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An integrated assessment of the impact of agrobiodiversity on the economy of the Euro-Mediterranean region

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ABSTRACT

In the past decades, agricultural landscapes have simplified with crop specialization and the reduction of seminatural covers leading to a decline of biodiversity and (biodiversity-driven) ecosystem services. This study measures the impact of landscape agrobiodiversity on the economy of southern Europe. The analysis relies on regression analyses to measure the effect of agrobiodiversity on the value added of farms. A regionalized Computable General Equilibrium model is then used to examine how these results affect the economy at large. The results show that increasing local richness and regional evenness tends to have positive impacts on the agricultural sector and GDP whereas increasing local evenness and regional richness tends to be harmful to the agricultural sector and GDP. The results also suggest that some regions of southern Europe are better off with more agrobiodiversity whereas other regions are better off with less. A targeted program may be better than a uniform policy across all of southern Europe.

1. Introduction

The focus of most ecological studies has been on biodiversity at the local plot level. Ecosystem services such as pollination, biological control of pests, erosion control, and water regulation occur at this local scale (Larsen and Noack, 2021). However, biodiversity at a more regional scale may also be important (Loreau et al., 2003; Isbell et al., 2011). Heterogeneous crop mosaics may benefit agrobiodiversity (Sirami et al., 2019) and enhance ecosystem services such as pollination and pest control (Larsen and Noack 2021) at both a local and regional scale. There is evidence that heterogeneous landscapes (regions) have a positive and significant effect on crop yield and productivity (Duflot et al., 2022; Burchfield et al., 2019; Nelson and Burchfield, 2021). In addition, heterogeneous agricultural landscapes provide a broader portfolio of agricultural outputs to protect against environmental and economic risks (Loreau et al., 2003; Isbell et al., 2017). Landscape biodiversity may help farms deal with stress and disturbance and maintain resilience (Swift et al., 2004). In contrast, regional specialization may give farmers economies to scale making it easier to gather inputs and outputs for a single crop. Whether a region is better off by specializing or developing a wide portfolio of cover types may also depend on the physical homogeneity versus heterogeneity within the region.

This study is perhaps the first empirical attempt that examines both local and regional crop agrobiodiversity at the micro and macroeconomic level. For both scales, we investigate three distinct measures of agrobiodiversity: richness, evenness, and the Shannon index. Richness is the *number* of different agricultural land cover types (this study considers 11 land cover types) within a given area. This is the most popular biodiversity concept. Evenness measures the *distribution* of agricultural land cover types in a given area. Intuitively, an even distribution has similar fractions of land in each cover type. An uneven distribution tends to favor one or possibly two land-cover types over all the others. The Shannon index combines evenness and richness into a single agrobiodiversity measure. Local scale agrobiodiversity captures ecosystem services that serve as positive or negative externalities across farms. Regional scale agrobiodiversity captures portfolio effects. For example,

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a low regional score captures the advantages of specialization whereas a high score captures the advantage of diversifying a portfolio. Note that we do not include the percent of a specific farmland use in the analysis, because such percentages are highly likely to be endogenous. By examining agrobiodiversity measures at both the local and regional scale, we can test how agrobiodiversity plays out and interacts at different scales. The agrobiodiversity measures themselves are not expected to be endogenous. Agronomic and agricultural economic models do not include agrobiodiversity as a factor explaining farm productivity. By examining where agrobiodiversity is beneficial versus harmful, we can also get a better sense of why it varies from place to place.

We begin with an econometric analysis that uses Net Value Added (NVA) to measure agricultural productivity. We regress farm NVA on the agrobiodiversity measures in order to understand how agrobiodiversity at the local and regional scale affects farm productivity. We control for climate, soil, and farm characteristics in order to reduce the probability of missing variables biasing the results and any endogeneity issue. The econometric analysis assesses whether or not local and regional landscape agrobiodiversity affects the NVA of individual farms in 5 Mediterranean countries.

The study then integrates these agrobiodiversity results into a multiregional Computable General Equilibrium (CGE) model for Mediterranean Europe (Bosello and Standardi., 2018). The CGE model captures the sub-national detail of the five countries and explores the higher order economic implications of agrobiodiversity for agriculture and the other sectors of the regional economies. This enables the analysis to quantify the effects on other sectors of the economy and the final net effect of agrobiodiversity on the GDP of each of the five countries.

The paper analyses two sets of agrobiodiversity policies. The first set uniformly increases several agrobiodiversity measures by a small amount and asks what effect each increase might have on agriculture value added, other sectors, and GDP. The second analysis uses a more targeted approach and only increases agrobiodiversity in the regions where it increases NVA. We again evaluate how each change in agrobiodiversity affects agricultural value added, other sectors, and GDP.

The next section describes the data and features of the econometric framework and the third section sets out the CGE model. The fourth section discusses the results. The fifth section concludes with a discussion of the policy implications of the results and the limitations of the analysis.

2. Data and econometric model

The analysis covers five countries in Mediterranean Europe: France, Greece, Italy, Portugal, and Spain. Fig. 1 details their sub-national characterization which includes 67 regions mostly defined at the NUTS2[1] level. We use NUTS1 level in Greece because of its relatively small size.

The econometric analysis assesses the impact of landscape agrobiodiversity on NVA of individual farms. Data of individual farms have been collected by FADN (Farm Accountancy Data Network) and refer to 27,472 farms in 2015.

We measure agrobiodiversity in terms of the heterogeneity of agricultural land cover types in the landscape. The cover types were defined by the Corine land cover inventory 2018 (European Union, 2018) which measures the proportion of land in each of 11 classes: Rainfed annual crops, Irrigated annual crops, Rice fields, Vineyards, Fruit trees and berry plantations, Olive groves, Pasture, Permanent crops, Complex cultivation patterns, Farmland with significant areas of natural vegetation, and Agro-forestry. With the exception of rice and olives, these land cover types do not identify individual crops. Most important, we do not use the individual land cover types directly in this study because they are likely to be endogenous with NVA. For example, vineyards and irrigated field crops are likely to be more productive than pasture and agroforestry.

We measure richness, evenness, and the Shannon index to capture agrobiodiversity. Richness is the biodiversity measure most commonly examined in economic studies. Richness, n, is the number of different farmland cover classes observed and can vary from 1 to 11.

Evenness is a measure of the distribution of land across the farmland cover types. Evenness depends on the proportion, p_i, of each landcover type i. The evenness index is defined as:

$$Evenness \equiv -\sum_{i=1}^{n} p_i ln p_i \Big/ ln(n) \tag{1}$$

Evenness is a measure between 0 and 1. For a given richness (n), higher values of evenness indicate that the area is more equally distributed amongst all the land cover classes. An evenness equal to 1 occurs when all classes have the same area. The evenness measure is similar in spirit to the Gini index commonly used in economics to measure the inequality of income.

The Shannon index is a combination of richness and evenness. It is defined as:

$$Shannon \equiv -\sum_{i=1}^{n} p_i ln p_i \tag{2}$$

In our sample, the values of the Shannon range between 0 and 2.

The agrobiodiversity values are measured at the local scale,[2] and at the NUTS3 scale. The local index measures the agrobiodiversity of neighboring farms in a 5 km circle around each farm. This local measure captures possible externalities (beneficial or harmful) amongst nearby farms. The NUTS3 measure investigates portfolio effects across farms. Low NUTS3 agrobiodiversity implies the area is highly specialized in one agricultural land cover type whereas a high NUTS3 agrobiodiversity implies the area is highly diversified across agricultural land cover types. Fig. 2 maps the average local and NUTS3 agrobiodiversity indicators across the European Mediterranean region. Both local and NUTS3 agrobiodiversity indicators are low in the plains of northern France, northern Spain, and northern Italy. They tend to be high in mountainous regions and especially along the Mediterranean coast. Regions in the Iberian Peninsula have the highest richness whilst France has the lowest richness in southern Europe.

