RESEARCH PAPER

Estimating the Effects of the European Agricultural Fund for Rural Development in Italy

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Abstract

The European Agricultural Fund for Rural Development (EAFRD) is an important part of the European Union's strategies under the Common Agricultural Policy (CAP). It contributes to the development of rural areas through both public and private investments. However, in the short term, there can be ambiguous effects of European funds in these areas. The aim of this paper is to examine the short-term dynamic effects of the EAFRD on the economy of the Italian regions and their agricultural sector. Using a Structural Vector Autoregressive (VAR) model on a panel of 21 NUTS-2 regions, over the period 1995–2018, we find significant positive impacts on both regional economic activity, agricultural sector output and private investment in the agricultural sector. However, EAFRD spending causes temporary job losses in the agricultural sector, highlighting the effects of labour substitution by investments in innovation. The effects are more pronounced in regions with larger agricultural sectors and become stronger after the 2003 Fischler reform.

Keywords EAFRD · CAP · Italian regions · Bayesian SVAR · Fischler reform · Agricultural sector

JEL Classification C23 · C50 · H53 · O21 · P25 · Q18

1 Introduction

The European Union (EU) cohesion policy has gained increasing prominence, particularly following recent crises affecting European regions (Di Caro and Fratesi 2022). The Covid-19 crisis posed new challenges for policymakers, prompting an increase

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in the EU budget to finance investment projects under the European Structural and Investment Funds (ESI), thereby supporting numerous investment initiatives in the agricultural sector and rural Small and Medium Enterprises (SMEs).[1] Within the agricultural sector, the European Agricultural Fund for Rural Development (EAFRD) plays a critical role, particularly concerning the second pillar of the Common Agricultural Policy (CAP), and targets rural areas. EAFRD investments are dedicated to fostering knowledge and innovation, competitiveness, technology, and efficiency in the agricultural sector.[2] Due to the importance of investments for economic growth and prosperity (Destefanis and Rehman 2023), understanding the effects of this structural fund is of crucial importance for the agricultural sector. Many researchers have analysed the effects of different ESI funds on the economy of the regions (see Mohl and Hagen 2010; Becker et al. 2010, 2012, 2018 among others). The bulk of the literature has concentrated on long-term effects given that this policy is designed for the long-run. However, some studies have analysed the effects in the short-run (e.g., Coelho 2019; Canova and Pappa 2021; Di Caro and Fratesi 2022). This is motivated by the fact that, by providing funds for public and private investments, the ESI funds may generate demand-side effects, thus supporting the regional economies in the short-run by means of Keynesian type effects (Neumark and Simpson 2014; Di Caro and Fratesi 2022). The literature on this issue is less abundant (Di Pietro et al. 2021), and especially in the Italian context, only one study by Destefanis et al. (2022), analysed the dynamic effects of the EU structural funds on output and private investment in the short-to-medium run in Italy. As far as the EAFRD, to the best of our knowledge, there are many papers studying the effects of the CAP on output and employment separately (see Lillemets et al. 2022 for an extensive review) using different methodologies. Few studies have focused on the response of labour (Bartolini et al. 2015; Mantino 2017; Salvioni and Sciulli 2018) and output (Felici et al. 2008; Salvioni and Sciulli 2011) to CAP incentives in Italy. This study contributes to the literature, by bringing together the analysis of the short-to-medium-run effects of the EAFRD fund on the economy and agricultural sector of the Italian regions. Unlike previous studies, we jointly study the response of total output, output of the agricultural sector, private investment in the agricultural sector and agricultural employment to an increase in the EAFRD expenditure in Italy. We construct a dataset at the NUTS-2 level[3] for Italy, over the period 1995–2018 and apply a panel VAR model with fixed effects. First, this allows us to control for unobserved regional heterogeneity, which is substantial in the Italian context, given the different structural conditions that characterize the North–South divide of Italy. Second, we can control for shocks common across the Italian regions. This model is estimated using Bayesian techniques and the shock to the EAFRD expenditure is identified by means of institutional information regarding the fund allocation. In particular, we follow Destefanis et al. (2022) and Destefanis and Di Giacinto (2023), and identify the EAFRD shock by restricting the response of

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[1] See https://ec.europa.eu/commission/presscorner/detail/en/ip_23_389.

[2] See https://agriculture.ec.europa.eu/common-agricultural-policy/rural-development_en.

[3] The NUTS classification (Nomenclature of Territorial Units for Statistics) is a geocoded standard that divides European countries for statistical and policy purposes. It consists of three different NUTS levels, moving from larger to smaller territorial units (e.g., one NUTS1 area typically contains several NUTS2 areas, and one NUTS2 area typically contains several NUTS3 areas).

the EAFRD allocation to the other shocks in the VAR equal to zero within a year. This is motivated, as already mentioned, by institutional reasons behind the allocation of the EU structural funds. They are designed for long-term policy, and are set during supra-national negotiations and the amount of allocation may not be changed immediately as a response to sudden economic shocks. There is therefore an inherent lag in the implementation of the policy, which, especially for small units like the Italian regions, make the policy implemented at the EU level exogenous to local idiosyncratic shocks within a year. Furthermore, we extend the analysis by, first distinguishing the effects in two groups of regions which differs by the relative size of the agricultural sector. Indeed, we wonder whether, the short-run effects of the EAFRD expenditure may be larger in regions where the size of the agricultural sector is higher. Finally, in light of the important reforms that involved the EU agricultural policy, namely, the Agenda 2000 and Fischler reform in 2003, we study whether the effects in the pre-reform period were different from the one in the post-reform period.

The results indicate that EAFRD investments stimulate the economies of Italian regions by increasing total and agricultural sector output and complementing private investments in the sector. However, these investments also result in temporary job losses, potentially due to innovation and technology investments that substitute labour.

The remainder of the paper is organized as follows. Section 2 outlines the EAFRD framework, the Italian context, and summarizes related literature. Section 3 describes the empirical methodology, with additional details provided in Appendices 1 and 2. Section 4 discusses the results, and Sect. 5 concludes.

2 The Background

2.1 CAP and EAFRD Programme

European funds dedicated to agriculture were established with the primary objective of assisting the agricultural sector of European regions and promoting the development of the entire economy. Various factors can influence the effectiveness of these funds in achieving growth, including the efficiency of public governance, institutional quality, economic development, and socio-cultural factors (Achim and Borlea 2015).

An essential part of this financing instrument is provided by the funds for rural development available within the Common Agricultural Policy (CAP). The initial and most important provisions related to the CAP were linked to increasing agricultural productivity and the efficiency of agricultural enterprises, levels of development in rural communities, ensuring satisfactory incomes for agricultural workers in EU countries, supporting European producers against international competition, intervening in product prices, and agricultural markets (Loux 2020). These core ideas have largely remained unchanged over time until the Fischler reform in 2003 (EC 2003), which introduced substantial organizational changes, especially in response to the problem of depopulation in rural areas, introducing the "second pillar" of the CAP, oriented towards rural development and co-financed by the EAFRD and regional or national funds.

The 2003 reform aimed to make the CAP more sustainable and equitable in fund distribution through several key measures. First, decoupling subsidies from production volumes, thus reducing incentives to overproduce. Second, implementing the Single Farm Payment (SFP) based on agricultural area rather than production to discourage surplus production. Third, introducing environmental conditionality by linking direct payments to compliance with environmental standards, food safety, and animal welfare. Fourth, strengthening the second pillar by reallocating a higher percentage of funds from the first pillar (direct payments and market support) to the second pillar, supporting rural development measures aimed at enhancing agricultural competitiveness, sustainable resource management, and economic diversification in rural areas (Esposti 2007; Piattoni and Polverari 2016). Finally, modulation involved transferring a portion of funds from the first pillar to the second to further support rural development and environmental initiatives.

The Fischler reform significantly impacted agricultural policy and rural economies, particularly in countries like Italy, by contributing to rural area development, promoting economic growth, improving rural infrastructure, and advancing innovative technologies. This enhanced productive efficiency and competitiveness in the international market.

Over time, subsidy mechanisms supported less agricultural products and more agricultural producers and the development of rural communities and the economy (Scown et al. 2020). The reform aimed to decouple production from subsidies, replacing direct aids with a SFP independent of production, and reducing direct payments to large agricultural enterprises to redirect resources toward rural development. These measures intended to reduce land overuse and promote sustainable agriculture. Moreover, the Fischler reform promoted greater equity in fund distribution across various regions, fostering sustainability and competitiveness in the European agricultural sector (Crescenzi et al. 2015).

The introduction of the EAFRD marked a significant change, emphasizing rural development over merely supporting agriculture as an economic sector. This shift led to more complex territorial approaches and regulations, including social functions (Mantino and Vanni 2019).

The literature evaluating the impact of rural development funds on rural areas is divided into two main groups. The first group indicates a positive impact, noting that rural areas have evolved and developed thanks to the CAP and European funds for rural development. The second group highlights the opposite effect. For example, in some countries, regional disparities have increased in rural areas rather than decreased.

Despite the significant growth of this common policy over time in terms of targeted objectives, funding, and implementation structures, it has not entirely addressed persistent problems such as the predominantly agricultural economic structure of many rural communities, inequalities in development between Member States, and the gap between urban and rural environments (Papadopoulos 2015; Matthews 2017). These challenges persist, with notable disparities in competitiveness, agricultural productivity, and economic efficiency of rural enterprises. Some studies show that periods of economic growth at the European level reduce differences and increase convergence speed in rural environments. Conversely, during recessions, the common policy does not effectively resolve economic and social inequalities (Papadopoulos 2015).

However, to our knowledge, no study has examined the short-to-medium-term dynamic effects of the European Agricultural Fund for Rural Development in Italian regions over approximately 20 years. This study aims to fill that gap.

2.2 Italian Context

Italy is one of the largest economies in Europe, yet it exhibits significant regional disparities, particularly between the more developed Central-Northern regions and the less developed Southern regions. Panel (a) of Fig. 1 illustrates substantial differences in income per capita, with Southern regions displaying notably lower GDP per capita. These territorial imbalances, often referred to as the North–South divide, have persisted for a long time.

