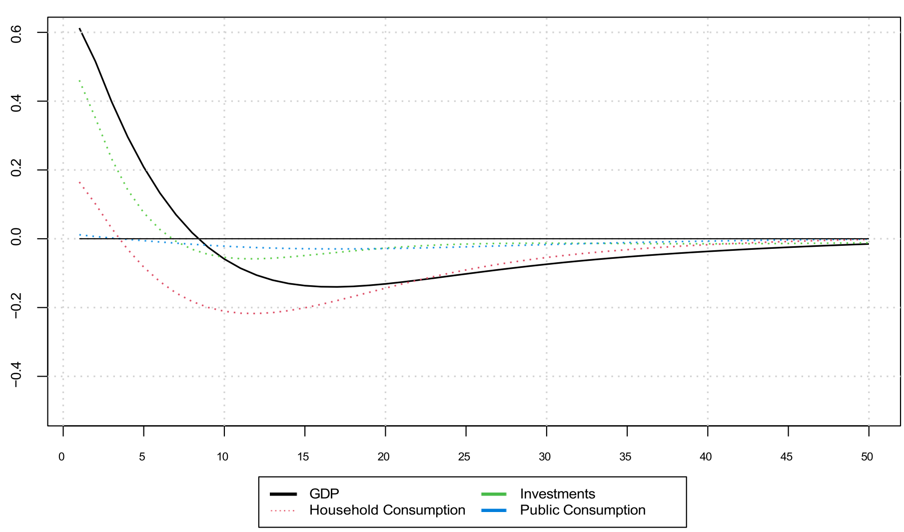

Fig. 6. Shock on neighboring regions: effects on the demand side.

5.3.2. Supply shock

On the supply side, we introduce a positive shock (+1 %) on indirect taxes in the Ligurian economy. We implement the raise in the tax wedge for only one year; therefore, the effects of this policy are only temporary. The result would be different if the tax growth was permanent because the system would move to a new steady-state equilibrium.

Household consumption exhibits the strongest fall: more than −0.5 % at its peak (Fig. 10). The shock also has a negative effect on the macro-components of aggregate demand. The GDP trend shows an initial phase of drop until a peak of −0.3 %, which is followed by a slow ascent phase until stabilisation. Public Consumption and investment also experience a negative boost, with one roughly doubling the other. On the supply side, the augmented indirect taxes have a negative impact, particularly on capital income and on Gross Operating Income, which both reach almost −0.6 % at their peak (Fig. 11). The effect on added value is also negative, exceeding −0.2 % at its peak, in a similar trend which sta- biles within 20 steps. Finally, total wages paid exhibits a small decrease, with an initial percentage reduction followed by a small positive peak.

On the employment side, we immediately verify the negative relationship between taxes and employment (Fig. 12). The fall in the number of self-employed people due to this increment in the indirect tax is greater than that for the employed. These two trend has a similar drop (-0.1/-0.2 %) but employed people come back to the baseline scenario in 10 steps while self-employed workers con- tinue to decrease for 10 steps until its negative peak (-0.38 %). The labour force reduces presumably since the tax growth discourage job seeking increasing the number of NEETs. Unemployment follows the economic cycle; when the shock is implemented it raises since the indirect taxes growth reduces the added value; in a second time, when the economy is coming back to its baseline equilibrium unemployment decreases.

