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Terroir takes on technology: Geographical indications, agri-food innovation, and regional competitiveness in Europe

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ABSTRACT

In the agri-food sector, firms and local systems can utilize both Geographical Indications and technological advancements as key strategic assets for growth in many European regions, but the combined contribution of Geographical Indications and innovation activities to the economy of European regions is still poorly investigated. This study aims to understand how Geographical Indications and agri-food innovation affect the competitiveness of the agriculture and food industry in European regions and how these strategies interact. To achieve this goal, a longitudinal and original dataset has been organized, including data related to Geographical Indications and agri-food patents from 265 European NUTS-2 regions between 1996 and 2014. The data for Geographical Indications and agri-food patents are collected from the eAmbrosia and OECD RegPat databases, respectively. The results show that Geographical Indications have a positive and significant impact on regional competitiveness, while the effect of agri-food innovations is controversial. The implications of these findings in terms of policy design are further discussed.

1. Introduction

The food and drink industry is the EU's largest manufacturing sector. In 2022, this industry employed more than 4.6 million workers and generated an annual turnover of 1.1 trillion euros, contributing 14.3% to the turnover of the manufacturing sector of the EU and 1.9% to the EU gross domestic product (FoodDrinkEurope, 2022).

The competitive strategies of such sectors are related to a considerable number of R&D investments in process and product innovations and to the adoption of labelling strategies based on the valorisation and preservation of the tradition and cultural heritage associated with food products. More precisely, in the EU territory, there are thousands of geographical indications (GIs), which aim to protect a product's origin, traditional processes and the related know-how connected with their *terroirs*[1] (Pagliacci and Salpina, 2022). These GIs comprise Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) designations. They all protect food with specific quality characteristics that are strictly linked to specific geographical areas or to the reputation of a production territory.

Since the introduction of such policy tools by Regulation 2081/92,[2] a growing number of new product registrations have been observed. For example, from 2005 to 2017, we find an 84% (69%) growth in GI turnover (sales volume), a value largely driven by the impressive growth in the number of PGIs registered during this period (European Commission, 2021). Among the motivations associated with the success of such trends, it is argued that they can foster regional economic growth because of the valorisation of food-related *terroirs* and traditional processes (Moschini et al., 2008; Rachão et al., 2019). However, different arguments need to be still verified to confirm such line of reasoning. Huysmans and Swinnen (2019) argue that the presence of GIs could be linked to the relatively low regional productivity of the agri-food industry and provide income and employment preservation. Nevertheless, existing assessments of the impact of GIs at regional level are mostly qualitative in nature and they refer to single certified products or specific production areas (e.g., De Roest and Menghi, 2000; Bouamra-Mechemache and Chaaban, 2010). To date, only Cei et al. (2018)

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[1] According to the Resolution OIV/Viti No 333/2010 the French term *terroir* refers to a geographic region in which there is shared knowledge of the interactions between the environmental factors, resulting in unique characteristics of the products produced in that area (Crescenzi et al., 2022).

[2] Modified by Regulation (EU) No 510/2006, Regulation (EU) No 1151/2012 on quality schemes and the new Regulation that will be implemented in 2024.

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provide quantitative evidence on the role of GIs at regional level, but only within the Italian territory. In specific, by using a difference-in-difference research design they estimate a positive impact of an index implemented to measure the intensity of GI presence at NUTS-3 level on the value added of Italian municipalities.

Another issue related to GI diffusion is the understanding of the impact of its contribution to long-term local competitiveness. On the one hand, it has been clearly demonstrated that such policy contributes to the preservation of agricultural labour within European regions. On the other hand, it has been demonstrated the capacity of GIs to foster innovation for certified firms but not their ability to foster innovation capacity of local systems and contributing to long-term competitiveness of local economies. For example, evidence of the territorial distribution of GIs and agri-food patents seems to suggest that there is a polarization between the adoption of GIs and innovation within European regions. GIs are mostly present in southern Mediterranean regions (Huysmans and Swinnen, 2019). Inventions, as proxied by patents, are mainly concentrated in Central-North regions (De Noni et al., 2018). However, the role of GIs in producing spill-over effects in local systems by stimulating innovation is still under investigated. Apart from a first quantitative assessment of Stranieri et al. (2023) showing that GIs stimulates innovation in technologically backward regions, most of the existing literature is still quite controversial and based mainly on qualitative considerations (Moerland, 2019; Josling, 2006; Marescotti et al., 2020; Ruiz et al., 2018; Mancini et al., 2019).