Related to this, there is also a heterogeneity in the sectoral composition of the regional economies. It is well known that the Centre-North area is more specialized in the manufacturing and service sectors. Instead, regions in the "Mezzogiorno" are the ones in which the agricultural sector plays a higher role. Panel (b) of Fig. 1 shows that, except for the Trentino-Alto Adige region, the share of agricultural output in total output is higher in the Southern regions.

Figure 2 reflects these characteristics of the Italian economy and aligns with the EU policy, which targets less developed regions of Europe. Panel (a) demonstrates that per capita expenditure in the South is significantly higher than in the rest of the country, a trend consistent throughout the period under investigation (1995–2018). Furthermore, Panel (b) of Fig. 2 indicates that EAFRD per capita expenditure is much higher in regions where the average agricultural output share (over the sample period 1995–2018) exceeds the Italian median. These last two points are corroborated by Fig. 3 panel (a), which shows that the per capita allocation of EAFRD expenditure is higher in the South and in some regions in the Centre-North where the size of the agricultural sector is larger, as shown in Fig. 1 panel (b) and in line with Fig. 2 panel (b). Additionally, Fig. 2 reveals an increasing trend in EAFRD per capita expenditure over time, particularly following the reforms in 2000 and 2003, as discussed in the
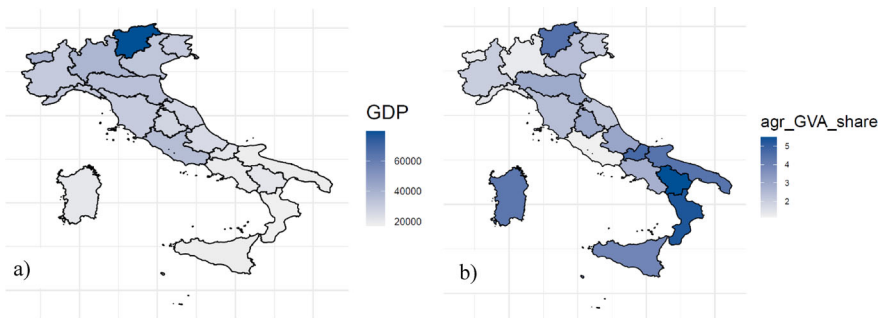

Fig. 1 Per capita GDP and agricultural output share. Note: The plot shows the regional averages, over the period 1995–2018, of GDP per capita (panel **a**) and the share of agricultural production (panel **b**)
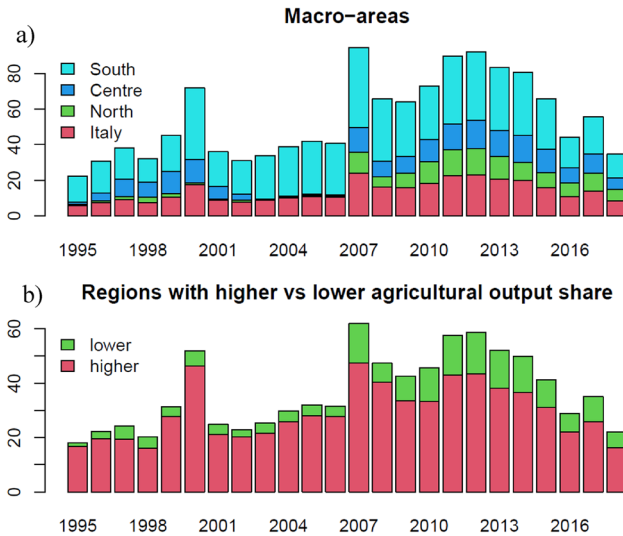
Fig. 2 Evolution of EAFRD per capita expenditure in different groups of regions. Note: Panel **a**) shows the evolution of EAFRD expenditure per capita and its decomposition into Italian macro-regions. Panel **b**) does the same but for two groups of regions: (i) Italian regions with a share of agricultural production below the median; (ii) Italian regions with a share of agricultural production above the median
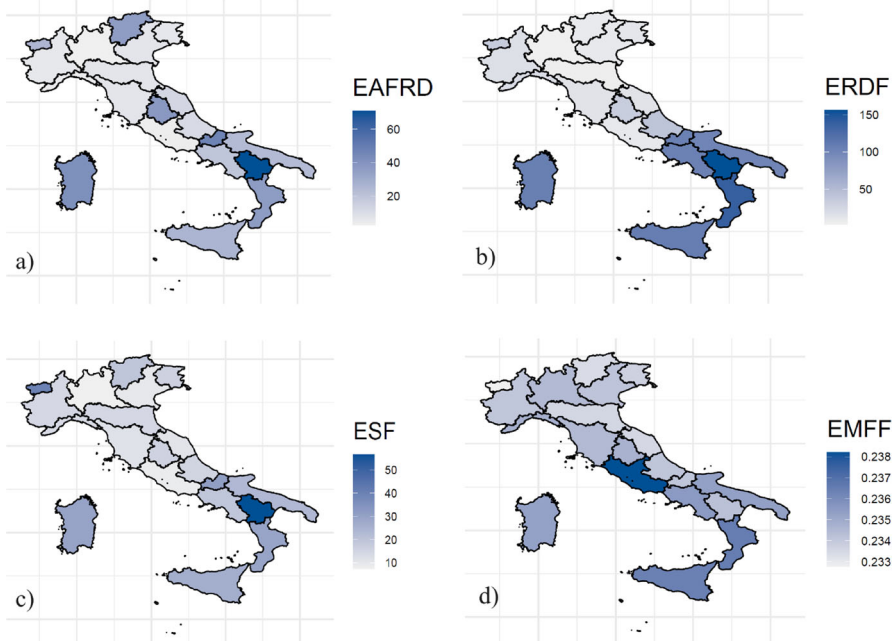

Fig. 3 Per capita allocation of ESIFs expenditure across the Italian regions. Note: Panel **a**) is for the EAFRD, panel **b**) for the ERDF, panel **c**) for the ESF and panel **d**) for the EMFF. For the EAFRD and the ERDF, this graph shows the average regional allocation per capita over the sample period of our analysis, i.e. 1995–2018. For the ESF, the average is calculated over the period 2000–2018, while for the EMFF, it is over the period 2014–2018, as the latter two funds were introduced later
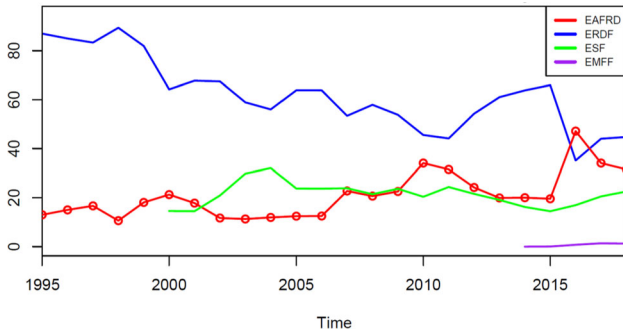
Fig. 4 Time series of the share (% of total) of the ESI Funds in Italy over the sample period explored in our analysis. Note: The graph shows the share of each fund as a percentage of the total ESIF in each year. The percentage shares of ERDF and EAFRD are available for the entire sample period, while those of ESF and EMFF are available from 2000 and 2014, respectively, as these two funds were introduced later

previous section. The average expenditure has been higher in the period following 2003.

Finally, it is useful to compare the EAFRD with the other funds comprised in the European Structural and Investment Funds (ESIFs), which in Italy are the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the European Maritime and Fisheries Fund (EMFF).[4] The ERDF is the largest and oldest fund among the ESIFs, devoted to strengthening the economic, social and territorial cohesion of the European regions by investing in sustainable development, innovation, supporting Small and Medium sized Enterprises (SMEs) and employment. It is followed by the EAFRD and then by the ESF, the latter introduced in 2000, which finance social inclusion measures and active labour market and training measures. The EMFF has been introduced recently, in 2014, and supports innovative projects with the aim of using the aquatic and maritime resources in a sustainable way.

Figure 4 illustrates the evolution of the percentage share of each fund within the total ESIFs over time, providing a comparative perspective. Historically, the ERDF has been the largest fund, though its relative importance has diminished over time. The EAFRD, while the second in importance (though occasionally surpassed by the ESF in certain years), has seen a significant increase in its relative size, becoming comparable to the ERDF between 2010 and 2018. The ESF is another major fund in Italy, whereas the EMFF covers a tiny portion of the ESIFs.

Moreover, Fig. 3 demonstrates the importance of the EAFRD in Italy in terms of per capita expenditure allocation. This graph reaffirms our observations regarding the ESIFs. The ERDF exhibits the highest per capita allocation across the Italian regions, followed by the EAFRD and then the ESF, while the EMFF has a minimal and relatively homogeneous per capita distribution across Italian regions.

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[4] See the website of the European Commission https://ec.europa.eu/commission/presscorner/detail/en/ip_23_389. The ESIFs also comprise the Cohesion Fund (CF) but Italy is not eligible (see https://ec.europa.eu/regional_policy/funding/cohesion-fund_en).

2.3 Related Literature

Our study involves different strands of the empirical literature on the CAP effects. This literature is really vast (Bonfiglio et al. 2016) and can not be entirely reviewed in this paper. However, in this sub-section we try to summarize studies which provided evidence for European and Italian regions regarding the effects of the EU agricultural policy on the regional economies. An extensive literature review is provided by Lillemets et al. (2022).