The augmentation in indirect taxes, induces a very positive return

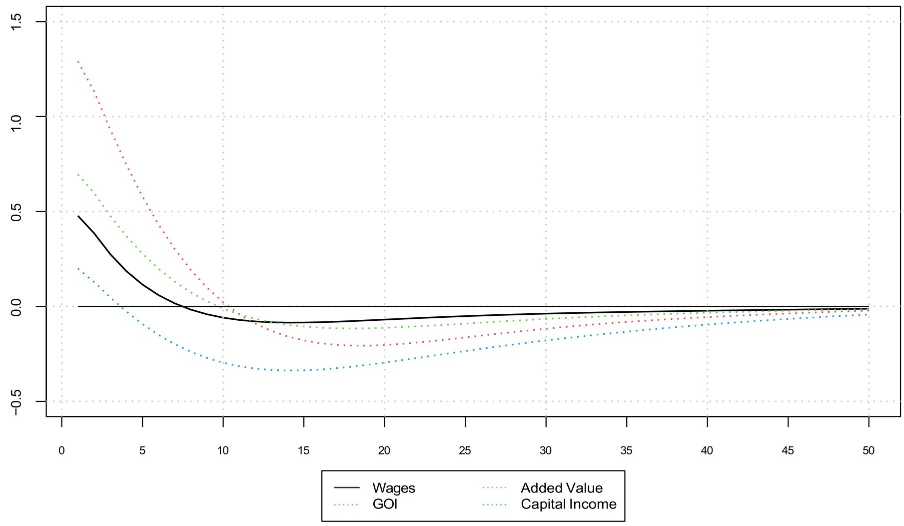

Fig. 7. Shock on neighboring regions: effects on the supply side.

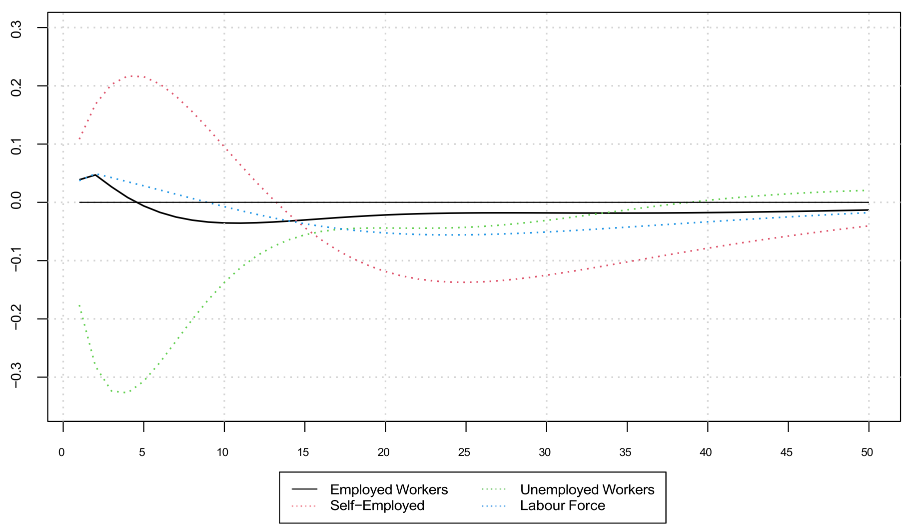

Fig. 8. Shock on neighboring regions: effects on workforce.