The scarce evidence of the contribution of GIs on regional competitiveness and the polarization between GIs and innovations among EU regions lead to the following key crucial questions:

RQ1. Do GIs contribute to the competitiveness of agri-food supply chains at the regional level?

RQ2. How the diffusion of GIs interacts with innovation in affecting competitiveness at the regional level?

To achieve these goals, we conducted a quantitative analysis of the influence of GIs and innovations on the competitiveness of the agri-food industry at the EU NUTS-2 level.[3] In specific, the study investigates the spread of GIs on competitiveness, as measured by gross value added (GVA) in the food and agricultural sector. This research not only explores the overall contribution of food and agricultural innovation, proxied by patents, and its interaction with GI diffusion at the territorial level but also examines how different GI product categories impact regional competitiveness. The study utilizes panel data econometrics to analyze the effects of GIs, differentiating between different categories, and agri-food patents on the GVA of European regions. We exploit information for 265 European Union regions observed from 1996 to 2014, sourced from the eAmbrosia (Database of Origin and Registration) and OECD (Organization for Economic Co-operation and Development) RegPat databases.

Our findings show that GIs are important determinants of competitiveness both for the food industry and the agriculture sector. We find also a weak negative effect of patent diffusion on agri-food competitiveness, a result difficult to interpret within the innovation-competition literature. Also, the results show evidence that GIs and patents act as substitutes in affecting competitiveness in the agri-food sector, i.e., in a region already specialized in producing GIs, growth in innovative food activities appears to dump competitiveness, and vice versa.

Our paper contributes to the current literature in different ways. First, our analysis is one of the few studies that quantitatively assess how GI policy stimulate the economic growth and success of rural areas in the EU regional level (NUTS 2). Second, it is among the first quantitative analysis that aim to examine the contribution of GIs on long-term competitiveness and their interaction with innovative capacity of European regions.

The paper is organized as follows. The next section discusses the economic importance of GIs. Section 3 discusses the background literature of GIs, innovation, and regional competitiveness. In Section 4, we address the methodology and how the two research questions are identified econometrically. Next, in Section 5, the main results are summarized and discussed. Section 6 presents the limitations of the study and addresses directions for further research.

2. The economic importance of GIs

GIs are defined in the second part of the Agreement on Trade Related Aspects of Intellectual Property Rights (standards concerning the availability, scope, and use of intellectual property rights) as 'indications which identify a good as originating in the territory of a member, or a region or locality in that territory, where a given quality, reputation or other characteristic of the good is essentially attributable to its geographical origin'.

In the EU, the policy framework on GIs is strictly related to the normative rules related to the wine sector, which were first introduced with Regulation (EU) 817/70. Such a policy was also progressively applied to other agri-food sectors, such as spirit drinks (Regulation EU 1576/89) and other agri-food products with Regulations (EU) 2081/92 and 2082/92. These latter two regulatory interventions introduced the rules for PDOs and PGIs for all agri-food products, except for wine products, which followed a slightly different normative path. The main objectives of such policy instruments are the preservation of rural areas and the development of regional economies throughout the valorisation of products and production methods whose characteristics are specific to a certain territory (Belletti et al., 2017). Such attributes relate to organoleptic, physical, microbiological, and chemical product characteristics, as well as other factors that depend on the peculiarities of the territory where the product originates, for example, the climate, human skills, traditions, and related savoir-faire (Moerland, 2019).

Specifically, on the one hand the PDO certification guarantees that all stages of production, processing, and preparation take place within a specific geographical area identified in the product specification. On the other hand, the PGI certification is given to products whose quality and reputation are linked to a particular territory, but ingredients used can come from different areas, including those outside the identified territory.