Output and EU agricultural policy. There is a large literature that studies the effects of public expenditure on output, especially in the US. Chodorow-Reich (2019) provides an extensive literature review on the estimation of government spending multipliers using regional data. This empirical evidence points at positive government spending effects on output. Looking at the public investment expenditure, Gechert et al. (2016) show that government investment expenditure has a higher impact than government consumption and transfers. In the context of Italian regions, there are few papers addressing the short-to-medium-run impact of government spending policies. A closer look at the methodologies and findings of the literature on government expenditure and fiscal policies using regional Italian data reveals that the economic disparity between northern and southern Italy is studied using Kaldor–Verdoorn approach, examining labour productivity, capital accumulation, and output growth via a P-SVAR model. Production growth impacts productivity more in the Centre–North, while investment does in the South, highlighting the need for public sector intervention to boost productivity in disadvantaged areas (Deleidi et al. 2021a). Faggian and Biagi (2003) showed significant regional economic multiplier differences using the Marginal Propensity Method (MPM) and the Aggregate Leakages Method (ALM), emphasising the need for region-specific policies. Acconcia and Monte (2000), utilising panel data regressions, found that infrastructure capital boosts productivity more in low-income areas, with public investment benefiting manufacturing regions. Piacentini et al. (2016) estimated the impact of budget consolidation in 2011–2013. This study uses annual regional data to contrast fiscal multipliers in Italy's northern and southern regions, the latter being less developed areas. Tax increases and budget cuts affect the South more than the North. Deleidi et al. (2021b), Destefanis et al. (2022), Lucidi (2023) and Matarrese and Frangiamore (2023) all make use of SVAR models to estimate the dynamic effects of government spending shocks using regional data. They find positive effects for both consumption and investment expenditure. Zezza and Guarascio (2023), also using a SVAR model on Italian regional data, demonstrated that public investment in green, digital, and knowledge areas positively influences GDP and private investment, suggesting that the National Recovery and Resilience Plan (NRRP) could reduce regional disparities.

Regarding EU regional policy, numerous studies demonstrate positive effects on regional growth (Mohl and Hagen 2010; Becker et al. 2010, 2018; Pellegrini et al. 2013; Aiello and Pupo 2012 for Italy) and few papers address the short-term and countercyclical effects of EU regional policies (see for example, Coelho 2019; Durand and Espinoza 2021; Canova and Pappa 2021; Di Caro and Fratesi 2022; Destefanis et al. 2022 for Italy). Considering now what most interests our research, some studies

have analysed the impact of the EU agricultural policy on regional output. In a study involving regions in 15 EU countries from 1989 to 2000, Esposti (2007) demonstrated modest GDP increases attributed to 1st Pillar expenditure. A small effect of both 1st and 2nd Pillars on GDP growth was also found by Crescenzi and Giua (2016) using regional data for 12 EU countries. Bonfiglio et al. (2016) applying Input–Output (I-O) models to regional data for the EU27 countries, over the period 2007–2011, also find positive effects of CAP on regional output. As for Italy, Salvioni and Sciulli (2011), using a Difference-in-Differences approach, find that 2nd Pillar measures positively affect GDP in Italian regions over the period 2003–2007, whereas Felici et al. (2008) show, using a I-O model, that 2nd Pillar measures were estimated to increase GDP by 0.1% in 2007–2013.

Employment and EU agricultural policy. Another relevant issue concerns the effects of the EU investments in agriculture on the employment. In general, sectoral impacts of investments are difficult to understand. Since the classical era (Marx 1969), economists have recognised that investment expenditures have a direct displacement effect, replacing workers with new machines and technologies. Marx's labour theory of value asserts that a commodity's value depends on the socially necessary labour time. Technology often reduces labour time, displacing workers because fewer people are needed to produce the same amount. This is related to Marx's biological capital theory. Capitalists maximise profits by investing more in constant capital, such as machinery and technology, and less in variable capital, like labour. This transition increases the fixed-to-variable capital ratio, leading to greater automation and mechanisation, and replacing labour with machines. Technical progress boosts productivity, but also increases displacement, thereby increasing capitalists' surplus value from labour. This develops Marx's concept of the "reserve army of labour", a population of unemployed or underemployed people maintained by capitalism's profit-driven nature. This paradigm leads to technological unemployment as robots perform jobs more efficiently and cheaply than humans. Technological unemployment illustrates how capitalist production processes displace workers when robots replace human labour in various industries.

According to Bogliacino and Pianta (2010) and Bogliacino et al. (2013), firms that innovate to reduce labour costs, mostly by introducing new machinery, hurt employment. However, Bogliacino and Vivarelli (2012) note that gross fixed capital formation, especially in high-tech sectors, is beneficial. Gross fixed capital formation negatively affects employment, especially in low-tech sectors where competition drives cost-cutting, according to Piva and Vivarelli (2018). In scale- and information-intensive industries, Dosi et al. (2021) found that expansionary investment is beneficial and replacement investment is detrimental. Acemoglu and Restrepo (2019) argue that slow productivity growth and the emergence of new tasks that could reintegrate labour into production lead to job loss when new technologies are introduced and adopted. Mondolo (2022), examines the process of replacing workers with new technologies and capital goods. This extensive research shows that new investments affect different workers differently, depending on whether they are high-skilled or low-skilled. Turning to our focus, the effects of the CAP on regional employment have also been extensively analysed. For example, Garrone et al. (2019) analyse the effects of the CAP on employment outflow from the agricultural sector, exploiting a panel of regions

belonging to the EU27 countries, over the period 2004–2014. They find that the I pillar reduces employment outflow, whereas the effects of the II Pillar (which is the one involving the EAFRD programme, namely, the fund of interest in our paper) are mixed. Destefanis and Rehman (2023) explores the effects of the EAFRD investments, along with the effects of other types of investment expenditures and European Structural and Investment Funds, on employment, for the European NUTS-2 regions, over the period 2000–2016, finding positive effects, especially in the more developed regions. By contrast, studies have found negative effects of the CAP on total labour use, family labour, and external labour, including Pillar I and II programmes. Bournaris and Manos (2012), Manos et al. (2013), Petrick and Zier (2011), Psaltopoulos et al. (2011), and Gohin and Latruffe (2006) have shown these negative effects. As for Italy, studies such as Bartolini et al. (2015), Mantino (2017), Salvioni and Sciulli (2018) estimate the effects of CAP and rural development program on employment. In particular, Bartolini et al. (2015) examines how the 2003/05 CAP reform, which decoupled payments, affects on-farm labour in the Tuscany region of Italy, including household and non-household workers' levels and allocation. They estimate the average treatment effects using propensity score-based matching. The Generalised Propensity Score (GPS) method is used to examine how different payment levels affect a subgroup of Tuscany farms, specifically arable farms with agricultural areas greater than the median value. Their results show that payments affect employment, but the impact varies by amount. Mantino (2017) examines CAP measures' employment effects in Italian agriculture from 2007 to 2014, finding negative effects from the I Pillar and positive effects from the II Pillar. Salvioni and Sciulli (2018), using farm level data, over the period 2003–2007 and a Difference-in-Differences approach, do not find any significant effect on employment.

2.4 Summing Up

In light of the related literature just discussed, there are no studies which jointly analyse the short-to-medium term response of regional economies and agricultural sector to EAFRD expenditure changes. While previous works focus on the effects on total output or employment, separately in most cases, to the best of our knowledge there are no studies looking at private investment in the agricultural sector in either European or Italian regions. We try to fill this gap, by analysing the short-to-medium term effects of EAFRD expenditure on total output, and output, private investment and employment of the agricultural sector. Additionally, considering the sectoral composition of regional economies, where Southern Italian regions exhibit higher shares of agricultural production, as shown in Sect. 2.2, we investigate how these effects vary based on the relative size of the agricultural sector. Finally, in light of the reforms occurred in the EU agricultural policy, as discussed in Sect. 2.1, we investigate whether the policy effectiveness have changed after these important reforms.

3 Empirical Analysis

3.1 Data

The dataset used in this research is a panel dataset for 21 NUTS-2 Italian regions over the period 1995–2018. The variables employed in this analysis come from two sources. The EAFRD expenditure is taken from the Historical EU Payments by NUTS-2 regions database (available here). According to the European Commission (see Sect. 4 of this guidance), the modelled expenditure is the one that has to be used for research purposes, since the Payments are made in the form of reimbursement, thus they are recorded after the actual expenditure has been incurred. We follow this suggestion and use the modelled expenditure. Furthermore, we aggregate this expenditure over the different programming periods, since at each year there is some overlap in spending between programming periods; that is, spending planned in one programming period could be implemented in the next period. Therefore, we consider the expenditure actually disbursed in each year, regardless of the programming period, by aggregating the expenditure incurred at each year from different programming periods. The other variables are (i) the GDP, (ii) the GVA of the agricultural sector, (iii) the private investment in the agricultural sector and (iv) the number of people employed in the agricultural sector, obtained from the Italian National Institute of Statistics (ISTAT), along with the population used to compute variables in per capita terms. The variables expressed in terms of euros (all but employment), are transformed into real terms by using the national GDP deflator from the World Bank database.

The starting year of our sample, 1995–2018, is due to the availability of data on the agricultural economy and GDP of the Italian NUTS-2 regions from ISTAT, whereas 2018 is the last observation available for the EAFRD expenditure. Table 1 shows some summary statistics of the variables used in the VAR.

Table 1 Summary statistics

	Mean	Standard deviation	Minimum	Maximum	Unit of measure
EAFRD	20.55	22.61	0.07	135.58	€ real per capita
GDP	28,308.04	7700.11	15,124.71	46,015.10	€ real per capita
GVA agriculture	741.59	375.93	256.39	2674.84	€ real per capita
Investment agriculture	232.30	208.30	34.29	1407.92	€ real per capita
Employment agriculture	47,604.17	38,269.32	2100.00	166,800.00	Number of people

3.2 Econometric Strategy

To estimate the short-to-medium-run dynamic effects of the EAFRD expenditure on the Italian regional economies, we use a structural panel VAR approach. This methodology has been used to study the effects of regional fiscal policy and EU structural funds (see for Italian regions, e.g., Destefanis et al. 2022; Matarrese and Frangiamore 2023; Destefanis and Di Giacinto 2023 for European regions).