Local and NUTS3 agrobiodiversity is correlated but not identical. The correlation of the local and NUTS3 measure of richness is 0.43, evenness is 0.35, and the Shannon index is 0.51.

Besides agrobiodiversity we have included numerous controls, $\boldsymbol{Z_i}$, such as climate, soils, geography, and economic characteristics to minimize the chance that missing variables are biasing the results. Farm-level independent variables include altitude, farm size, and crop subsidies per hectare. Local variables include the percentage of urban land, roads and railroads, ports, and airports. Climate, soil characteristics and population density are also included for each NUTS3 region. Climate variables are seasonal temperature normals and seasonal precipitation normals from ERA5 dataset (Hersbach et al., 2019). Soil data come from topsoil physical properties for Europe (Ballabio et al., 2016) and include percentage of coarse soil, clay soil, and bulk soil. The description and the basic statistics of the data set are reported in Table A-1 and Table A-2 of Annex.

The regression model estimating the impact of agrobiodiversity on

[1] NUTS (Nomenclature of Territorial Units for Statistics) is a geographical nomenclature subdividing the economic territory of the European Union into regions. There are four nested levels, NUTS0 is the national level, NUTS1 is the most aggregate sub-national level, NUTS2 is an intermediate sub-national level corresponding to Italian regions, NUTS3 is the most detailed and corresponds to a Department in France and a United States county.

[2] The data at local scale of the proportions of land in each class of the Corine inventory were created specifically for this study by FADN.

Fig. 1. Map of the study area.

France (NUTS2): 1. Île de France, 2. Champagne-Ardenne, 3. Picardie, 4. Haute-Normandie, 5. Centre, 6. Basse-Normandie, 7. Bourgogne, 8. Nord -Pas-de-Calais, 9. Lorraine, 10. Alsace, 11. Franche-Comté, 12. Pays de la Loire, 13. Bretagne, 14. Poitou-Charentes, 15. Aquitaine, 16. Midi-Pyrénées, 17. Limousin, 18. Rhône-Alpes, 19. Auvergne, 20. Languedoc-Roussillon, 21. Provence-Alpes-Côte d'Azur, 22. Corse.

Greece (NUTS1): 23. Voreia, Ellada, 24. Kentriki Ellada, 25. Attica, 26. Nisia-Aigaiou-Kriti.

Italy (NUTS2): 27. Piemonte, 28. Valle d'Aosta, 29. Lombardia, 30. Trentino-AltoAdige, 31. Veneto, 32. Friuli-VeneziaGiulia, 33. Liguria, 34. Emilia-Romagna, 35. Toscana, 36. Umbria, 37. Marche, 38. Lazio, 39. Abruzzo, 40. Molise, 41. Campania, 42. Puglia, 43. Basilicata, 44.Calabria, 45. Sicilia, 46. Sardegna.

Portugal (NUTS2): 47. Norte, 48. Algarve, 49. Centro, 50. Lisboa, 51. Alentejo.

Spain (NUTS2): 52. Galicia, 53. Principado de Asturias, 54. Cantabria, 55. País Vasco, 56. Navarra, 57. La Rioja, 58. Aragón, 59. Comunidad. de Madrid, 60. Castilla y León, 61. Castilla-La Mancha, 62. Extremadura 63. Cataluña, 64. Comunidad Valenciana, 65. Illes Balears 66.Andalucía, 67. Región de Murcia.

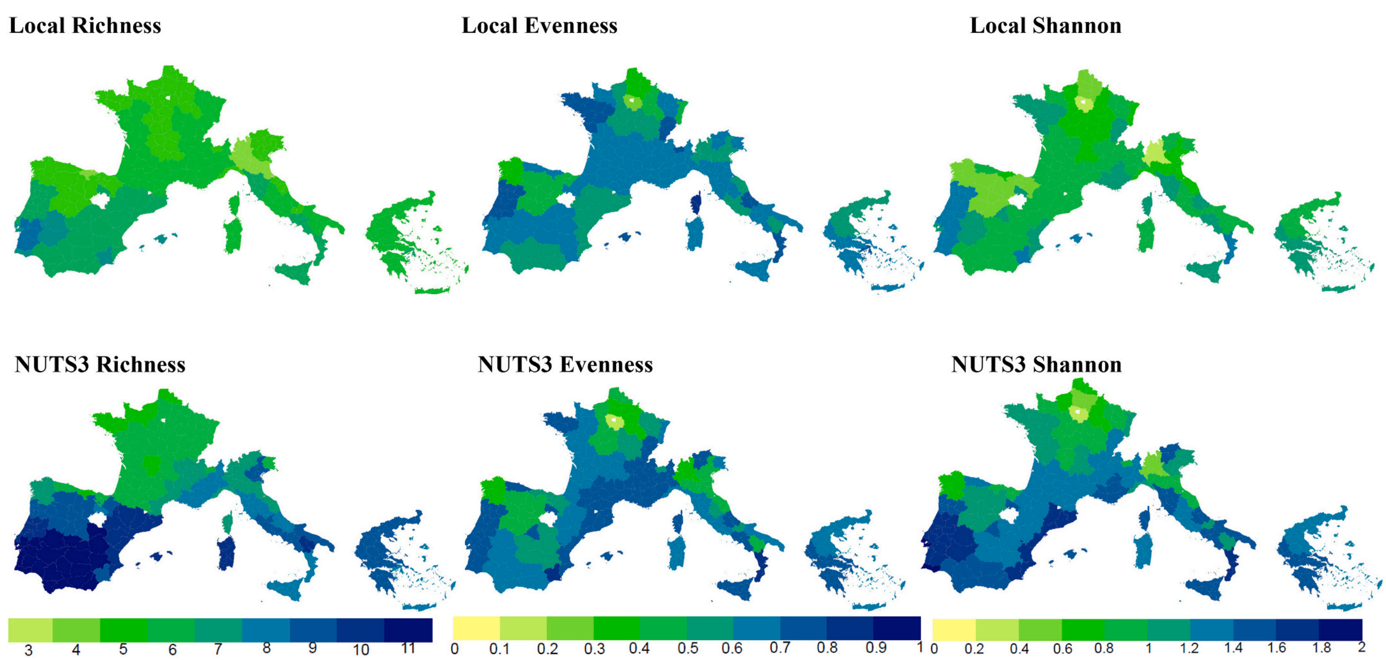

Fig. 2. Local and NUTS3 agrobiodiversity across Mediterranean Europe.

NVA is specified in eq. 3. For each farm i, the natural log of NVA is regressed on a quadratic function of agrobiodiversity at the local scale, $\boldsymbol{AL_i}$, agrobiodiversity at the NUTS3 scale, $\boldsymbol{AR_i}$, and an interaction between scales to test whether they are complements or substitutes. To complete the model, we also include country fixed effects, $\boldsymbol{D_i}$:

$$lnNVA_i = \gamma_0 + \gamma_1 AL_i + \gamma_2 AL_i^2 + \gamma_3 AR_i + \gamma_4 AR_i^2 + \gamma_5 AL_i AR_i + \gamma_6 Z_i + \gamma_7 D_i + \varepsilon_i \quad (3)$$

ε_i is the disturbance term and the estimated coefficients are γ_j.

The marginal impact (MI) across the sample of an increase of local agrobiodiversity in each region is measured by the weighted average percentage change in NVA:

$$MI_{AL} = \sum (\widehat{\gamma}_1 + 2\widehat{\gamma}_2 AL_i + \widehat{\gamma}_5 AR_i)\theta_i \quad (4)$$

Where $\widehat{\gamma}$ are the estimated coefficients from model (3) and the weight, $\boldsymbol{\theta_i}$, is the ratio between the NVA of each farm and the total NVA in the region.