The GI policy has been modified by Regulation (EU) 510/2006 and Regulation (EU) 1151/2012, which aim to protect the names of PDO- and PGI-certified products as intellectual property rights and ensure clear and transparent information to consumers. These types of regulation introduce amendments as possible measures to modify product specifications, which allows producers to adapt to changing environmental and market conditions and, indirectly, to introduce innovation within their production processes (Ruiz et al., 2018). Recently, Regulation (EU) 664/2014 has also supplemented Regulation (EU) 1151/2012 with new specific rules related to the establishment of PDO and PGI labels and their implementation to increase consumers' information and related awareness of certified products. Moreover, a new Regulation approved in 2024 for GIs will come into force soon with the aim of giving greater responsibilities for certified producer associations; enhancing the visibility for sustainable practices in agrifood and wine production and augmenting the protection for GIs employed as ingredients in packaged food products.

A recent study conducted by the European Commission revealed that in 2020, PDOs and PGIs accounted for 98% of the total GIs (European Commission, 2021). Moreover, 80% of GIs were concentrated in only six

[3] The NUTS (Nomenclature of territorial units for statistics) are territorial units arranged in a hierarchical system and are used to divide the EU economic territory to facilitate data analysis. Three types of NUTS exist: NUTS-1, NUTS-2, and NUTS-3, arranged from the largest to the smallest unit. The NUTS-2 level represents the basic regions of the EU and the UK for the application of regional policies.

European countries, i.e., Italy, France, Spain, Greece, Portugal, and Germany.

The sales value of GIs was approximately 77.15 billion euros, which represented 7% of the total value of the EU28 food and drink sector (European Commission, 2021). Most of the value created came from GI products. Specifically, out of 74.8 billion euros of sales, 51% belonged to wines, 35% to agricultural products and foodstuffs and 13% to spirit drinks. From 2010 to 2017, the sales value of GIs increased by 42%, which was mainly due to an increase in the registrations achieved and the improved market penetration of certified products.

There are large differences among countries in terms of the value created by GIs. France and Italy are the leading countries in terms of not only number but also value created by GIs, followed by Germany, the UK and Spain. GIs also play an important role in Portugal, Greece, the Czech Republic, and Austria, where they represent 4%–12% of the food industry's value (European Commission, 2021). However, there are some countries, such as Belgium, Finland, Lithuania, Estonia, and Latvia, where GIs are of limited importance. Moreover, there are also countries where the value of GIs is sector specific. For example, in Hungary, Romania, Slovenia, Croatia, Slovakia, Bulgaria, Cyprus, Luxembourg and Malta, the value of GIs is mainly associated with wines.

Regarding the distribution of GIs among different certifications, in 2017, PGI products represented 54% of the total sales value; PDO products accounted for 38%. Importantly, if we considered turnover in 2017, approximately 70% of GI products were considered processed food. This suggests that most of the value created by GIs should come from processing activities, whereas the impact on the agricultural sector depends on the origin of the raw material used for the certified products.

3. GIs, innovation, and regional competitiveness

Most of the studies on GIs concentrate on consumers' willingness to pay and related price premiums for specific certified products (Deselnicu et al., 2013), on firms' determinants of GI adoption (López-Bayón et al., 2018; Teuber, 2011; Bouamra-Mechemache and Chaaban, 2010; Dimara et al., 2004), on the economic performance of certified agri-food firms (Iraizoz et al., 2011; Sellers-Rubio and Más-Ruiz, 2015), and on the impact of protecting GIs in international markets and trade flows (Raimondi et al., 2020; Curzi and Huysmans, 2021).

Notwithstanding the important economic contribution of GIs to European regional economies, only a few studies have provided an evaluation of the effectiveness of GIs on the competitiveness of European regions and most of them relate to some specific GI products and geographical areas. For example, Bouamra-Mechemache and Chaaban (2010) studied the impact of GIs on the French cheese supply chain. Their findings show that the introduction of the PDO label increased the number of cheese firms, which resulted in more employment on dairy farms and in processing firms. Gracia et al. (2007) studied the impact of GIs on farmland prices in Aragon within the Spanish territory. Their results highlight that participating in a GI product specification is among the significant determinants affecting farmland prices. Raimondi et al. (2018) investigated the socioeconomic impact of PDOs in the Italian, French and Spanish regions listed in the product specifications using a dynamic panel model. The analysis showed that GIs caused an increase in employment in agriculture and in industry sectors in both the short and long run. As introduced above, the analysis of Cei et al. (2018) provided evidence of a positive effect of GI protection intensity on Italian agricultural value added, suggesting a positive influence of EU policy on rural development.