The reduced form of the panel VAR(1)[5] is as follows:

$$Y_{i,t} = AY_{i,t-1} + CW_{i,t} + u_{i,t} \tag{1}$$

where i and t index regions and time, respectively, $Y_{i,t}$ is the vector of endogenous variables, $Y_{i,t-1}$ the corresponding lags, A is the matrix containing the coefficients of the lags of the endogenous variables, $W_{i,t}$ is a vector of exogenous variables with C the associated matrix of coefficients, and $u_{i,t}$ is the vector of reduced-form residuals (innovations), which is assumed to be normally distributed with zero mean and constant covariance matrix, namely, $u_{i,t} \sim N(0, \Sigma)$. In order to preserve the cointegrating relationship between the endogenous (macroeconomic) variables, we estimate the model with the variables in log-levels.[6] In particular, the vector of endogenous variables includes the logarithm of real EAFRD expenditure per capita, the logarithm of real GDP per capita, the logarithm of real GVA per capita in the agricultural sector, the logarithm of real private investment per capita in the agricultural sector, and the logarithm of the number of people employed in the agricultural sector, observed in region i at time t, i.e. $Y_{i,t} = \left[EAFRD_{i,t}, GDP_{i,t}, GVA_{i,t}, INV_{i,t}, EMP_{i,t} \right]$.

Furthermore, we incorporate the a priori information, in a Bayesian setting,[7] that the macroeconomic variables behave as random walks with unit root (see Minnesota prior in Litterman 1986). Therefore, the model is estimated using the approach proposed by Bańbura et al. (2010), which allows us to impose a Normal-Inverse Wishart prior on the VAR coefficients and the reduced-form covariance matrix. Furthermore, the Gibbs algorithm only retains those draws of the VAR coefficients that satisfy the stability condition.[8]

The choice of including the aforementioned variables in the vector of endogenous variables is explained as follows. Firstly, because our aim is to trace the dynamic effects

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[5] We follow the rule of thumb to include as many lags as the sample frequency of the data. Since our data are observed with annual frequency, we include one lag in the baseline model. We also follow the common practice of calculating the BIC criterion, which suggests using one lag (results are available on request). However, in Appendix 3 we show that the results are robust to estimating the model with 2 lags (see Fig. 12 in Appendix 3).

[6] We also conducted unit root tests and panel cointegration tests. The results are available in Appendix 1. They show that there is no clear-cut evidence of stationarity in the series. In particular, the Hadri (2000) test shows that at least one series in the panel has a unit root for all variables, whereas some of the other tests for GDP and GVA cannot reject the null of non-stationarity. However, we also find the presence of cointegration in our variables (see Table 6 in Appendix 1), so we estimate the model with the variables in log-levels.

[7] We use Bayesian estimation which can help with the small size of our sample. The use of shrinkage methods allows dealing with this issue.

[8] Details on Bayesian estimation and the Gibbs sampling algorithm can be found in Appendix B.

of an increase in EAFRD expenditure on production, investment and employment in the agricultural sector. Secondly, we have also included GDP to see how total output responds and to take into account the overall state of the Italian regional economies.

In the baseline model, the vector of exogenous variables includes time and regional dummies to control for time and regional fixed effects. We follow the empirical literature which estimates the effects of an increase in spending in a region relative to another on relative outcome variables (see Nakamura and Steinsson 2014; Chodorow-Reich 2019). Thus, our model is a fixed effects panel VAR. The advantage of this is that it allows us to capture the effects of common shocks, such as national shocks, global shocks, or monetary policy changes, since they are common to all the Italian regions, and are somehow captured by the time dummies (see Gabriel et al. 2023). Furthermore, the inclusion of regional dummies allows to account for unobserved time-invariant regional heterogeneity. This is really crucial in the context of the European Regional Policy, since its aim is to reduce regional imbalances among regions in the long-run, creating a correlation between time-invariant regional factors and level of per capita expenditure, implying a bias in the estimation if one does not control for regional fixed effects.[9] In addition, we include a linear and quadratic time trend, as other empirical papers do with log-levels macroeconomic variables, to capture time trends in macroeconomic time series[10] (see Blanchard and Perotti 2002 and Khan and Reza 2017 in fiscal policy VAR).

The structural form model is represented as follows (Lütkepohl 2005):

$$u_{i,t} = \Gamma \varepsilon_{i,t} \qquad (2)$$

where $\varepsilon_{i,t}$ are the structural shocks, which are assumed to be normally distributed with zero mean, unitary variances and orthogonal to each other, that is, $\varepsilon_{i,t} \sim N(0, I)$. By substituting Eq. (2) into Eq. (1), the model is now as follows:

$$Y_{i,t} = A Y_{i,t-1} + C W_{i,t} + \Gamma \varepsilon_{i,t} \qquad (3)$$

Because of the order of the endogenous variables in the VAR, our aim is to identify the first column of matrix Γ, which gives the on-impact effects of an EAFRD shock.

Following Destefanis et al. (2022) and Destefanis and Di Giacinto (2023), we assume that the EAFRD allocation is not driven by contemporaneous shock hitting the economy, because of inherent lags in the implementation of the policy and in the process of distribution of EU funds, which are set during supranational negotiation.

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[9] The advantages of this modelling strategy are important for our analysis, although it implies that the parameters are homogeneous across regions. However, given the Italian context discussed in Sect. 2.2, we test whether the results are driven by the regions with the highest and lowest per capita income and EAFRD expenditure. Figure 11 in Appendix 3 shows that the results remain unchanged when excluding the region with the highest and lowest GDP per capita and the region with the highest and lowest EAFRD expenditure per capita (more details can be found in Appendix 3).

[10] However, we check whether the results are driven by the choice about the variables to include in the vector $W_{i,t}$. In particular, we test whether the results are affected by the inclusion of the time trends, or by the inclusion of time and regional dummies instead of using the within transformation of the panel dataset. More details on this can be found in Appendix 3. Figure 9 shows that the results are robust to changing the variables in the vector $W_{i,t}$.

This decision process implies the policy's unresponsiveness to regional idiosyncratic shocks within a year, especially when the focus is on small geographical units, as it is the case of the Italian regions (there is also extensive literature that resorts to this assumption in the context of the nationally financed government expenditure, see Blanchard and Perotti 2002, and many others and also Deleidi et al. 2021b and Destefanis et al. 2022 for analyses conducted on the Italian regions). Related to this, through the inclusion of time fixed effects, we can capture the effects of business cycle at the national level, and therefore, we can expect that this guarantee the exogeneity with respect to the local economic conditions, since the sources to finance the projects are decided via negotiations between the EU and the national authorities, and the regions are too small to influence the national programs (Canova and Pappa 2021).

To implement this identification assumption, we compute the Cholesky factor of the covariance matrix of the reduced-form residuals Σ, with the EAFRD expenditure ordered first in the vector of endogenous variables. This is done for each draw of the Gibbs sampling in order to obtain posterior distributions for the Impulse Response Functions and make inference on these objects of interest. This is a partial identification strategy, as our focus is exclusively on identifying the EAFRD shock. Using a Cholesky decomposition with EAFRD expenditure ordered first, the position of this variable in the vector of endogenous variables is crucial, and changing the ordering of other variables does not affect the results (Christiano et al. 1999; Beetsma and Giuliodori 2011). Nevertheless, from an economic perspective, the ordering of these variables in the baseline model warrants some consideration. First, total output results from the sum of outputs from all sectors, but placing agricultural output after GDP implies a 1-year lagged effect of agricultural output on GDP. Second, investment is a significant component of agricultural production and total output, influencing their volumes. However, ordering investment after GVA and agricultural GDP means that it affects them with a 1-year lag. To ensure these ordering choices do not affect our baseline results, in Appendix 3 we conduct robustness tests in which we change the ordering of these variables in the baseline VAR. In line with Christiano et al. (1999) and Beetsma and Giuliodori (2011), the ordering of GDP and agricultural sector variables does not affect the results (see Fig. 13 in Appendix 3).

4 Results and Discussion

4.1 Effects of EAFRD Spending on the Economy and Agricultural Sector in the Italian Regions

Table 2 and Fig. 5 show the dynamic effects of an increase in EAFRD expenditure. Specifically, in Table 2 we report the point number of the posterior median of the percentage elasticity of variables in response to a one standard deviation shock in EAFRD expenditure, at the time of the shock and up to 5 years after the shock. Figure 5

Table 2 Short-to-medium term dynamic effects of a one standard deviation positive shock to EAFRD expenditure

	Impact	1 year	2 years	3 years	4 years	5 years
GDP	0.06*	0.20**	0.28**	0.31**	0.32**	0.31**
GVA agriculture	0.53**	0.33*	0.19	0.11	0.06	0.03
Investment Agriculture	3.32**	3.27**	2.91**	2.44**	1.96**	1.52**
Employment Agriculture	− 0.27*	− 0.47**	− 0.54**	− 0.54**	− 0.49**	− 0.44**

The table shows the median of the posterior distributions of IRFs (% elasticity) to a one standard deviation shock to EAFRD expenditure

** and * indicate the case in which, respectively, the 90% and 68% posterior credibility intervals do not contain zero
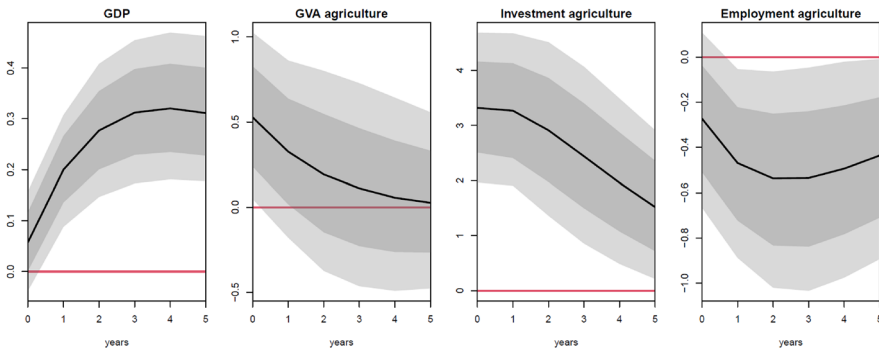

Fig. 5 IRFs of the variables of interest to a one standard deviation positive shock to EAFRD expenditure. Note: The solid black line is the posterior median; the darker and lighter grey areas are the 68% and 90% credibility intervals; the horizontal red line indicates zero (color figure online)

plots this elasticity together with the 68% and 90% credibility intervals represented by shaded areas.[11]