Similarly, the weighted marginal impact of NUTS3 agrobiodiversity in each region is:

$$MI_{AR} = \sum \left(\widehat{\gamma}_3 + 2\widehat{\gamma}_4 AR_i + \widehat{\gamma}_5 AL_i\right) \theta_i \tag{5}$$

We estimate two regressions, one with the Shannon index of agrobiodiversity and the other with the component parts of the Shannon index, richness and evenness.

3. A regionalized CGE model for the Euro Mediterranean regions

The econometric method described in the previous section explains how the alternative measures of agrobiodiversity affect farm NVA and highlights the interdependencies between local and NUTS3 agrobiodiversity measures. It enables projections that estimate how changes in agrobiodiversity can, ceteris paribus, impact farm NVA. We use these predicted changes in value added as inputs into a multi-regional Computable General Equilibrium model (Bosello and Standardi., 2018) to predict the overall macroeconomic changes.

The CGE model describes the economy of the five Euro-Mediterranean countries at regional level and covers also the rest of Europe and the rest of world. It is based on the GTAP model (Hertel, 1997) and is calibrated upon the GTAP 8 database (Narayanan et al., 2012) for the reference year 2007. Calibration of the NUTS2 regions relies on Eurostat data (Economic Accounts for Agriculture, (Eurostat, 2018b); Structural Business Statistics, (Eurostat, 2018c); Gross value added at basic prices by NUTS3 regions, (Eurostat, 2018a)). The model has a neoclassical structure: total endowments (labor, capital, land) are fully employed and their supply is exogenous. Global investments are savings-driven and allocated across regions following capital returns. Intermediate and final demand are a combination of good and services produced within the region and outside the region as described in Fig. A-1 in the Annex. The model has a rich description of trade relationships. For each region, it specifies the trade flows with the other regions, the rest of Europe and the rest of world. The trade structure assumes imperfect substitution between products produced within and products produced outside the region, the so-called Armington assumption (Armington, 1969). Armington elasticities are different across sectors and higher within the country than across borders.[3]

A representative firm in each sector uses labor and capital as primary factors. Those factors can be reallocated across sectors in the same region, but not across regions.[4] Agriculture is the only sector to use land. Its production structure is described in Fig. A-2. A Leontief technology (perfect complementarity) links valued added and intermediate inputs. The intermediate inputs can be produced domestically or imported from other regions within the country or outside the country.

Agricultural Value Added (VA) in each region $\boldsymbol{r}$ is represented in the CGE model by a constant return to scale function of land, capital and labor as follows:

$$VA_r = \left(\phi_r Z_r^{\frac{\sigma-1}{\sigma}} + \chi_r K_r^{\frac{\sigma-1}{\sigma}} + \psi_r L_r^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{6}$$

where total land (Z), capital (K) and labor (L) are exogenous but their sectoral allocation is endogenous. Sectoral allocations depend on region-sector factor productivities: ϕ, χ and ψ, respectively, andthe elasticity of substitution between primary factors, σ.

The average marginal impact of agrobiodiversity on farm NVA in each region, has been defined above in Eq. 4 and Eq. 5. We assume that this direct impact in percentage change, γ_r, shifts the total factor productivity of the agricultural sector.[5] Eq. (6) thus becomes:

$$VA_r = (1+\gamma_r)\left(\phi_r Z_r^{\frac{\sigma-1}{\sigma}} + \chi_r K_r^{\frac{\sigma-1}{\sigma}} + \psi_r L_r^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{7}$$

We are assuming that the regression analysis is measuring the partial equilibrium effect of agrobiodiversity holding prices, interest rates, and wages constant. The CGE analysis then investigates how changes in the productivity of agriculture in each region from agrobiodiversity changes lead to changes in sectoral allocations of inputs and sectoral outputs in the wider economy.

Accordingly, after inserting NVA changes of increasing agrobiodiversity through γ_r as in (7), the CGE model computes the higher order or general equilibrium effects on agriculture, other economic sectors, prices, and GDP coming from market interactions.

4. Results and discussion

4.1. Direct impact of agrobiodiversity on farmland value

We first regress farm value added on agrobiodiversity and other control variables. Two regressions were estimated: a model estimating the role of the Shannon index and a model capturing both richness and evenness. Estimated coefficients of just the agrobiodiversity indices are shown in Table 1. The estimated coefficients for the other independent variables in the regression are shown in Table A-3.

Overall, we find that agrobiodiversity at the local scale has a linear impact on farm NVA (higher order terms were not significant). Agrobiodiversity at the NUTS3 scale has a nonlinear effect on farm NVA. The relationship is also shaped by the coefficient of the interaction term between local and NUTS3 agrobiodiversity which is systematically

Table 1
Log-linear regression of farm NVA (Euro).

	Coef	SE	Coef	SE
Local Shannon	0.211**	0.091		
NUTS3 Shannon	−0.265**	0.131		
NUTS3 Shannon_sq	0.200***	0.066		
Interaction Local Shannon & NUTS3 Shannon	−0.153***	0.066		
Local Evenness			0.688***	0.135
Local Richness			0.185***	0.028
NUTS3 Evenness			−1.562***	0.291
NUTS3 Evenness _sq			2.083***	0.280
NUTS3 Richness			0.259***	0.039
NUTS3 Richness_sq			−0.013***	0.003
Interaction Local Evenness & NUTS3 Evenness			−1.223***	0.215
Interaction Local Richness & NUTS3 Richness			−0.018***	0.003

[3] This is done implementing a CRESH (Constant Ratios of Elasticities of Substitution Homothetic) specification (Hanoch, 1971; Pant, 2007) that enables to increase the CGE model default elasticity for product substitution by 20% in the regions belonging to the same country. A description of the main equations and assumptions of the CGE model can be found in section A-1 in the Annex. Also, in the Annex Table A-4 and A-5 include the values of the elasticities of substitution between production factors and those of the trade elasticities respectively.

[4] This simplifying assumption that extends to regions the same “treatment” of countries, has been kept to increase the tractability of the problem. Often, labour and capital mobility across many small regions determine strong amplification effects and unrealistic loser/winner patterns across regions. Moreover, labour mobility within different EU countries and across Europe is not easy to calibrate.

[5] Note that in a constant return to scale function an increase in total factor productivity increases uniformly the productivity of all production factors.

negative across all agrobiodiversity measures. This negative interaction is much larger for evenness than richness. When there is little NUTS3 agrobiodiversity, local agrobiodiversity is more beneficial. When there is a lot of NUTS3 agrobiodiversity, more local agrobiodiversity is much less beneficial and can even be harmful.

NUTS3 Shannon has a convex (U shaped) effect on NVA. It is better to have either very little or high NUTS3 Shannon than having just some NUTS3 Shannon. When the NUTS3 Shannon is high (low), the local Shannon is harmful (beneficial).

Evenness behaves very much like the Shannon index. NUTS3 evenness has a convex U-shape on NVA. When the NUTS3 evenness is high (low), local evenness is harmful (beneficial). For both the NUTS3 Shannon and the NUTS3 evenness measure, the optimal level of each measure is low in the plains of northern Spain, Italy, and France. The plains are homogeneous regions where there is a single most productive farmland type growing grains. In contrast, the regions in the rest of southern Europe tend to be heterogeneous being composed of mixtures of coast, mountains, and small valleys. A different farmland type tends to dominate in each of these landscapes. High NUTS3 evenness is desired so that there is a mix of farmland types that are evenly spread. However, locally, there tends to be just a few farmland types that are ideal for each local place. This explains why there is high regional evenness and low local evenness for most of the coastal regions of southern Europe.