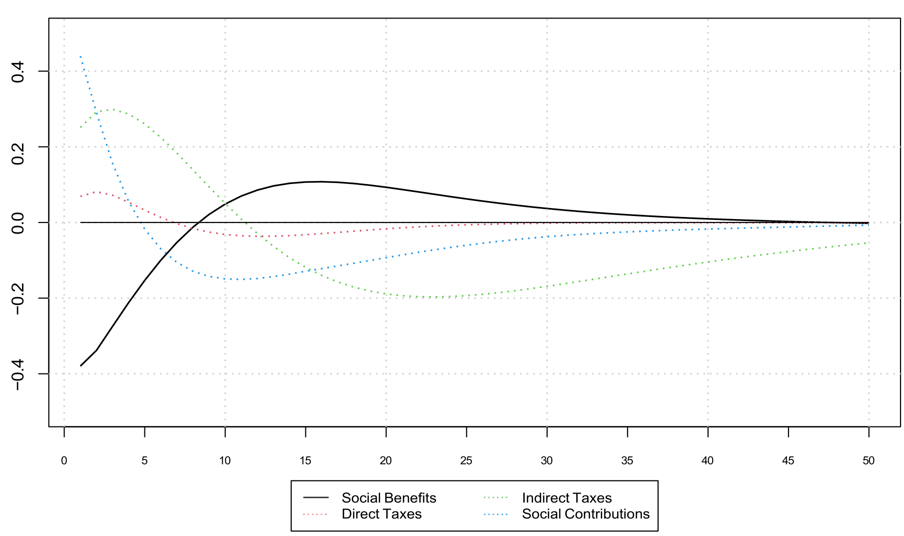

Fig. 9. Shock on neighboring regions: effects on taxes and social benefit.

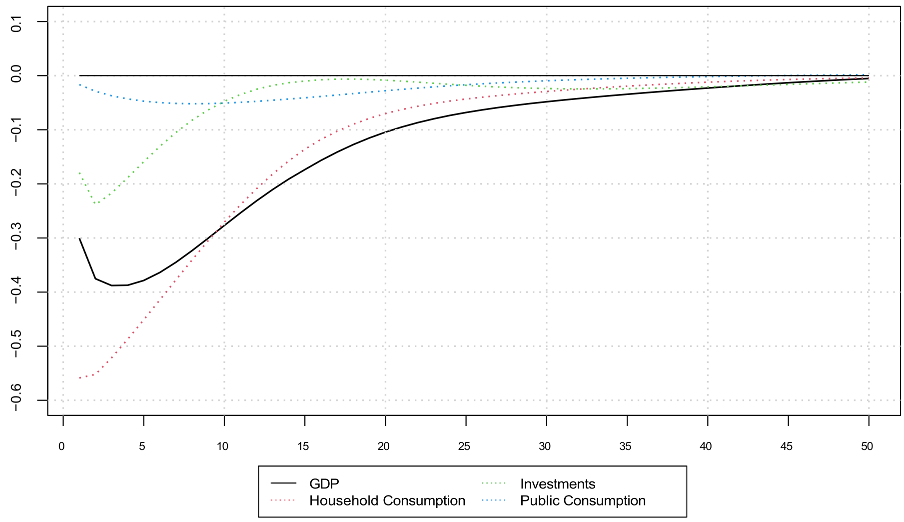

Fig. 10. Shock on indirect taxes: effects on demand side.

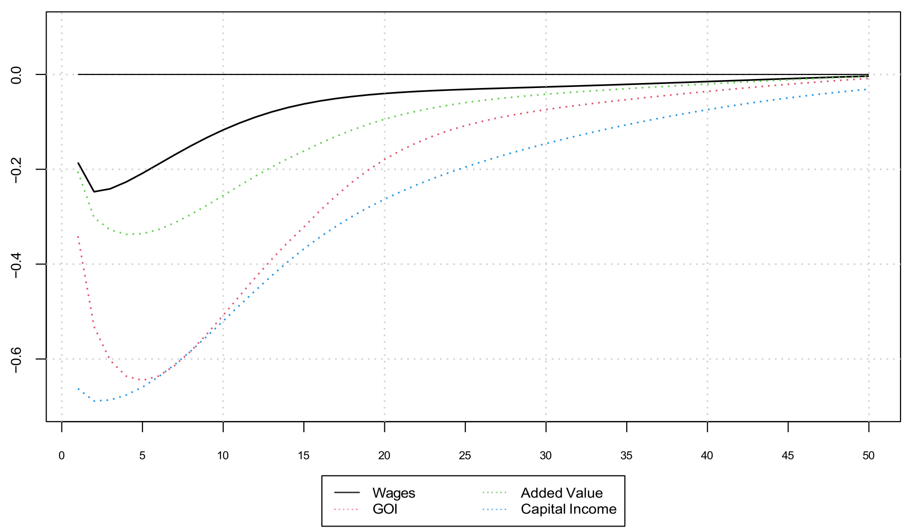

Fig. 11. Shock on indirect taxes: effects on supply side.