Moreover, the analysis of the impact of GIs on the long-term regional competitiveness of local economies and its relationship with innovation is also a topic of interest in recent research, even if most of contributions are qualitative and concentrate the attention only on those innovations which are product-specific, like for example, GIs amendments, product and process innovations, or the organizational innovations associated to specific GIs throughout the enhancement of producers supply networks (i.e., consortia). For example, Kuhne and Gellynck (2009) argued that innovation measured as new or improved products, processes, markets and organisational developments may conflict with tradition as it could contrast local identities and traditional production methods. The case study of Bowen and Zapata (2009) on Mexican tequila also revealed that amendments on product specification related to the enlargement of the geographical area of production can negatively impact firm performance. Such evidence highlights the need for a balance among innovation, traditional production methods and product characteristics for success. On the other hand, Ruiz et al. (2018) suggested that firms producing GIs combine innovation with traditional production methods to adapt to changing markets and increase international competition. In their analysis of GI amendments, they conclude that PDO/PGI certifications are evolving institutions that aim to increase efficiency at the micro and local levels. Their findings indicate that most amendments relate to processed foods, such as cheese, which are more affected by technological advances and old certifications. Furthermore, Guerrero et al. (2009) and Linnemann et al. (2006) specified that the adoption of product and process innovations by firms producing traditional products often depends on the type of product. Mancini et al. (2019) analysed the innovation process within the Parmigiano Reggiano PDO system and found that such GI is characterized mostly by technological and organisational innovation and that the last one is closely linked to existing supply chain networks. They also found that the impact of innovation on GI competitiveness depends on the degree of collaboration among certified producers and their willingness to share knowledge and resources.

The literature reported above clearly indicates a link between innovation and GIs at product or supply chain level. However, there is a lack of empirical evidence to validate the effect of tradition represented by the diffusion of GIs and innovation, especially in relation to their capacity to spur innovation activities within local systems. Indeed, it is clear throughout the analysis of existing literature that GIs can promote innovation of their product specifications throughout the amendments, but there is still scarce evidence on their ability to stimulate innovation strategies at the regional level notwithstanding the fact that the strict rules associated to the geographical production limitation favour very often the implementation of innovative activities within the certified area that are linked to the product specification but are not controlled by it (Mancini et al., 2019). In other words, the presence of GIs in a certain geographical area incentives innovation outside the production specifications and facilitates production, preservation, and the overall management of the production process of certified products. This last aspect is a key point from a policy perspective to add insights on the role of GIs on regional growth. To date, only Stranieri et al. (2023) investigated how the diffusion of GIs affects innovation in different regions and found that this impact is contingent on the region's proximity to the technological frontier. The results show that GIs have a positive effect on innovation in regions that are far from the technological frontier, but this relationship becomes negative in regions that are closer to it. However, the analysis of the indirect effects of GIs on local innovation systems, through the examination of the relationship between the adoption of GIs and innovation performance indicators of a specific territory, such as regional patenting activities within a particular geographical area, remains largely unexplored.

4. Methodology

4.1. Research setting and data

To set up the empirical analysis we organized a new and original dataset to investigate the relationship among regional competitiveness, GIs, and innovation. Data were collected from different sources. The ARDECO database[4] was used to collect socioeconomic variables and, specifically, data on GVA as a proxy of regional competitiveness in the agri-food industry. eAmbrosia provided information to identify and geolocalize GIs across European regions. The OECD RegPat database provided patent data for measuring the regional innovation capacity in agriculture and the food industry, and the Eurostat and European Tertiary Education Register[5] (ETER) provided data for the different control variables (i.e., human capital, population density, employment rate in manufacturing activities and gross fixed capital formation). All data were aggregated at the NUTS-2 regional level since the European Commission adopted the NUTS-2 classification to identify the 'basic regions for the application of regional policies'. In Section 4.2 we describe in detail the variables extracted from the above databases.

The final dataset encompasses approximately 1,600 GI products,[6] 16,800 patents in the food industry and 25,460 patents in agriculture across 265 NUTS-2 European regions over a time window from 1996 to 2014. The selection of the timeframe covered by this analysis is driven by the European regulation on GIs and data availability. On the one hand, the protected designation of the origin framework came into effect in 1992, but the first registrations began in 1996. On the other hand, fully reliable regional data regarding patents[7] and other regional statistics are available up to 2014.