EAFRD investments display positive short-run effects on the output of the agricultural sector, which increase by about 0.5% at the year of the shock, and then the response start reducing, being equal to 0.3% after 1 year. The response of private investment in the agricultural sector is positive and strong, with an increase of about 3.3%, on impact. In the following horizons, the response starts to decrease, reaching 1.5% after 5 years. Therefore, our results point to a complementary effect of EAFRD spending on private investment in the sector, rather than a crowding out. This is reasonable in the context of the European Structural Funds, as they do not usually cover the entire project amount, but there is some degree of co-financing. However, the last row of Table 2 shows that EAFRD spending causes job losses. Employment in the sector decreases by 0.3% at the time of the impact, peaks at − 0.54% after 2

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[11] We follow the empirical literature on Bayesian VAR, reporting significant IRFs at 68% and 90%. All tables indicate with ** and *, respectively, the IRFs whose 90% and 68% credibility intervals do not contain zero.

and 3 years and reaches a – 0.44% response after 5 years. This result is in line with the theoretical and empirical literature, reviewed in Sect. 2.3, that find displacement effects from investments in innovation. The fact that this fund invests in the development and innovation of the agricultural sector, may reduce employment due to the replacement of labour with new technology and machinery. Therefore, despite the positive effects on the activity of the agricultural sector, labour substitution effects prevail. Finally, as a result of the positive effect on the agricultural sector's output and investment, the Italian regions' total economic activity increases, since GDP shows a positive dynamic response. On impact the effect is small and equal to about 0.06%, but then, after the effects on the agricultural sector materialise, the total output response increases accordingly. In fact, it is noteworthy how total output and agricultural output behave. There is a strong immediate effect on agricultural output, whereas the GDP response is close to zero. After 1 year, the effect on agricultural GVA remains strong and higher than that of total output. Thereafter, as the effect on agricultural output begins to dissipate, the GDP response increases.

This result highlights the presence of potential sectoral spillovers that transfer the EAFRD stimulus in the agricultural sector to the rest of the economy.[12] Indeed, it can be hypothesised that the positive effects in the agricultural sector produced by EAFRD investments can also increase demand for the other sectors of the economy. This can also be rationalised by the strong positive investment response we have found. An increase in agricultural investments can lead to an increase in demand for goods and services produced by the other sectors.[13] Finally, the fact that the EAFRD is a relevant fund in Italy among the ESIFs, as we have documented in Sect. 2.2, may help to explain its important impact on aggregate GDP. Overall, therefore, our baseline results shed light on the potential beneficial effects of EAFRD spending in the short-to-medium term, not only in the agricultural sector but also potentially in the rest of the economy, despite a displacement effect on agricultural employment.

4.2 Size of the Agricultural Sector

As discussed in Sect. 2.2, the Italian regions differ for the sectoral composition, with some regions, especially the ones located in the South, and few others in the Centre and the North, having a higher share of agricultural output (see Fig. 1). This means that the relative size of the agricultural sector differs between Italian regions. Moreover, the distribution of GVA across Italian regions is crucial for understanding economic dynamics and territorial disparities (Crescenzi and Rodríguez-Pose 2011). Rural areas and regions more concentrated in the agricultural sector may be more vulnerable to shocks. For example, climate shocks are of great concern in recent times. The predominance of agriculture in less developed countries or regions may make these areas more vulnerable to climate change (Tubiello and Fischer 2007). Furthermore,

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[12] Recent empirical evidence has emphasised the role of economic networks and shown that sectoral spillovers are important within a country (Acemoglu et al. 2016; Das et al. 2022).

[13] Another potential reason why the persistency of the response of GDP and agricultural GVA may be related to the different integration properties of the two variables. However, from Table 5 in Appendix 1 it is not clear whether they have very different integration properties. Some of the panel unit root tests cannot reject the null of unit root in the two series.

Table 3 Short-to-medium term dynamic effects of EAFRD expenditure in regions with a higher versus lower than the median agricultural output share

	Impact	1 year	2 years	3 years	4 years	5 years
GDP						
Lower agricultural Output share	0.05	0.12**	0.16**	0.18**	0.17**	0.16**
Higher agricultural Output share	0.06	0.27**	0.39**	0.44**	0.46**	0.46**
GVA agriculture						
Lower agricultural Output share	0.43*	0.27	0.19	0.15	0.13	0.11
Higher agricultural Output share	0.56*	0.61*	0.60*	0.56*	0.50*	0.42*
Investment agriculture						
Lower agricultural Output share	2.63**	2.53**	2.32**	2.05**	1.78**	1.51**
Higher agricultural Output share	4.11**	4.34**	3.93**	3.22**	2.45**	1.75*
Employment agriculture						
Lower agricultural Output share	0.13	− 0.48*	− 0.67**	− 0.66**	− 0.57**	− 0.45**
Higher agricultural Output share	− 0.75**	− 0.82**	− 0.83**	− 0.80**	− 0.75**	− 0.70**

The table shows the median of the posterior distributions of IRFs (% elasticity) to a one standard deviation shock to EAFRD expenditure

** and * indicate the case in which, respectively, the 90% and 68% posterior credibility intervals do not contain zero

as discussed in Sect. 2.1, the EAFRD was designed for the agricultural sector, with the aim of promoting development, innovation and competitiveness in the sector. In Sect. 2.2 we also showed that regions with a higher share of agricultural production are those that receive a higher allocation of EAFRD expenditure per capita (see Fig. 2). Therefore, considering these points, it is useful to explore the effects of EAFRD investments in Italian regions where the agricultural sector is more predominant, and to see how the short- to medium-term effects of these investments, analysed in Sect. 4.1, change depending on the relative size of the agricultural sector in the Italian regional economies. Thus, we study the effects of the EAFRD in two different groups of regions, based on the share of agricultural production. We group the Italian regions into those with an average share (over the period 1995–2018) of agricultural GVA in total GVA above the Italian median share, and those with a share below the national median. The results are illustrated in Table 3 and Fig. 6.[14]

The effects of the EAFRD are larger in the Italian regions where the relative size of the agricultural sector is larger. The output of the agricultural sector reacts much

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[14] In Fig. 6, we only show the 68% credibility intervals to make the graph clearer, as all the bands would have overlapped and the IRF graph would have been confusing, making the results hard to understand. However, the reader can refer to Table 3 to see which results are significant even at the 90% level.
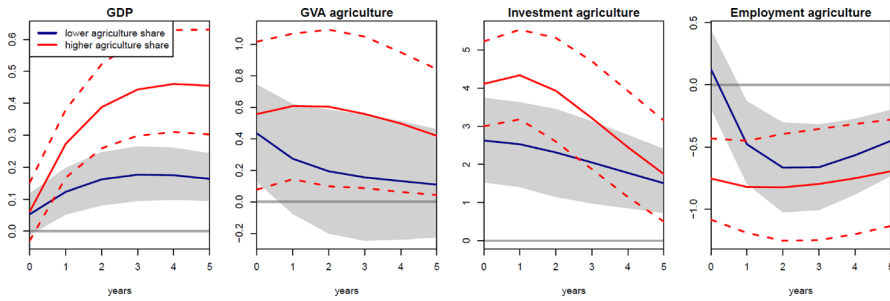
Fig. 6 IRFs of the variables of interest to a one standard deviation positive shock to EAFRD expenditure in the Italian regions with a higher versus lower agricultural output share. Note: The blue solid lines represent the posterior median for regions with a lower agricultural production share and the grey shaded areas the corresponding 68% credibility intervals. The red solid lines show the posterior median for regions with a higher agricultural production share and the red dashed lines the corresponding 68% credibility intervals (color figure online)

more in regions with a larger share of agricultural production. In particular, the effects are more persistent and significant over a much longer period. The response is slightly below 0.6% at the time of the shock, peaks at 0.61% after 1 year and remains positive and significant after 2, 3, 4 and 5 years, where the response is, respectively, 0.6%, 0.56%, 0.5% and 0.42%. In regions with a lower share of agricultural production, on the other hand, the response is lower (about 0.4% on impact) and quickly reduces, becoming not significantly different from zero. Stronger responses and higher reactions are also observed for private investment and employment in the agricultural sector in regions with a higher share of agricultural production. We find a 4% immediate increase in regions with a higher agricultural output share, which diminishes to approximately 1.8% after five years. In contrast, regions with a smaller agricultural sector experience an immediate increase of 2.6%, reducing to 1.5% after five years. Employment declines significantly on impact in regions with a larger agricultural production share, with an initial response of approximately −0.75%, peaking at −0.83% after 2 years, and settling at −0.7% after five years. In regions with a smaller agricultural output share, the initial employment response is not significant, but it declines thereafter, showing a response of −0.48% after 1 year, peaking at −0.67% after 2 years, and reaching −0.45% after five years. Consequently, GDP reacts much more to an increase in EAFRD expenditure in the group of regions with a higher share of agricultural output. In particular, the response of total output is small at the impact and then starts to increase in both groups of regions. However, the response is much higher in the group of regions with a higher share of agricultural production. It is also interesting to compare the response of agricultural and total output, as we did in Sect. 4.1. Compared to the results for the entire sample reported in Sect. 4.1, the response of agricultural production to the EAFRD expenditure shock in regions with a higher agricultural output share is markedly stronger than the response of total production. Additionally, this response is more persistent than the agricultural production response observed for the whole sample. Notably, the medium-term effects on agricultural production in these regions exceed those of total production, with significant impacts lasting up to four years following the increase in EAFRD expenditure.

4.3 Fischler Reform

As we discuss in Sect. 2.1, the Fischler reform in 2003 represents the most substantial reform of European agricultural policy. In fact, it introduced important changes to European agricultural policy, to improve the agricultural competitiveness and strengthen their modernisation and rural development process. The aim was to increase the funds for financing and strengthening rural development policy. For this reason, part of the resources from the first pillar of the CAP were transferred to the second pillar, which is dedicated to rural development. This was important, as more funds were channelled to measures with the aim of improving the development of the agricultural sector and the economic diversification of rural areas (Esposti 2007; Piattoni and Polverari 2016). Furthermore, the Fischler reform introduced a way to make the distribution of funds between regions better and fairer, thus improving the competitiveness of the agricultural sector (Crescenzi et al. 2015). In light of the increase in CAP Pillar II expenditure and the important changes introduced by the reform, it is interesting to explore how the effects of the EAFRD, which we studied in Sect. 4.1, change after the Fischler reform. Hence, we provide an ex-post empirical assessment, which, to the best of our knowledge, is lacking in the literature, but also a comprehensive view of the short- to medium-term effects of the agricultural policy instruments adopted by the EU before and after the reforms. Specifically, we investigate the short-to medium-term effects of EAFRD expenditure in the period before and after the Fischler reform, in order to try to understand how this reform changed the effectiveness of EAFRD programmes. For this purpose, we estimate the model from 1995 to 2002 (before the reform) and from 2003 to 2018 (after the reform).