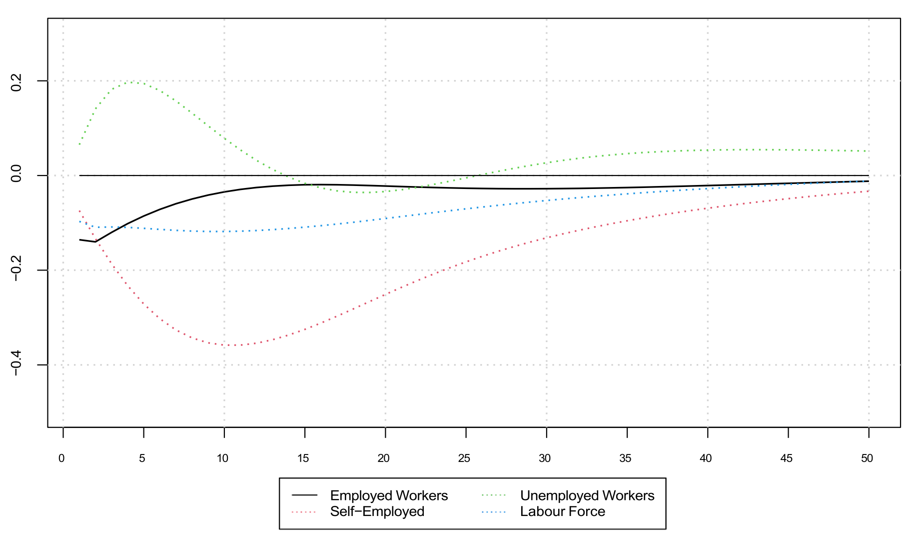

Fig. 12. Shock on indirect taxes: effects on workforce.

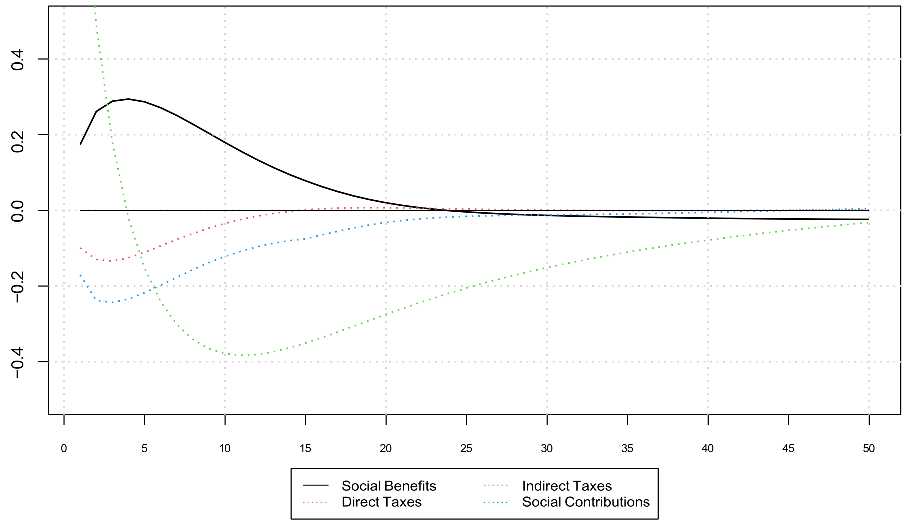

Fig. 13. Shock on indirect taxes: effects on taxes and social benefit.