4.2. Variable description

The dependent variables used in the panel regression analysis are the gross value added in the food sector (food GVA) and the gross value added in agriculture (agricultural GVA). The key explanatory variables are the number of GIs, food patents and agricultural patents, and a vector of controls.

4.2.1. Dependent variables

Gross value added measures the economic value created by an activity from the supply side. It is calculated by deducting the cost of inputs and raw materials (at the purchaser's price) from the goods and services produced (at basic prices); thus, it is output minus inputs. The data for gross value added were taken from the ARDECO database, and the years considered ranged from 1996 to 2014.

GVA can be considered a mark-up added by the producers of a region to increase the value of local products and services. The higher this "mark-up" is, the greater the capacity of producers in a region to transform internal and external inputs into highly competitive products and services using their abilities, skills, competences, and cultural heritage. For the purpose of this research, the dependent variable is operationalized at the NUTS-2 level by distinguishing the GVA of the food and agricultural sectors.

Food GVA is calculated as proxied by the GVA for the manufacturing sector in million euros (at 2015 constant price) as provided by ARDECO for the NUTS-2 regions and year excluding the construction industry and weighted by the ratio between the number of employees in the food sector and the number of employees in the manufacturing sector (excluding the number of employees in the construction industry). We are forced to use this strategy because reliable GVA data by region and year are still lacking for the food industry. Data related to the number of employees in the food sector were collected from the Eurostat database using the 2-digit NACE codes C10 (Manufacture of food products) and C11 (Manufacture of beverages). Thus, it represents the competitiveness of the food sector at the regional level in a specific year.

Agricultural GVA is the GVA for the agricultural sector in million euros (at 2015 constant price) per NUTS-2 region and year provided by the ARDECO database. It represents the competitiveness of the agricultural sector at the regional level in a given year.

4.2.2. Explanatory variables

Geographical Indications (GIs) are measured by the number of GIs registered per NUTS-2 region and year, using the eAmbrosia dataset. eAmbrosia is the EU's legal repository for registered and protected names of foodstuffs, agricultural goods, wines, and spirits across all member states.[8] It provides comprehensive data on geographical indications, including legal protection details, product specifications, and key dates for applications and publications before registration. We assessed the 'Code of Conduct' in eAmbrosia to link each GI product with the corresponding NUTS-2 region that represents the area of supply for Protected Designations of Origin (PDOs) and area of production for PDOs and Protected Geographical Indications (PGIs). We excluded wines and spirits from our sample since the harmonization of wine laws with GI policy is a recent development, coming into effect with the EC Regulation 1308/2013. Even though the structure of the normative framework of quality for wines was already very closed to the GI law in the food sector, the introduction of GIs for wine dates to approximately twenty years before the Reg. 2081/92 and the relative economic impact of the property rights associated to such product certification on the value added of the agri-food sector within the time span considered in the analysis is different compared to the introduction of new GIs in the food sector. Also, we have excluded few products that cannot be unequivocally assigned to a specific NUTS-2 region. The final dataset covers about 1,600 products across 265 NUTS-2 regions from 1996 to 2014. Each GI product is registered under the year it was granted protection, and if applicable to more than one region, it is listed separately for each. The timing of each GI's market introduction is recorded as year $t + 1$ relative to its registration year in eAmbrosia.

Additionally, in our analysis, we controlled for the number of *PDOs* and *PGIs* per region per year. We further categorized the GIs into subclasses based on the eAmbrosia classification system to provide specificity in assessing the impacts of different types of agri-food products on regional competitiveness. These subclasses were defined as follows: *Meat* which combines Class 1.1. Fresh meat and Class 1.2. Meat products; *Dairy*, consisting of Class 1.3. Cheeses and Class 1.4. Other dairy products of animal origin; *Oil*, covering Class 1.5. Oils and fats along with Class 3.2. Essential oils; *Fruit & Vegetables*, which includes Class 1.6. Fruits and vegetables; and *Other*, a category encompassing all other

[4] The ARDECO database, previously managed by Cambridge Econometrics, is the Annual Regional Database of the European Commission's Directorate General for Regional and Urban Policy, maintained and updated by the Joint Research Centre. The database contains a set of long time-series indicators for EU regions, as well as for regions in some EFTA and candidate countries, at various statistical scales (NUTS-1, NUTS-2 and NUTS-3), starting from 1980 (EU Commission).