Unlike NUTS3 evenness and NUTS3 Shannon index, NUTS3 richness has a concave hill-shaped effect on NVA. There is an optimal amount of NUTS3 farmland types of around 8 in southern Europe. The marginal benefit of increasing NUTS3 richness is high in the plains and in France in general. However, coastal regions already have a lot of NUTS richness. If NUTS3 richness is already high, adding more can be harmful and adding local richness can also be harmful.

Table 2 summarizes the average marginal impact on NVA of increasing agrobiodiversity. Local richness, NUTS3 evenness, and NUTS3 Shannon all have sizable positive marginal impacts on farmland value added. In southern Europe, increasing the evenness of farm types at NUTS3 scale generally will increase value added. Increasing evenness locally, however, is harmful. It is not necessary for each local area to have an even allocation of farmland types. It is generally better that local areas specialize. Richness, in contrast, is more beneficial when applied to local areas.

The impacts on NVA differ across regions within each country for both local and NUTS3 agrobiodiversity measures (Fig. A-3). Most regions especially the southern regions gain from an increase in the NUTS3 Shannon or NUTS3 evenness whereas the opposite is true for the local Shannon and evenness measures. The plains in the north of France, Italy, and Spain, however, are made worse off with increases in the NUTS3 Shannon or NUTS3 evenness measures. Those plains are homogeneous regions where specializing in high valued grains at the NUTS3 scale is more valuable. Only increasing local evenness has a benefit in the plains. Italy is the biggest beneficiary of more local evenness because the majority of Italian regions have low NUTS3 evenness. In contrast, in the rest of southern Europe, it is best to diversify farmland types. The mountainous and coastal regions in the rest of southern Europe are more heterogeneous. The agricultural sector in these regions has a higher NVA the more even is the distribution across different farmland types, each of which is devoted to different conditions within each region. Therefore, increasing local evenness is harmful in these places with a great deal of NUTS3 evenness. An increase in NUTS3 richness is beneficial in the northern French and Italian regions, where a few farmland types dominate. The positive impact of local richness is more widespread. The results suggest that there is not a single best agrobiodiversity strategy but rather different strategies to overlay across regions of southern Europe.

Table 2
Marginal impact of agrobiodiversity on farm NVA (%).

	Shannon		Evenness and Richness	
	Coef	SE	Coef	SE
Local Shannon	0.27	0.004		
NUTS3 Shannon	2.27***	0.007		
Local Evenness			−0.89**	0.003
Local Richness			4.43***	0.006
NUTS3 Evenness			3.46***	0.008
NUTS3 Richness			−1.95**	0.008

Marginal impacts are calculated as the average of marginal effects of the covariate of interest. Marginal impacts of agrobiodiversity are calculated for a 10% increase in the index upper bound. Marginal impacts of Shannon index are calculated for 0.2 increase in the index, marginal impacts of evenness index are calculated for 0.1 increase in the index, marginal impacts of richness are calculated for 1 increase in the index.

4.2. Economy wide impacts

Changes occurring in the agricultural sector propagate through the economy as primary factors reallocate across sectors and intermediate input reallocate across sectors and regions, demand and supply shift, and inter-regional trade changes. Overall, there is a complex set of higher-order cascading effects.

In the first experiment, a comparative-static CGE analysis captures the economic impact across sectors and regions of a uniform 10% increase in each agrobiodiversity index, separately. With the Shannon index, each region sees a 0.2 increase. With the evenness index, each region sees a 0.1 increase. With richness, we add one more agricultural land cover type.

Fig. 3 displays the percentage change of regional agricultural production predicted by the CGE model by each policy. The relative production changes of the agricultural sector in the CGE resemble the direct relative effect of agrobiodiversity on the NVA in the econometric analysis. However, in the CGE it is also possible to examine the consequences of other relevant macroeconomic mechanisms. For example, regions with relatively larger increases (decreases) in productivity see inputs, going into (out of) the agricultural sector, output increases (falls) and the price of agricultural commodities declines (increases). The output change predicted by the CGE model is therefore different as what the partial equilibrium econometric model predicted. In particular, some amplification effects both negative and positive can be noted in the agricultural output, as production factors re-allocate across sectors and this takes place on top of the TFP shift via trade and sectoral market interactions.

Table 3 presents the economic consequences of the policy increasing agrobiodiversity. The largest increase in the Euro-Mediterranean agricultural sector stems from more local richness which increases agricultural output by 4% and almost $9 billion. A recent work confirms that local richness of farmland cover types may contribute to increasing crop yields (Duflot et al., 2022). Our results also find that adding one more agricultural cover type to a local area can have a large effect on agricultural output especially in countries such as Greece (3%), Italy (4%) and especially France (7%) which currently has relatively low levels of local richness.

In contrast, adding one more crop cover type at the NUTS3 scale will harm the agriculture sector in Southern Europe causing a loss of nearly −0.8% of agricultural output or $1.7 billion. France benefits from more NUTS3 richness because regional richness in France is generally low, but there is no net gain in any other country.

An increase in NUTS3 evenness causes a large increase in agricultural production of 2.6% or $5.8 billion across Southern Europe. Most of this gain comes to Portugal (7%) followed by Greece (5%), and Spain (4%). Those countries are characterized by a high level of NUTS3 richness and local richness and would substantially gain from a more even distribution across different farmland types, each of which is devoted to different conditions. More NUTS3 evenness is only harmful to the valuable grain producing regions in France, Italy, and to a lesser extent Spain.

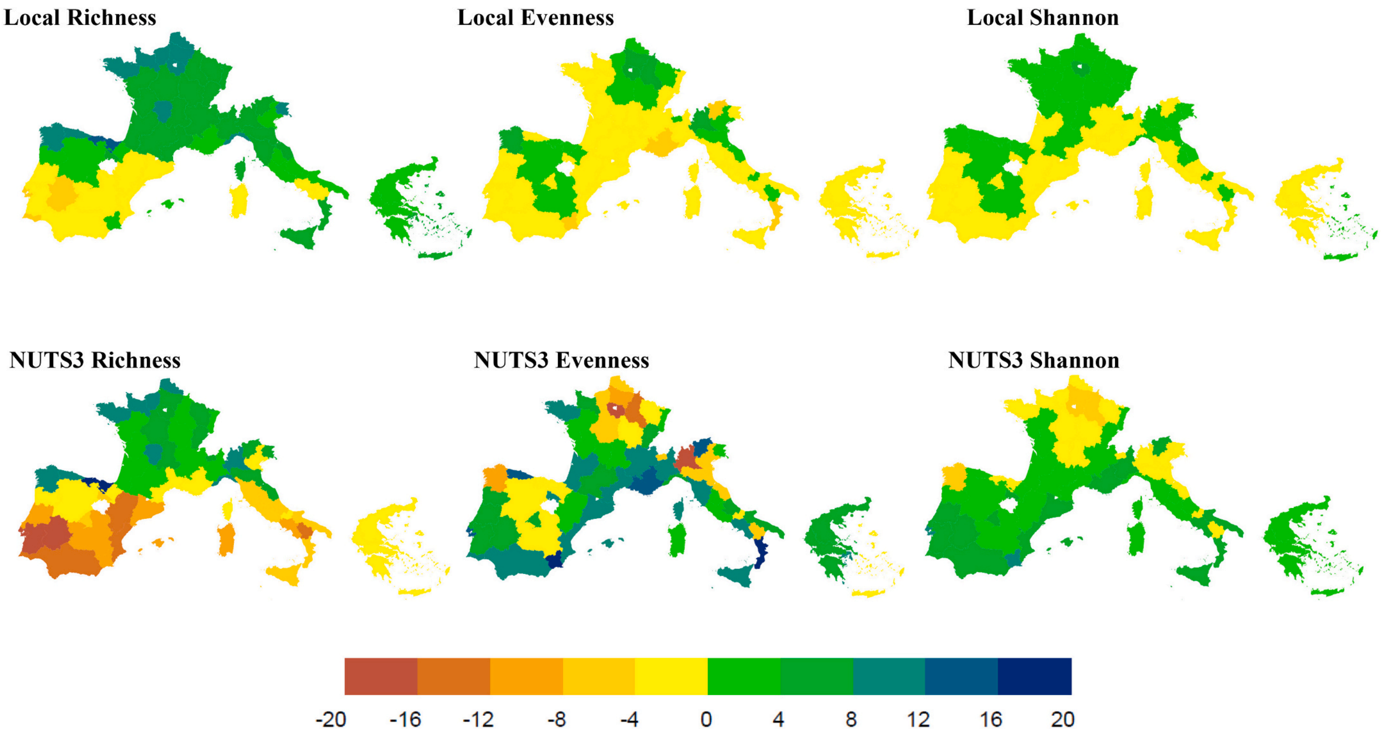

Fig. 3. Impact of local and NUTS3 agrobiodiversity increase on agricultural output across regions. (Percentage change).