The results are in Table 4 and Fig. 7.[15] A broad look at the results clearly reveals that EAFRD expenditure has become more effective after the reform. The response of agricultural sector output is positive and stronger after the reform, where GVA increases by 0.6% on impact, and by about 0.4% and 0.3% 1 and 2 years after the shock. In contrast, there is a negative response in the pre-reform period, but it is short-lived. This implies that the reform improved the effectiveness of the policy and reduced its inefficiency. Despite a stronger response on impact, investment reacts more strongly and with greater persistence after the reform, peaking at 3% after 1 year, whereas the pre-reform response goes to zero immediately after 1 year, and the only significant effect occur on impact. Another interesting result concerns the effects on employment, which shows that the negative effects found in the baseline analysis are actually attenuated after the reform, where the response is small and the credibility intervals include zero for all horizons, while a negative and significant effect is still present in the pre-reform period. The response of the agricultural sector before and after the reform is reflected in the response of total economic activity in these two periods, where the highest and most positive effects of the EAFRD shocks are reflected in a significant increase in GDP after the reform, whereas, in contrast, there was no response before the reform.

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[15] As we did in Fig. 6 of the previous section, in Fig. 7 we only show the 68% credibility intervals to make the graph clearer, as all the bands would have overlapped and the IRF graph would have been confusing, making the results hard to understand. However, the reader can refer to Table 4 to see which results are significant even at the 90% level.

Table 4 Short-to-medium term dynamic effects of a one standard deviation positive shock to EAFRD expenditure before and after the Fischler reform

	Impact	1 year	2 years	3 years	4 years	5 years
GDP						
Before reform	− 0.07	− 0.05	− 0.02	0.00	0.00	0.00
After reform	0.03	0.14**	0.21**	0.24**	0.25**	0.25**
GVA agriculture						
Before reform	− 0.33	− 0.84**	− 0.35*	− 0.09	− 0.01	0.01
After reform	0.63**	0.37*	0.28*	0.24	0.22	0.19
Investment agriculture						
Before reform	4.60**	0.37	− 0.42	− 0.40	− 0.27	− 0.17
After reform	1.76**	2.94**	2.91**	2.48**	1.96**	1.49**
Employment agriculture						
Before reform	− 0.63**	− 0.39	− 0.13	− 0.03	0.00	0.00
After reform	− 0.20	− 0.22	− 0.20	− 0.16	− 0.11	− 0.07

The table shows the median of the posterior distributions of IRFs (% elasticity) to a one standard deviation shock to EAFRD expenditure

** and * indicate the case in which, respectively, the 90% and 68% posterior credibility intervals do not contain zero
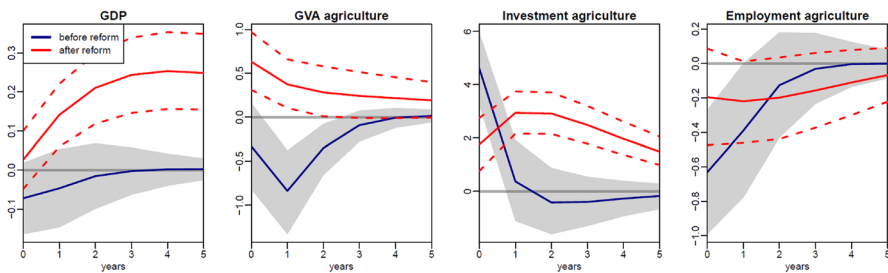
Fig. 7 IRFs of the variables of interest to a one standard deviation positive shock to EAFRD expenditure in the period before and after the Fischler reform. Note: The blue solid lines represent the posterior median for the period before the Fischler reform and the grey shaded areas the corresponding 68% credibility intervals. The red solid lines show the posterior median for the period after the Fischler reform and the red dashed lines the corresponding 68% credibility intervals (color figure online)

Moreover, looking at the response of total output and output of the agricultural sector, it can be seen that, compared to the full sample, the post-reform sample shows a more persistent response of agricultural output, which in the short run is much higher than that of total output and in the medium run is comparable in size to the latter. Once again, these results shed light on sectoral spillovers, as we pointed out in Sect. 4.1, an aspect that needs to be explored in future research. In summary, our results show an improvement in the short- to medium-term effectiveness of EAFRD policy after the Fischler reform.

5 Conclusions

In this study, we evaluate the short-to-medium-term impact of the European Agricultural Fund for Rural Development (EAFRD) on real economic activity and key macroeconomic variables within the Italian agricultural sector. Employing a panel Bayesian Structural Vector Autoregression (SVAR) analysis with a dataset spanning 21 Italian NUTS-2 regions from 1995 to 2018, this study pioneers the application of this methodology to EAFRD expenditure using regional data, contributing to the empirical literature on the short-to-medium-term dynamic effects of EU investments.

We identify the EAFRD shock by assuming its independence from other shocks within a year, given inherent lags in policy implementation and fund distribution processes. Our findings reveal that increased EAFRD expenditure stimulates regional economies and their agricultural sectors. Notably, EAFRD investments enhance agricultural output with strong short-run effects. Importantly, private investments in the agricultural sector are not crowded-out by EAFRD investments; instead, they increase significantly. These positive effects are transmitted to the rest of the economy, with GDP showing a small (close to zero) response on impact to EAFRD spending increases, but then, after the effects on agricultural output and investments materialize, the effects on total output become more important. However, while EAFRD expenditure enhances output and investment, it negatively impacts employment in the agricultural sector due to substitution effects from investments in information and communication technology (ICT) and research and development (R&D).

Furthermore, we investigate whether the effects of EAFRD differ based on the relative size of the agricultural sector within the total economy. Given the documented heterogeneity in the sectoral composition of Italian regional economies and the focus of EAFRD investments on agriculture, we examine the short-to-medium-term effects in regions with higher versus lower agricultural output shares. Results indicate that the agricultural sector's role is pivotal for EAFRD effectiveness, with stronger effects observed in regions where agriculture plays a more significant role. In these regions, increases in agricultural output, investment, and total output are higher, while displacement effects on agricultural labour are more pronounced. Moreover, given the occurrence of the relevant reform in the CAP policy during the period explored in our analysis, known as "Fischler reform", we investigate the effectiveness of the EAFRD before and after this reform. Our results indicate heightened effectiveness post-reform, with more pronounced positive effects on agricultural output and more persistent investment responses in the medium run, despite a lower immediate response post-reform. Significantly, displacement effects on labour in the agricultural sector disappear after the reform. Consequently, total output increases significantly post-reform, while showing no significant response pre-reform.

Our results indicate that the EAFRD can have important positive effects in the short-to-medium-term on the economy and the agricultural sector. However, policymakers should pay more attention to the substitution effects that these investments in innovation may have on agricultural employment, to understand whether these job losses can be absorbed by other sectors or mitigated in some way. Maximizing returns from EU Regional Policy requires concentrating funding from various policies in targeted areas. The reinforcement of the local socioeconomic environment is crucial for the

success of regional policies, particularly in the most deprived areas (Crescenzi and Giua 2016). This is especially relevant for rural development interventions, where the growth potential depends heavily on the pre-existing conditions of the target areas. The future development of regions, including critical macroeconomic indicators such as employment and income, largely depends on the availability of rural development funds, especially during economic crises. It is imperative to develop integrated policies that encompass rural development, agriculture, manufacturing, and the environment (Loizou et al. 2019).

Looking ahead to the CAP post-2020, continuing the shift from coupled payments to decoupled payments in Pillar I and to rural development in Pillar II appears to be the appropriate direction. Policymakers should allocate a greater proportion of EAFRD funds to regions where agriculture is a significant part of the local economy, maximizing the economic impact of these investments. Moreover, it is essential to balance the drive for innovation with measures that support employment, including retraining programs for displaced agricultural workers and the promotion of labour-intensive agricultural practices where applicable (EC 2023).

Given that EAFRD investments can lead to job losses in the agricultural sector due to automation and technological advancements, policies should facilitate the transition of displaced workers to other sectors. This can be achieved through vocational training, education programs, and incentives for businesses in other sectors to hire these workers (EC 2023). Encouraging diversification within rural economies is also crucial. Investments in rural infrastructure and other non-agricultural sectors can create alternative employment opportunities, thereby absorbing labour displaced from agriculture.

The findings of this study indicate that the effectiveness of EAFRD investments has increased post-Fischler reform, underscoring the need for continuous monitoring and adaptation of policy measures based on empirical evidence to enhance their effectiveness. Considering the observed heterogeneity in the effects of EAFRD across different regions, future policies should be tailored to the specific needs and characteristics of each region to ensure optimal outcomes.

However, it is also fair to acknowledge the limitations of our analysis, which deserve to be addressed in future research Firstly, we provide an average effect without exploring a higher degree of regional heterogeneity beyond subgroups of regions. The small sample size and the short time series length limited this extension, which we aim to address in future research. Secondly, although not the focus of this work, potential spillover effects were not considered. This issue will need to be addressed in future studies.

Appendix 1: Panel Unit Root and Cointegration Tests

See Tables 5, 6.