[5] The European Tertiary Education Register is a database collecting information on Higher Education Institutions (HEIs) in Europe with data on their basic characteristics and geographical position, educational activities, staff, finances and research activities.

[6] A GI can be attributed to more than one NUTS-2 region when the area of the GI is spread over two or more neighbouring regions; this operation leads to a higher number of GIs than the number reported in the introduction section.

[7] OECD RegPat database, January 2021 covers patent applications to the EPO (derived from PATSTAT, Autumn, 2020) and PCT patents at international phase until the end of 2014.

[8] The European Union has also concluded more than 30 international agreements, which allow the recognition of many EU Geographical Indications outside the EU countries and the recognition of non-EU Geographical Indications in the EU (EU Commission).

classes such as bread, pastry, pasta, fresh fish, seafood, and beer.

Each category's number was documented in our database, reflecting the total GIs registered under each subclass per NUTS-2 region annually from 1996 to 2014. This categorization allowed for a nuanced analysis of the specific contributions of different agri-food sectors to regional competitiveness.

Regional innovation capacity in the food and agricultural sectors (PAT). Agricultural patents (*Agricultural PAT*) and food patents (*Food PAT*) data are used as a proxy of the technological capacity of local systems and for assessing its effects on the competitiveness of the agricultural sector and the food industry in European regions (EU-28 plus Norway). In order to regionalize patent data effectively (Maraut et al., 2008), only patents with at least one applicant from a European region were included. The region of assignment for each patent is determined by the address of the applicant, who may be an individual, company, or organization. Generally, when an invention is made by an employee, the employer is recorded as the applicant while the actual inventor is the employee, unless the invention remains the property of the individual inventor. This approach allows for a clearer connection between the economic impact of inventions and the regions where they are developed and utilized.

Patents without an applicant from a relevant region, or from regions categorized as 'not classified', were excluded. For patents with multiple applicants, an 'applicant share' method was applied: if all applicants are from the same region, the patent is assigned entirely to that region; if from different regions, it is proportionally divided among those regions. Applicants based outside of the EU-28 or Norway were not included. The 'priority year' from the RegPat database specifies the year of assignment for each patent.

Patents in the food industry are calculated by the number of patents registered at the European Patent Office per region and year, categorized into specific technological classes: A21—baking and dough processing; A22—butchering and meat or fish processing; A23—preservation and treatment of foodstuffs not included in other categories. The distribution of these patents indicates significant activity in specific areas, such as the addition of substances to preserve flour or dough (A21, over 20%), the shirring of sausage casings (A22, 18%), and the preservation of foodstuffs through methods like pasteurization (A23, 16%).

Similarly, agricultural patents are quantified by registrations at the European Patent Office, classified under A01, which covers a broad range of agricultural activities. These patents often relate to the development of more robust and efficient agricultural processes, such as improving plant resistance to environmental stresses and enhancing growth rates (6%), or innovations in animal husbandry and product extraction (4%).

Despite the limitations of measuring technological knowledge (Alcacer and Gittelman, 2006) through patents, they have nevertheless been found to be a good proxy for calculating innovation performance compared to other innovation proxies and they have been used to study innovation in other non-food sectors. Jensen and Webster (2009) compare the dominant coverage of commonly used innovation proxies, i.e. R&D data, patents, trademarks, surveys of managers and launches of new products, are highly correlated especially in the manufacturing sectors. Also, Hagedoorn and Cloodt (2003) found strong correlations between different innovation proxies amongst firms in high-tech sectors. Moreover, Marrocu et al. (2013) analysed innovation activities within European region among 44 sectors by using both inventors of patents and applicants. Also, Lee and Lee (2013) analysed the energy-technology related patents during the period 1991–2010 to study the characteristics of the innovation and evolution of energy technology.

The control variables used in the analysis are human capital, population density, employment rate in manufacturing activities and gross fixed capital formation.