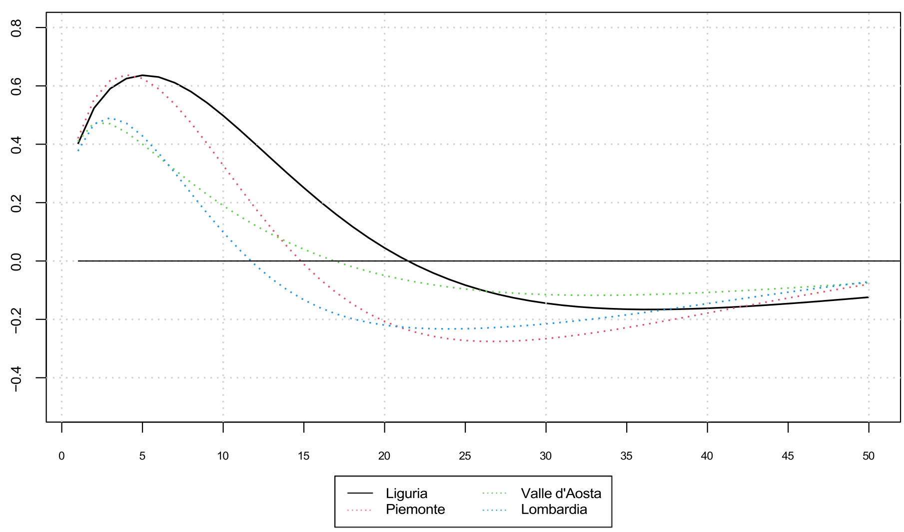

Fig. 14. Shock on public consumption (+1 %): effects on GDPs.

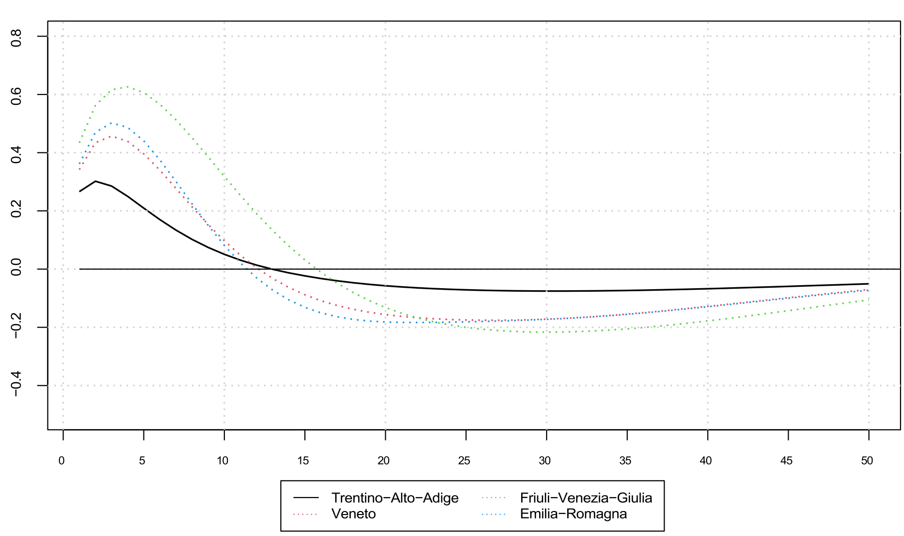

Fig. 15. Shock on public consumption (+1 %): effects on GDPs.