Table 5 Panel unit root tests (p-values)

	Intercepts			Trend		
	IPS (2003)	MW(1999)	H(2000)	IPS (2003)	MW(1999)	H(2000)
EAFRD	6.366e–05	0.0001253	< 2.2e–16	0.04028	0.06067	< 2.2e–16
GDP	0.001032	0.002696	< 2.2e–16	0.05522	0.1859	< 2.2e–16
GVA agr	0.2936	0.3446	< 2.2e–16	0.3525	0.02008	< 2.2e–16
INV agr	0.003818	0.003935	< 2.2e–16	4.875e–06	4.128e–08	< 2.2e–16
EMP agr	3.261e–05	6.151e–05	< 2.2e–16	0.557	0.2417	< 2.2e–16

IPS (Im-Pesaran-Shin) is the Im et al. (2003) test; MW is the Maddala and Wu (1999) test; H is the Hadri (2000) test. The null hypothesis in the first two tests is unit root against the alternative of stationarity. Instead, the Hadri (2000) test has under the alternative hypothesis that at least one series in the panel has a unit root The first block, labelled intercepts presents the p-values of the tests from models including individual intercepts only. The second block, labelled trend contains the p-value of the tests from models including individual intercepts and a time trend

Table 6 Standardized Pedroni (1999) panel cointegrating tests

	EAFRD		GDP		GVA agr		INV agr		EMP agr	
	Intercepts	Trend	Intercepts	Trend	Intercepts	Trend	Intercepts	Trend	Intercepts	Trend
Panel v-Statistic	– 6.35	– 8.09	– 7.41	– 9.23	– 7.39	– 9.21	– 7.33	– 9.13	– 7.4	– 9.22
Panel ρ-Statistic	6.83	8.45	7.6	8.68	8.39	10.41	8.22	9.74	7.27	8.71
Panel t-Statistic (non-parametric)	9.69	11.9	11.61	12.75	14.45	18.75	13.75	16.36	10.88	13.28
Panel t-Statistic (parametric)	– 65.2	– 72.14	– 25,401	– 33,822	– 1799	– 1339	– 749	– 1023	– 6234	– 7904
Group ρ-Statistic	8.61	9.93	9.19	10.25	10.42	11.96	10.69	11.63	9.23	10.22
Group t-Statistic (non-parametric)	10.9	13.34	11.86	13.9	16.52	20.16	17.56	19.48	12.15	13.81
Group t-Statistic (parametric)	10.41	12.53	11.13	13.08	16.32	20.43	15.32	16.73	11.33	12.99

The null hypothesis is no cointegration. These statistics are asymptotically normal (see Pedroni 1999)

Appendix 2: Bayesian estimation

First, let us rewrite the VAR(1) in Eq. (1) of the paper in a more compact way, which is more suitable for the representation and discussion of the Bayesian estimation:

$$Y = XB + U \tag{4}$$

This representation of the model is obtained by stacking all the time observations of every regions, where Y is the $NT \times n$ matrix of endogenous variables, X is the $NT \times (np+m)$ matrix of regressors, which combines both the lags of the endogenous variables in $Y_{i,t-1}$ and the vector of exogenous variables $W_{i,t-1}$, with an associated $(np+m) \times n$ matrix of coefficients B, and finally U is the $NT \times n$ matrix of reduced-form residuals. In this representation, N is the number of regions, T is the number of years, n is the number of endogenous variables, p is the number of lags (1 in our case), and m is the number of exogenous variables. As stated in Sect. 3 of the paper, in the baseline model we include in $W_{i,t-1}$ regional dummies to control for regional fixed effects, time dummies to control for time fixed effects, and a linear and quadratic time trend to accommodate the inclusion of log-level macroeconomic variables (we perform some robustness tests in Appendix 3, where we change the variables in the vector $W_{i,t-1}$). To estimate this model we implement a Normal-Inverse Whishart prior imposed by using dummy observations (or artificial data) as proposed by Bańbura et al. (2010).

The prior distributions are defined as follows:

$$p(B|\Sigma) \sim N\left(b_0, \Sigma \otimes \left(X_D{}'X_D\right)^{-1}\right)$$
$$p(\Sigma) \sim IW(S, T_D - n + m) \tag{5}$$

with the following moments:

$$B_0 = \left(X_D'X_D\right)^{-1}X_D'Y_D$$
$$b_0 = vec(B_0)$$
$$S = (Y_D - X_D B_0)'(Y_D - X_D B_0) \tag{6}$$

From these equations we can see that the VAR coefficients are assumed to follow a Normal distribution, whereas the covariance matrix of the reduced-form residuals is assumed to follow an Inverse-Wishart distribution.

Bańbura et al. (2010) propose to construct artificial data, given by Y_D and X_D, which are appended to the matrices containing the actual data in Eq. (4), in a way that the econometrician can impose his/her prior information (Blake and Mumtaz 2012). Furthermore, in Eq. (5) S is the scale matrix of the Inverse-Whishart distribution, and T_D is the number of artificial observations. These artificial observations are constructed

in such a way that we can obtain a prior close to the Minnesota prior (Litterman 1986):

$$Y_D = \begin{pmatrix} diag(\delta_1\sigma_1, \cdots, \delta_n\sigma_n)/\lambda \\ 0_{n(p-1)\times n} \\ \cdots \\ diag(\sigma_1, \cdots, \sigma_n) \\ \cdots \\ 0_{m\times n} \end{pmatrix} \quad X_D = \begin{pmatrix} J_p diag(\sigma_1, \cdots, \sigma_n)/\lambda & 0_{np\times m} \\ \cdots & \cdots \\ 0_{n\times np} & 0_{n\times m} \\ \cdots & \cdots \\ 0_{m\times np} & diag(\epsilon)_{m\times m} \end{pmatrix}$$

(7)

where δ_i are the prior means on the coefficients of the first lag of the i-th endogenous variable, which are set equal to 1 as in the Minnesota prior, since we work on log-level variables and therefore this is done to incorporate the prior information that macroeconomic variables in levels behave as random walk processes with unit root. σ_i are variances of the endogenous variables estimated by fitting AR(1) models on each endogenous variables and taking the variance of the residuals, λ is a parameter that governs the overall tightness of the prior and it is set equal to 10, ϵ controls the tightness of the prior on the coefficients of the exogenous variables and it is set to a small number (1/1000). In setting these parameters we follow Mumtaz and Theodoridis (2020). Both of these parameters are set in such a way that we have an uninformative prior. In the matrices in (7), the first block is used to impose priors on the VAR slope coefficients, the second block on the reduced-form covariance matrix, whereas the last one on the coefficients of the m exogenous variables.

As stated above, these artificial data are appended to the actual data:

$$Y^* = \begin{bmatrix} Y \\ Y_D \end{bmatrix} \quad X^* = \begin{bmatrix} X \\ X_D \end{bmatrix}$$

(8)

Then, the conditional posterior distributions are defined as follows:

$$H(b|\Sigma, Y) \sim N(vec(B^*), \Sigma \otimes (X^{*\prime}X^*)^{-1})$$

$$H(\Sigma|b, Y) \sim IW(S^*, T^*)$$

(9)

where T^* is the total number of observations including the artificial data, and the other posterior moments are given by the following:

$$B^* = (X^{*\prime}X^*)^{-1}X^{*\prime}Y^*$$

$$S^* = (Y^* - X^*b)'(Y^* - X^*b)$$

(10)

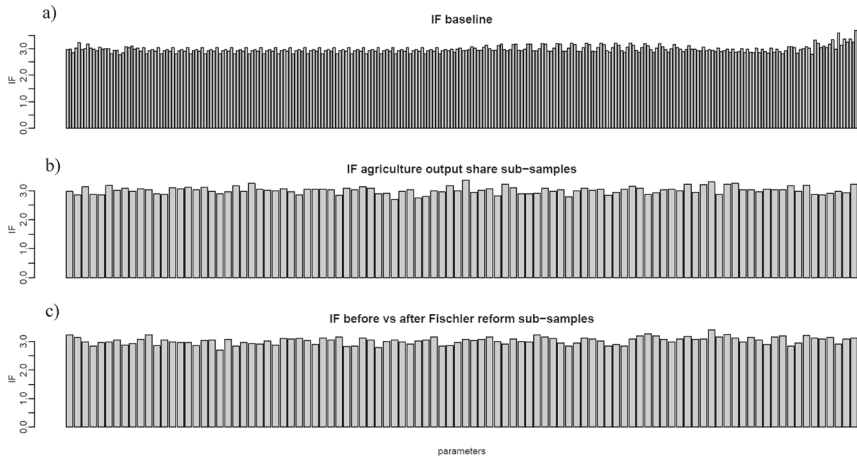A Gibbs sampler is used to draw from these posteriors. The algorithm is described as follows:

Fig. 8 Inefficiency factors. Note: Panel **a** shows the IFs of the baseline model in Sect 4.1. Panels **b** and **c** show the IFs of the model estimated on the subsamples in Sect 4.2 and 4.3, respectively

1. draw the vectorized matrix of VAR parameters from $H(b|\Sigma, Y)$ in (9). In this step, only stable draws are retained, taking the ones whose eigenvalues of the companion form matrix are less than or equal to one;
2. use the draw of b from the previous step to compute S^*, then draw the covariance matrix of the reduced-form residuals from $H(b, Y)$ in (9).

We perform 10,000 iterations, but we use the last 5000 draws to make inference. Since Gibbs sampling algorithms produce auto-correlated draws, we evaluate the chains obtained from the algorithm by computing the Inefficiency Factors of all the parameters, up to an order of auto-correlation equal to 20 (see Mumtaz and Theodoridis 2020; Primiceri 2005). The Inefficiency Factor is computed in the following way: $IF = 1 + 2\sum_{i=1}^{20}\widehat{\rho_i}$, where $\widehat{\rho_i}$ is the i-th order auto-correlation. The rule of thumb widely used in the empirical literature compares the inefficiency factors with a fixed threshold equal to 20. Figure 8 shows that for the baseline model and for the models estimated on sub-samples, in Sects. 4.2 and 4.3 of the paper, the inefficiency factors are around 3, a very small value, indicating low correlation in the retained chains.

Appendix 3: Robustness Checks

This appendix describes the robustness checks conducted to test the baseline results discussed in Sect. 4.1.