Scientific universities are a proxy of the attitude of a region towards the production of knowledge and innovation to allow them to efficiently compete on the market (Lee et al., 2010). Scientific universities generate and diffuse state-of-the-art knowledge to innovation ecosystem stakeholders (industry, researchers, etc.). The higher the number of scientific universities in a local system is, the higher the potential of that region to generate new knowledge and technologies, support firms and local organizations in innovative processes, produce more efficiently and compete in an effective way (Anselin et al., 1997).

Population density is the number of people per square kilometre (population divided by square kilometre of land) for each region and each year. Population density is often used as a proxy for urbanization externalities (Mameli et al., 2012). The higher the concentration of the population is, the higher the number of industry research laboratories, trade associations and other knowledge-generating organizations in that area (Frenken et al., 2007). Moreover, urbanization is likely to have a positive effect on economic growth and innovation activity (Frenken et al., 2007; Marrocu et al., 2013).

Manufacturing specialization is operationalized as the employment rate per region and year in the manufacturing sector. It is a proxy of the specialization of the region in manufacturing activities (Hipp and Grupp, 2005). The employment rate shows employed persons as a percentage of the economically active population. It is included as a control variable, as it is expected to positively influence the regional food GVA and negatively influence the agricultural GVA.

Gross fixed capital formation (GFCF) measures the value in million euros (at 2015 constant price) of acquisitions of new or existing fixed assets by the business sector, governments, and households less the disposal of fixed assets in a given region and year. Fixed assets are produced assets that are used repeatedly or continuously in production processes for more than one year. It is included as a control variable, as it is expected to have a positive impact on the regional GVA (Darma, 2020).

4.3. Model specification

After running poolability tests (F-test) and checking for the presence of random effects (Hausmann test), our baseline estimator is based on a (static) panel twoway fixed effects model with individual and time effects. This estimator controls for both observed and unobserved heterogeneity among regions (knowledge base, culture, institutions, etc.) as well as idiosyncratic shocks (economic crisis, extreme weather, etc.) at certain times common to all regions. As usual in this kind of application, the dependent variable is taken in logs.[9] All the explanatory variables enter the equation with a one-year lag to mitigate the possible effect of reverse causation[10]. Formally, our baseline static model can be represented by the following equation:

$$\log\left(y_{i,t}\right) = \beta_1 PAT_{it-1} + \beta_2 GI_{it-1} + \beta_3 (PAT \times GI)_{it-1} + \gamma X_{it-1} + \alpha_i + \theta_t + \epsilon_{i,t} \tag{1}$$

where y_{it} is the (log) of GVA in the food industry (Food GVA) or agriculture (Agriculture GVA) for region i at time t; X_{it} represents a vector of controls, with γ being the respective estimated coefficients; α_i and θ_t are regions and time fixed effects, respectively; and $\epsilon_{i,t}$ is the error term.

Our key variables of interest are PAT_{it} and GI_{it}, i.e., a technological innovation proxy based on the number of patents in the food industry (Food PAT), in agriculture (Agricultural PAT), and the number of certified GIs in each NUTS-2 region. In addition, through the interaction term $(PAT \times GI)_{it}$, we aim to test the extent to which the diffusion of GIs

[9] We ran the Paseran-Shin test to check for stochastic trends, and it confirmed that there is no unit root in our time series sample.

[10] Note, because it is reasonable to assume that a new GI will enter the market (with its own label) only one year after of the approval process, it will enter the equation with a two-year lag. For symmetry, the patent variable and the interaction term, also enter the equation with a two-years lag

Table 1
Descriptive statistics.

Variables	Mean	St. Dev.	Min	Max	Obs.
Food GVA	920,05	982,27	1,74	9937,86	5168
Agricultural GVA	663,04	761,72	0,41	8222,24	5225
Food PAT	3,17	7,76	0	103,17	5580
Agricultural PAT	4,85	13,20	0	234,50	5580
GIs	0,31	1,03	0	22	5580
PDO	0,14	0,67	0	18	5580
PGI	0,16	0,58	0	11	5580
Class_Meat	0,08	0,47	0	11	5580
Class_Dairy	0,08	0,44	0	9	5580
Class_Oil	0,03	0,20	0	5	5580
Class_Fruit & Vegetables	0,07	0,36	0	8	5580
Class_Other	0,04	0,25	0	4	5580
Scientific universities	2,04	3,92	0	27	5420
Population density	0,37	0,91	0,00	10,76	5580
Manufacturing specialization	0,17	0,07	0,02	0,42	5301
GFCF	1786,60	1942,54	0,87	20096,73	5225

Table 2
Correlation matrix.