Increasing local Shannon has only a small effect increasing average agricultural output in Southern Europe by only 0.3% or about $0.7 billion.

In general, the CGE model predicts that as the agriculture sector expands (contracts), there is also an expansion (contraction) of the food industry that uses agricultural output as an input. The predicted increase in the food industry is about three fourths of the increase in agricultural output. There is also a predicted increase in the service industry caused by the overall change in logistics. The change in the service industry is about 90% of the size of the change in the agriculture sector. But the expansion (contraction) of these sectors withdraws (adds) inputs from other sectors, notably industry, which shrinks (grows). The final change in aggregate GDP, reflects the change in the agricultural sector, but tends to be slightly smaller (see Fig. 4) The sum of all the indirect effects tends to be a small change in the opposite direction of the change in agriculture.[6]

Table 4, Fig. 5 and Fig. 6 describe the effects of targeting agrobiodiversity. In this experiment, agrobiodiversity is only increased in a NUTS2 region, if the marginal effect on farm NVA is positive. Agrobiodiversity is not changed in regions where the change is harmful to farm NVA. Targeted increases in agrobiodiversity cause all the agrobiodiversity measures to have a positive effect on GDP. Targeting improves the effect of local richness only slightly because there are few places where increased local richness is harmful. However, the NUTS3 Shannon becomes 10% more effective at increasing the overall GDP of Southern regions (0.045% in Table 3 vs 0.05% in Table 4). NUTS3 evenness becomes 30% more effective once targeting protects the plains regions from having to increase regional evenness (0.07% in Table 3 vs 0.094% in Table 4). Targeting also turns indices that were previously harmful into being beneficial. A uniform local evenness policy leads to a $1.1 billion loss in GDP but a targeted local evenness policy focusing on regions where regional evenness is low (the plains) would lead to a GDP gain of $0.7 billion. A uniform NUTS3 richness policy leads to a $1.7 billion loss of GDP. However, a policy aimed at increasing NUTS3 richness would target the plains in France, northern Italy, and Spain, and lead to a $2.8 billion gain in the Southern Europe (see Table 4).

5. Conclusion

The present work conducts an empirical analysis in five countries of southern Europe to link changes in agrobiodiversity to outcomes in the agricultural sector and the wider economy. We examine agrobiodiversity measures of agricultural land cover types. The results reveal that agrobiodiversity has an important effect on regional farm NVA and that different agrobiodiversity indices have very different effects across southern Europe.

The effect of richness depends a lot on how much richness is already in a region. NUTS3 richness has a concave effect on NVA. There is an optimal amount of richness and having more than this optimum is harmful. Places, like France, with little richness would benefit from more. Most regions in Spain and Portugal, where there is a lot richness already, would be harmed by more richness at both the local and NUTS3 scale. In Greece and most Italian regions, only an increase in local richness is beneficial.

The effect of NUTS3 evenness and the NUTS3 Shannon depends on whether a region is homogeneous (a plain) or heterogeneous (a mix of coast, valleys, and mountains). Less evenness (Shannon) is ideal in a homogeneous plain where a single high-valued farmland cover type (grains) dominate. But more evenness is ideal in a region with a combination of coasts, mountains, and small valleys. The Shannon index and evenness consequently both have a convex (U-shaped) effect on farm productivity. It is better to have a lot of evenness or very little. The homogeneous northern plains of France and Italy have specialized in valuable grains. Here, the NVA is higher with specialization. In contrast, the entire southern tier and the mountains of Mediterranean countries are characterized by heterogeneous conditions within each NUTS2 region. The best strategy is to diversify at the regional scale and specialize at the local level with the most suitable cropland cover type.

[6] Our results are robust to changes in the trade elasticity for sub-national regions and to change in the elasticity of substitution between primary factors (capital, labour, and land) of the agricultural sector. Results of the sensitivity analysis are reported in section A-2 of the Annex.

Table 3
Impact of agrobiodiversity increase on the economy (absolute and % change with respect to benchmark scenario).