1. Changing the exogenous variables in $W_{i,t}$ in the baseline model

As we mentioned in Sect. 3.2, we include time and regional dummies in the baseline model to control for time and regional fixed effects, and we also include a linear and quadratic time trend. In this first robustness check, we test whether the results are affected by these choices. (i) The first exercise consists of removing the time and

regional dummies and using the within transformation of the data, another popular method in panel data analysis to control for time and regional fixed effects. Therefore, we apply the within transformation to the endogenous variables, which is given by: $y_{i,t}^{within} = y_{i,t} - \overline{y}_i - \overline{y}_t + \overline{y}$, that is, we remove the cross-sectional and time averages and add the total average. The dashed red lines in Fig. 9 show that the results remain unchanged. This strategy significantly reduces the number of parameters and makes the Gibbs sampling much faster, and it was used to estimate the model in the subsamples considered in Sect. 4.2 and 4.3. (ii) The second exercise is based on removing the linear and quadratic time trend. The results are represented by the blue dashed lines in Fig. 9. The exclusion of time trends does not affect the results.

(iii) The third exercise only removes the quadratic time trend. The dashed red lines in Fig. 9 show that this test also gives similar results.

2. Changing the value of the prior tightness parameters

    See Fig. 10.

As described in Appendix 2, we adopt a Bayesian approach to estimate the panel VAR. In that Appendix, we mention how the prior tightness parameters are set. To
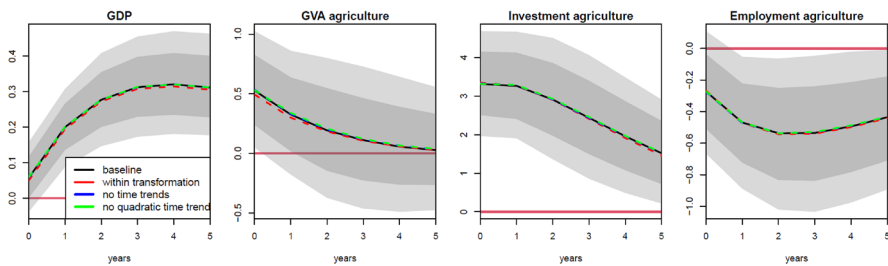
Fig. 9 Robustness checks-changing the set of exogenous regressors in the VAR. Note: This plot reports the baseline results in Fig. 5 and depicts, using dashed lines, the median IRFs of the robustness checks in which we change the set of exogenous regressors in the VAR: (i) the red dashed lines are obtained using the within transformation of the data in place of introducing time and regional dummies; (ii) the blue dashed lines are obtained by excluding both the linear and quadratic time trend; (iii) the green dashed lines are from the model which excludes the quadratic time trend only (color figure online)
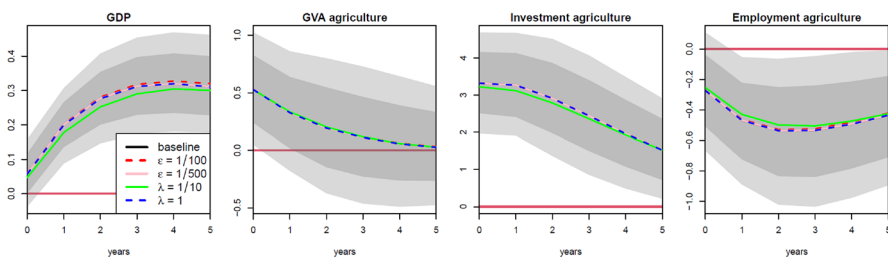

Fig. 10 Robustness checks-changing the value of the prior tightness parameters. Note: this plot reports the baseline results in Fig. 5 and depicts the median IRFs obtained from robustness checks in which we change the value of the prior tightness parameters, which are λ and ϵ, described in Appendix B. (i) Red dashed lines, $\epsilon = 1/100$; (ii) pink solid lines, $\epsilon = 1/500$; (iii) green solid lines, $\lambda = 1/10$; (iv) blue dashed lines, $\lambda = 1$ (color figure online)

check whether this choice affects the results, we try to assign different values to these parameters. In the baseline model $\lambda = 10$ and $\epsilon = 1/1000$. As justified in Appendix B, these values have been assigned in order to have an uninformative prior (Mumtaz and Theodoridis 2020). We estimate the model using different values: (i) $\epsilon = 1/100$; (ii) $\epsilon = 1/500$; (iii) $\lambda = 1/10$, (iv) $\lambda = 1$. Figure 10 shows that the results are unaffected by these changes and the IRFs are all within the 68% and 90% credibility intervals of the baseline model.

3. Excluding the region with the highest and lowest GDP per capita and the highest and lowest EAFRD expenditure per capita

The third robustness test we conduct is based on the removal of certain regions with certain characteristics. In Sect. 3.2 we specified that the model assumes homogeneous parameters across Italian regions. However, as shown in Sect. 2.2, these regions exhibit a certain degree of heterogeneity, which is somewhat controlled for by the inclusion of regional fixed effects. To test whether this is an important issue in our analysis, we perform three checks: (i) removing the region with the lowest GDP per capita (IRFs represented by red dashed lines in Fig. 11); (ii) removing the region with the highest GDP per capita (IRFs represented by pink solid lines in Fig. 11); (iii) removing the region with the lowest level of EAFRD expenditure per capita (IRFs represented by green solid lines in Fig. 11); (iv) removing the region with the highest level of EAFRD expenditure per capita (IRFs represented by blue dashed lines in Fig. 11). Figure 11 shows that the results are robust to these changes, and the IRFs are all within the 90% credibility intervals of the baseline model.

4. Changing the number of lags in the baseline VAR

As mentioned in Sect. 3.2, we include one lag of the endogenous variables since our panel dataset is observed at an annual frequency. This choice is also confirmed by the application of the BIC criterion. However, we further test whether increasing the number of lags can heavily influence the baseline results. Therefore, we estimate the VAR with two lags. The results in Fig. 12 show that this produces minimal changes,
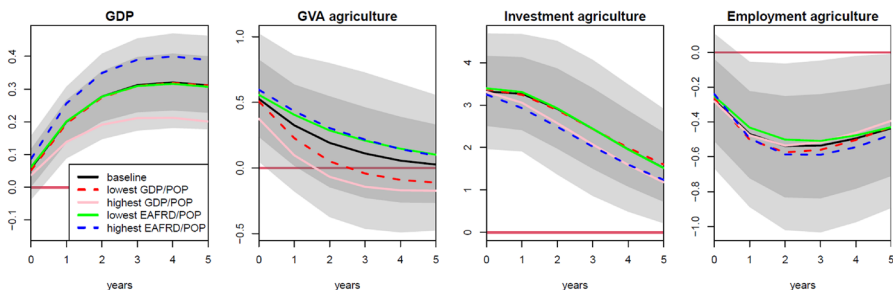

Fig. 11 Robustness checks-excluding regions with lowest and highest GDP per capita and lowest and highest EAFRD per capita expenditure. Note: This plot reports the baseline results in Fig. 5 and depicts the median IRFs obtained from the following robustness checks: (i) excluding the region with the lowest GDP per capita (red dashed lines); (ii) excluding the region with the highest GDP per capita (pink solid lines); (iii) excluding the region with the lowest level of EAFRD per capita expenditure (green solid lines); (iv) excluding the region with the highest level of EAFRD per capita expenditure (blue dashed lines) (color figure online)
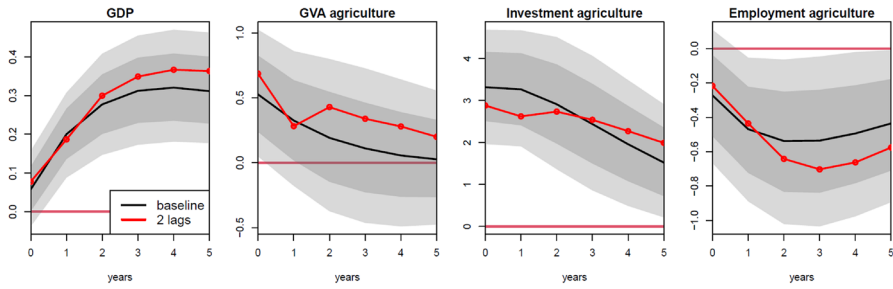
Fig. 12 Robustness checks-changing the number of lags in the VAR model. Note: This plot reports the baseline results in Fig. 5 and depicts the median IRFs obtained from estimating the VAR with two lags (red lines with dots) (color figure online)
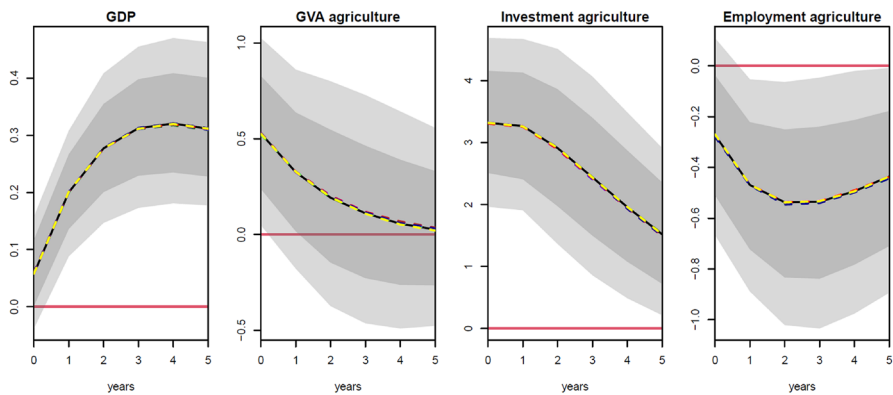

Fig. 13 Different variables ordering. Note: This plot reports the baseline results in Fig. 5 and includes the median IRFs, in dashed lines with different colours, obtained by 9 different combinations of variables ordering in the VAR (color figure online)

and the IRFs are contained within the 68% and 90% credibility intervals of the baseline model.

5. Changing the order of the endogenous variables

Finally, the last check is to change the order of GDP and agricultural sector variables in the VAR to see whether this affects the results (see discussion at the end of Sect. 3.2). We estimate the model with 9 different ordering of the variables. Figure 13 shows the baseline results and the IRFs obtained by changing the ordering of the variables, represented by dashed lines with different colours. These IRFs are quite identical to those obtained from the baseline model, indicating that our results are robust to these changes.

Data Availability All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Conflict of Interest The authors do not have any competing interests to declare.

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