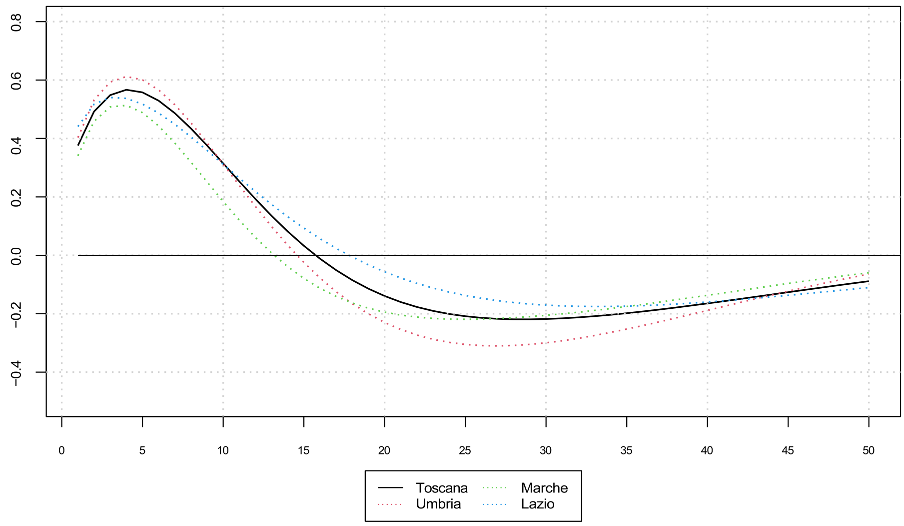

Fig. 16. Shock on public consumption (+1 %): effects on GDPs.

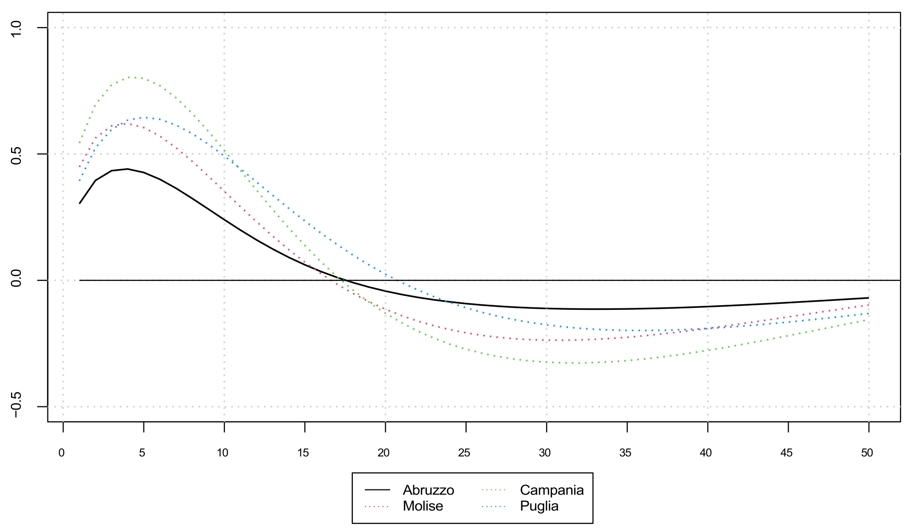

Fig. 17. Shock on public consumption (+1 %): effects on GDPs.

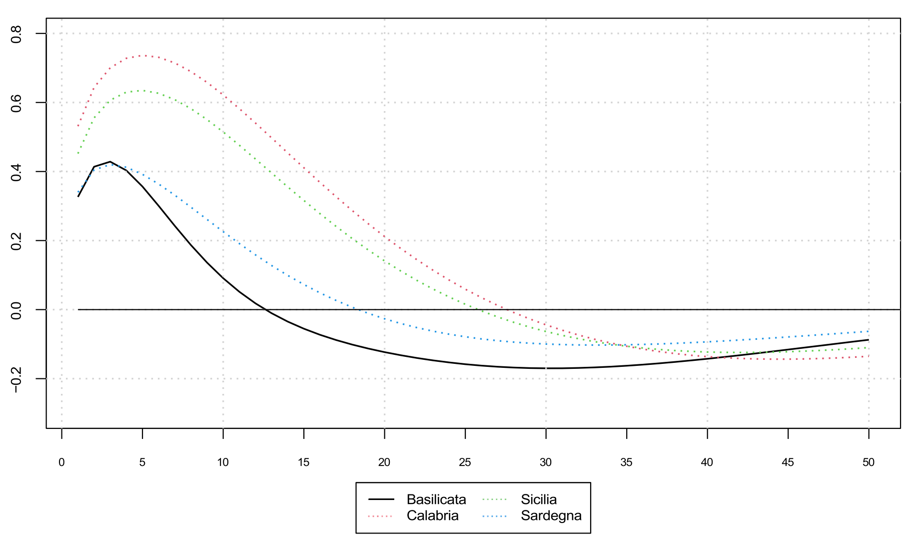

Fig. 18. Shock on public consumption (+1 %): effects on GDPs.

effect on indirect taxation (Fig. 13). However direct taxes and social contributions are negatively affected following the negative shock on demand and supply side caused by increased indirect taxation. Conversely, social benefits have been positively affected this shock (+0.2 % at its peak), as a direct effect of lower employment and more than offsetting government cuts.