	Local Richness	Local Evenness	Local Shannon	NUTS3 Richness	NUTS3 Evenness	NUTS3 Shannon
Whole sample						
Agricultural production (%)	3.964	−0.594	0.336	−0.781	2.649	1.623
Agricultural production (B$)	8.749	−1.310	0.743	−1.723	5.847	3.581
Food Industry (%)	0.960	−0.126	0.094	−0.122	0.532	0.351
Food Industry (B$)	6.317	−0.829	0.620	−0.805	3.500	2.306
Rest of Industry (%)	−0.243	0.033	−0.024	0.041	−0.136	−0.092
Rest of Industry (B$)	−8.866	1.223	−0.866	1.489	−4.967	−3.376
Services (%)	0.426	−0.049	0.043	−0.059	0.239	0.158
Services (B$)	7.988	−0.958	0.797	−0.834	4.472	2.819
GDP (%)	0.107	−0.016	0.009	−0.025	0.070	0.045
GDP (B$)	7.195	−1.096	0.615	−1.703	4.730	3.023
France						
Agricultural production (%)	7.126	−0.455	0.878	4.853	1.958	−0.242
Agricultural production (B$)	6.054	−0.387	0.746	4.123	1.663	−0.205
Food Industry (%)	1.452	−0.142	0.167	0.805	0.529	−0.185
Food Industry (B$)	3.573	−0.348	0.411	1.981	1.301	−0.058
Rest of Industry (%)	−0.457	0.031	−0.059	−0.346	−0.114	0.051
Rest of Industry (B$)	−5.908	0.402	−0.763	−4.470	−1.479	0.126
Services (%)	0.127	−0.012	0.014	0.044	0.053	0.016
Services (B$)	4.223	−0.410	0.466	1.452	1.759	0.529
GDP (%)	0.150	−0.013	0.017	0.062	0.056	0.014
GDP (B$)	3.952	−0.345	0.456	1.638	1.480	0.365
Greece						
Agricultural production (%)	3.155	−1.424	−0.216	−2.395	4.892	3.064
Agricultural production (B$)	0.539	−0.243	−0.037	−0.409	0.836	0.524
Food Industry (%)	1.249	−0.506	−0.055	−0.854	1.730	1.098
Food Industry (B$)	0.481	−0.195	−0.021	−0.329	0.666	0.423
Rest of Industry (%)	−0.174	−0.001	−0.028	0.015	−0.005	−0.067
Rest of Industry (B$)	−2.549	−0.021	−0.414	0.218	−0.071	−0.987
Services (%)	0.134	−0.049	−0.004	−0.081	0.174	0.109
Services (B$)	0.463	−0.171	−0.012	−0.278	0.598	0.377
GDP (%)	0.163	−0.061	−0.005	−0.101	0.211	0.134
GDP (B$)	0.504	−0.189	−0.014	−0.313	0.654	0.415
Italy						
Agricultural production (%)	3.837	−0.152	0.514	−0.709	1.061	1.709
Agricultural production (B$)	2.159	−0.086	0.289	−0.399	0.597	0.962
Food Industry (%)	0.789	0.024	0.134	0.054	−0.004	0.234
Food Industry (B$)	1.680	0.051	0.285	0.115	−0.008	0.499
Rest of Industry (%)	−0.174	−0.001	−0.028	0.015	−0.005	−0.067
Rest of Industry (B$)	−2.549	−0.021	−0.414	0.218	−0.071	−0.987
Services (%)	0.086	−0.002	0.012	0.002	0.021	0.027
Services (B$)	2.251	−0.055	0.321	0.052	0.546	0.698
GDP (%)	0.098	−0.007	0.012	−0.014	0.037	0.039
GDP (B$)	2.080	−0.157	0.247	−0.287	0.792	0.833
Portugal						
Agricultural production (%)	−0.950	−2.270	−1.250	−10.377	6.609	4.282
Agricultural production (B$)	−0.086	−0.205	−0.113	−0.935	0.596	0.386
Food Industry (%)	0.049	−0.642	−0.305	−2.837	1.972	1.273
Food Industry (B$)	0.013	−0.165	−0.079	−0.731	0.508	0.328
Rest of Industry (%)	0.067	0.204	0.110	0.921	−0.565	−0.363
Rest of Industry (B$)	0.079	0.238	0.128	1.075	−0.660	−0.424
Services (%)	0.030	−0.042	−0.016	−0.181	0.137	0.089
Services (B$)	0.087	−0.123	−0.046	−0.527	0.397	0.260
GDP (%)	0.016	−0.052	−0.022	−0.235	0.161	0.106
GDP (B$)	0.038	−0.119	−0.052	−0.542	0.372	0.244
Spain						
Agricultural production (%)	0.154	−0.745	−0.274	−7.837	4.037	3.588
Agricultural production (B$)	0.082	−0.390	−0.143	−4.103	2.156	1.916
Food Industry (%)	0.435	−0.131	0.018	−1.404	0.786	0.710
Food Industry (B$)	0.570	−0.171	0.023	−1.841	1.031	0.931
Rest of Industry (%)	0.015	0.044	0.019	0.610	−0.259	−0.254
Rest of Industry (B$)	0.104	0.302	0.128	4.150	−1.763	−1.726
Services (%)	0.057	−0.012	0.004	−0.090	0.069	0.056
Services (B$)	0.964	−0.201	0.067	−1.533	1.172	0.955
GDP (%)	0.043	−0.021	−0.002	−0.159	0.100	0.081
GDP (B$)	0.621	−0.286	−0.023	−2.199	1.432	1.165

A uniform agrobiodiversity policy is not advantageous for every region in southern Europe. The optimal policy for the Mediterranean countries is to choose the right policy for each region within each country. For the valuable flat plains, specializing in grains is optimal. The coastal and mountainous regions, however, are heterogeneous and it makes sense for these regions to have a lot of diversity within each region in order to match these varying conditions.

The CGE model takes the econometric regression results as inputs and predicts how the economy would respond. In addition to the direct impacts on agricultural TFP, factor reallocation between sectors and trade effects across regions, determine the size and direction of market changes and the overall effect on the economy. In general, the CGE

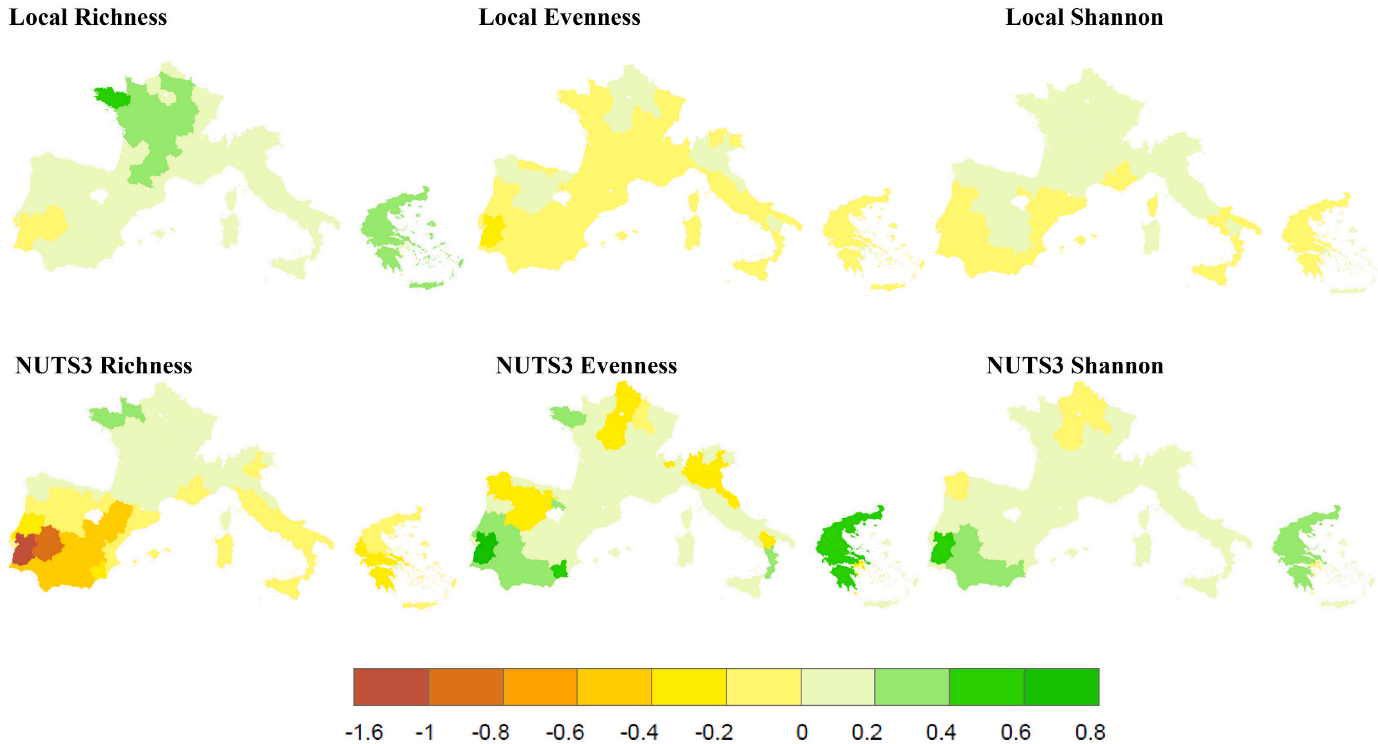

Fig. 4. Impact of local and NUTS3 agrobiodiversity increase on GDP across regions. (Percentage change).

model predicts that if an agrobiodiversity policy increases (decreases) farm productivity in a region, agricultural output would increase (decrease). This in turn would increase (decrease) both the food industry and services in that region. In contrast, industry would move in the opposite direction.

With uniform agrobiodiversity changes throughout southern Europe, the CGE predicts that the overall effect on GDP moves in the same direction as the change in agricultural productivity in each region. But the overall change in GDP in each country appears to be slightly smaller than the direct effect on the agricultural sector. The indirect effects tend to balance out to a small negative. The effect on GDP is largely determined by the effect on agricultural output.

How agrobiodiversity policy affects GDP in each region depends on which agrobiodiversity measure is used (Shannon index, evenness, or richness) and at which scale (local or regional). In general, increasing local richness by one more land use type has the biggest effect on GDP, +$7.2 billion (+0.11%) while increasing NUTS3 evenness by 0.1 unit adds another $4.7 billion (+0.07%). In contrast, increasing local evenness and NUTS3 richness are both harmful, decreasing GDP by $1.1 billion and $1.7 billion respectively.

Even when a uniform policy is beneficial to Southern Europe, generally what is the best for the mountainous and coastal regions is not the best for the plains and vice versa. Therefore, we also explore a targeted policy where agrobiodiversity is increased only in NUTS2 regions where it would be beneficial. This increases the magnitude of the benefits of the NUTS3 Shannon and the regional evenness measures. But it also changes the effect of the NUTS3 richness and the local evenness measures from being harmful to being beneficial.

The study shows that changing agrobiodiversity may have an effect on agricultural output and GDP. However, that effect is complex and varies from place to place and from one measure of agrobiodiversity to another. It appears that there is no universal agrobiodiversity policy that should be overlaid across all of southern Europe. Rather, each country, and each region within each country needs to tailor their agrobiodiversity policy to fit their situation.

The market is not able to take into account agrobiodiversity impacts directly. There is no reward for an individual farmer improving local conditions for everyone else in the neighborhood. There are rewards for regional agricultural systems to move towards specialization versus diversification but the market alone does not optimize regional agrobiodiversity. There appears to be a role for government to improve agricultural outcomes with a targeted agrobiodiversity program. First, each region would have to identify whether it is desirable to increase either local or NUTS3 richness or local or NUTS3 evenness. Second, they would have to identify which land cover types they want to increase in each zone. Third, they would need to provide subsidies to encourage farmers to switch towards the desired land cover type in each place. The government would need to set limits on how much acreage they want to shift. The overall cost of such a program is not known since it has not been tried yet. A logical beginning is to conduct some experimental programs on a small scale in promising locations to measure the cost, the benefit, and the best administrative approach.

Of course, this study has limitations. It does not explore every aspect of agrobiodiversity or biodiversity in general. For example, the study ignores the effects of different portfolios of individual crops. The study also does not explore how the diversity of nearby natural ecosystems affects farm outcomes. Finally, agrobiodiversity may have effects on recreation and residential land values not only on farms. There are a rich set of questions that remain to be answered. Future research could also test the robustness of our results and improve the modelling. For example, panel data could explore how crop cover types perform over time under changing conditions. The CGE could allow factors of production to move inter-regionally; develop a dynamic analysis that explores effects over time, or develop a closed loop between the micro and the macro mechanisms in this exercise (Pérez-Blanco et al., 2022; Parrado et al., 2020).

CRediT authorship contribution statement

Lea Nicita: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration, Supervision.

Table 4
Impact on the economy of a policy increasing agrobiodiversity only in regions where the effect on TFP is positive (absolute and % change).

	Local Richness	Local Evenness	Local Shannon	NUTS3 Richness	NUTS3 Evenness	NUTS3 Shannon
Whole sample						
Agricultural production (%)	4.019	0.364	0.517	1.603	3.460	1.793
Agricultural production (B$)	8.871	0.804	1.141	3.537	7.637	3.957
Food Industry (%)	0.973	0.093	0.132	0.402	0.762	0.391
Food Industry (B$)	6.398	0.611	0.866	2.644	5.013	2.573
Rest of Industry (%)	−0.245	−0.024	−0.034	−0.097	−0.197	−0.103
Rest of Industry (B$)	−8.955	−0.888	−1.229	−3.562	−7.189	−3.769
Services (%)	0.432	0.044	0.060	0.178	0.341	0.177
Services (B$)	8.088	0.779	1.097	3.302	6.261	3.185
GDP (%)	0.108	0.010	0.014	0.041	0.094	0.050
GDP (B$)	7.300	0.683	0.949	2.793	6.334	3.347
France						
Agricultural production (%)	7.094	0.382	0.816	3.638	2.644	0.147
Agricultural production (B$)	6.026	0.324	0.693	3.091	2.246	0.125
Food Industry (%)	1.451	0.073	0.167	0.748	0.674	0.122
Food Industry (B$)	3.569	0.180	0.410	1.840	1.657	0.300
Rest of Industry (%)	−0.455	−0.023	−0.053	−0.240	−0.157	0.003
Rest of Industry (B$)	−5.875	−0.298	−0.691	−3.101	−2.025	0.036
Services (%)	0.127	0.008	0.015	0.061	0.070	0.022
Services (B$)	4.237	0.281	0.516	2.020	2.337	0.747
GDP (%)	0.150	0.010	0.018	0.071	0.078	0.022
GDP (B$)	3.956	0.276	0.487	1.885	2.054	0.591
Greece						
Agricultural production (%)	3.148	−0.066	−0.044	−0.255	4.715	3.033
Agricultural production (B$)	0.538	−0.011	−0.008	−0.044	0.805	0.518
Food Industry (%)	1.249	0.000	0.014	−0.005	1.729	1.098
Food Industry (B$)	0.481	0.000	0.005	−0.002	0.666	0.423
Rest of Industry (%)	−0.173	−0.033	−0.032	−0.048	−0.115	−0.070
Rest of Industry (B$)	−2.533	−0.484	−0.472	−0.707	−1.692	−1.026
Services (%)	0.134	0.002	0.004	0.007	0.177	0.110
Services (B$)	0.464	0.006	0.012	0.025	0.611	0.380
GDP (%)	0.163	0.001	0.004	0.006	0.214	0.135
GDP (B$)	0.505	0.005	0.012	0.018	0.664	0.417
Italy						
Agricultural production (%)	3.821	0.637	0.633	1.018	3.024	1.773
Agricultural production (B$)	2.150	0.358	0.356	0.573	1.702	0.997
Food Industry (%)	0.787	0.144	0.149	0.287	0.454	0.259
Food Industry (B$)	1.675	0.307	0.316	0.611	0.968	0.552
Rest of Industry (%)	−0.173	−0.033	−0.032	−0.048	−0.115	−0.070
Rest of Industry (B$)	−2.533	−0.484	−0.472	−0.707	−1.692	−1.026
Services (%)	0.086	0.013	0.014	0.032	0.056	0.030
Services (B$)	2.258	0.330	0.376	0.852	1.471	0.779
GDP (%)	0.098	0.013	0.015	0.031	0.076	0.042
GDP (B$)	2.082	0.280	0.314	0.662	1.615	0.890
Portugal						
Agricultural production (%)	−0.299	−0.141	−0.188	−0.514	6.298	4.206
Agricultural production (B$)	−0.027	−0.013	−0.017	−0.046	0.567	0.379
Food Industry (%)	0.209	−0.009	−0.012	−0.027	1.943	1.272
Food Industry (B$)	0.054	−0.002	−0.003	−0.007	0.501	0.328
Rest of Industry (%)	0.019	0.014	0.019	0.050	−0.533	−0.357
Rest of Industry (B$)	0.022	0.016	0.022	0.058	−0.623	−0.416
Services (%)	0.040	0.002	0.003	0.008	0.141	0.091
Services (B$)	0.115	0.006	0.008	0.024	0.408	0.263
GDP (%)	0.031	0.001	0.001	0.004	0.163	0.106
GDP (B$)	0.072	0.002	0.003	0.009	0.375	0.245
Spain						
Agricultural production (%)	0.351	0.277	0.223	−0.070	4.425	3.700
Agricultural production (B$)	0.184	0.145	0.117	−0.036	2.316	1.937
Food Industry (%)	0.472	0.097	0.104	0.154	0.932	0.740
Food Industry (B$)	0.619	0.127	0.137	0.202	1.222	0.971
Rest of Industry (%)	0.003	−0.021	−0.015	0.018	−0.279	−0.256
Rest of Industry (B$)	0.022	−0.141	−0.105	0.119	−1.902	−1.743
Services (%)	0.059	0.009	0.011	0.022	0.084	0.060
Services (B$)	1.014	0.155	0.184	0.382	1.433	1.015
GDP (%)	0.049	0.009	0.010	0.016	0.117	0.087
GDP (B$)	0.685	0.121	0.133	0.220	1.625	1.204