5.3.3. *Response functions: a comparison among Italian regions*

In this section, we analyze the different ways in which regional economies, according to our model, respond to the same shock. In particular, we propose a demand-side shock, with increased public consumption (+1 %). Our estimates on panel data provide 20 different systems of behavioral equations; in this sec- tion we intend to show that, thanks to these different systems of equations, each regional economy responds in a specific way to the same shock (in relative terms), although with a performance comparable to that of the other regions. Regions are in fact highly integrated economies and therefore we can reasonably expect similar response functions to the same shocks; how- ever, they are also eco- nomic systems characterized by their own specificity that clearly emerges from the comparison of the different response functions.

From the response functions found in Figs. 14, 15, 16, 17, 18, it can firstly be concluded that the effects of a shock that hits the economy in a single year produce effects that are almost completely exhausted within 15 years, and this is in line with what is observed in the most well-known macroeconometric models, starting from Cicinelli et al. (2010). A second fact that emerges is the heterogeneity of the economic systems of the Italian regions; in some regions, the same shock produces an increase in GDP that is the half of other regions. For example, the GDP of Liguria, Piemonte, Friuli-Venezia-Giulia, Umbria, Molise, Puglia and Sicilia, at its peak, reaches +0.6 %; the GDP of Veneto, Abruzzo, Basilicata and Sardegna at its peak is only +0.4 %; while Campania and Piedmont are the regions that respond most intensely to the shock on public con- sumption (+0.8 %); on the other hand, the region that respond the least is Trentino-alto-Adige (+0.3 %).

6. Conclusions

We provide a detailed description of the main features of the IREM, confirming that the model provides consistent simultaneous determi- nation of the supply and demand sides of regional GDP, accounting for several interactions between a large number of endogenous behavioural variables. In the long run, the out- put level is determined by some specific supply and demand side conditions. In particular, technical progress led by ICT investments promotes productivity growth, which subsequently affects the GDP pattern. Long-term growth on the demand side is influenced by the tax rate set at regional and national levels and consumer confidence. GDP is computed on demand, supply and income sides. A distinctive feature of the IREM is that it accurately models public finance in terms of revenue and expenditure using specific equations for regional fiscal balance sheets that separate national gov- ernment revenue and expenditure from those only applicable to regional administration. The model's response to many shocks on demand and supply sides, in addition to exogenous variables' responses, provide insights regarding its properties and characteristics. According to the projected economic responses to implemented shocks over time, the model exhibits relatively standard properties, making it a potentially useful quantitative tool for informing regional policy development.

IREM may be used as a powerful instrument of policy analysis or of policy forecast for local governments. However, we need to recall its limitations. There are not behavioral equations for imports and exports because of the lack of data; data form regional government balance sheet (from CPT database) was adjusted through a filter to make it comparable with all others; the model pre- diction ability is accurate for the first 3 years decreasing for further steps.

Nevertheless, potential future research could extend this kind of model to other European countries; multi-equational macroeconometric models for regional economies could be useful, for example, for local German policymakers. Germany, indeed, is a federation of regions with relevant autonomy; the same holds for Switzerland.

CRediT authorship contribution statement

Simone Lombardini: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

I declare I did not receive any financial or non-financial assistance provided by a third party for the reported work.

I declare I do not have any financial interest or relationship — *within the last 3 years* — related to the subject matter but not directly to this manuscript.

I do not have patents or copyrights that are relevant to the work in the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.pirs.2024.100060.

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