Francesco Bosello: Supervision, Writing – original draft, Writing – review & editing. **Gabriele Standardi:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Robert Mendelsohn:** Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

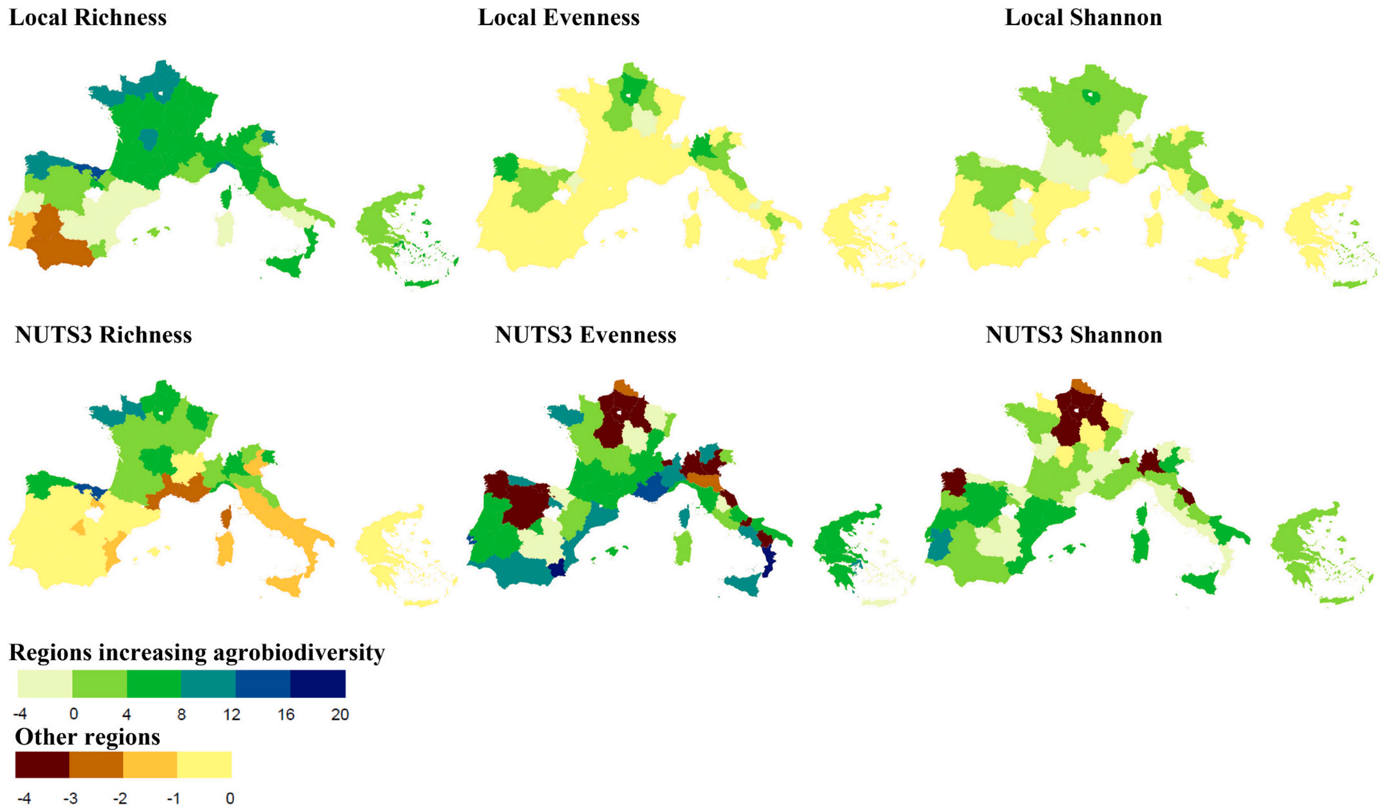

Fig. 5. Impact on agricultural output of a policy increasing agrobiodiversity only in regions where the effect on TFP is positive. (Percentage change).

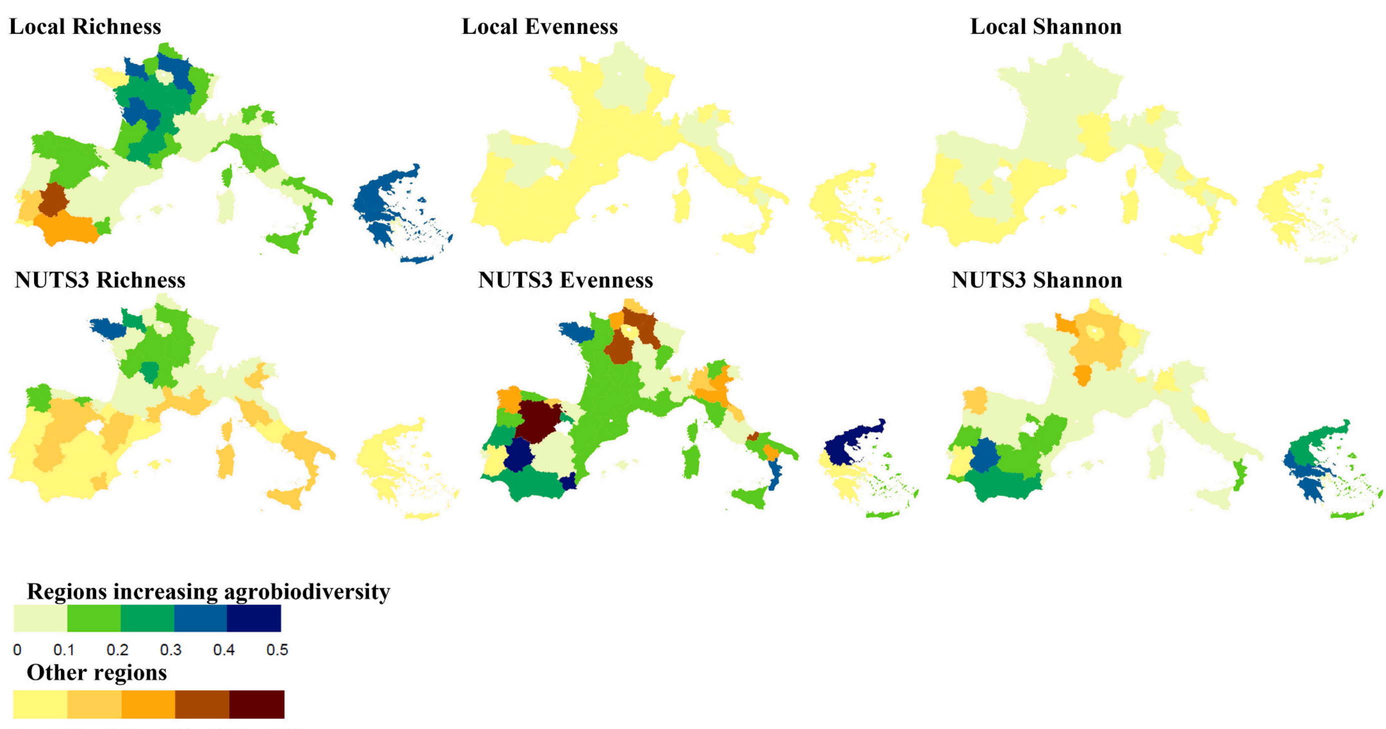

Fig. 6. Impact on regional GDP of a policy increasing agrobiodiversity only in regions where the effect on TFP is positive. (Percentage change).

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2024.108125.

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