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Food GVA	1															
2	Agricultural GVA	0,45	1														
3	Food PAT	0,49	0,17	1													
4	Agricultural PAT	0,37	0,11	0,48	1												
5	GIs	0,13	0,26	0,01	0,00	1											
6	PDO	0,08	0,20	−0,01	−0,02	0,85	1										
7	PGI	0,14	0,22	0,03	0,02	0,79	0,36	1									
8	Class_Meat	0,09	0,16	0,00	0,00	0,71	0,48	0,72	1								
9	Class_Dairy	0,06	0,11	0,01	−0,01	0,72	0,74	0,43	0,36	1							
10	Class_Oil	0,05	0,21	−0,01	−0,02	0,45	0,52	0,20	0,15	0,22	1						
11	Class_Fruit & Vegetables	0,11	0,23	0,02	0,01	0,63	0,54	0,48	0,23	0,26	0,25	1					
12	Class_Other	0,05	0,08	0,00	0,01	0,27	0,15	0,30	−0,01	0,02	0,03	0,06	1				
13	Scientific universities	0,05	−0,06	0,14	0,13	0,00	−0,01	0,01	0,04	−0,01	−0,04	−0,02	0,01	1			
14	Population density	0,04	−0,17	0,21	0,08	−0,07	−0,05	−0,06	−0,05	−0,04	−0,03	−0,04	−0,03	0,11	1		
15	Manufacturing specialization	−0,11	−0,01	−0,13	0,00	0,03	0,00	0,05	0,03	0,02	−0,05	−0,01	0,07	0,01	−0,29	1	
16	GFCF	0,80	0,47	0,43	0,35	0,16	0,12	0,15	0,10	0,09	0,09	0,14	0,05	0,03	0,01	0,08	1

may interact with innovation, by discouraging and/or spurring competitiveness, as discussed in the conceptual framework. According to existing studies, the expectation for the coefficient is $\beta_1 > 0$, and $\beta_2 > 0$, i.e. both innovation and GIs should contribute to GVA growth. However, the expected coefficient of the interaction term, β_3, is an empirical question, namely, it will be positive, $\beta_3 > 0$, if there is some complementarity between GIs and patents in affecting GVA; it will be negative, $\beta_3 < 0$, if instead the diffusion of GIs have a dampening effect on innovation activities (Acemoglu et al., 2012).

For each dependent variable, various specifications are considered: (a) a baseline model including only the vector of control, X_{it}; (b) a model testing for the effects of the number of patents on the respective GVA; (c) a model testing for the effects of the number of GIs on the respective GVA; (d) a model including both the number of GIs and patents and, finally, (e) a full model with both GIs and patents as well as their interaction term. Additionally, we have included regression models that explore the impact of PDOs and PGIs on the GVA in the food and agriculture sectors, as well as the effects of specific GI product categories.

We experiment with different assumptions about the correlation of the error terms. Baseline regressions are run by using clustered robust standard errors within NUTS-2 regions to account for heteroskedasticity and within unit autocorrelation of unknown form. However, the results are virtually the same when using clustered standard errors at the country and year levels to account for within-country spatial correlation.

Concerning identification issues, by including region and time fixed effects, Eq. (1) will estimate the impact of GIs and patents on competitiveness by exploiting the within-region variation in the variables of interest, controlling for omitted variable bias and common time effects. Thus, the main concern is simultaneity bias because the decision to introduce a new GI or invest in innovation could be clearly himself the consequence of competitiveness.

To account for this potential simultaneity bias, we also run some dynamic panel models. Specifically, following Chudik et al. (2018), we use an autoregressive distributed lag (ARDL) model, estimated through both the standard fixed effects and the half-panel jackknife fixed effects (xtspj) estimator.[11] The xtspj estimator addresses the so-called Nickell bias in (dynamic) fixed effects panel models (see Nickell, 1981). As shown by Chudik et al. (2018), the Nickell bias exists regardless of whether lags of the dependent variable are included or not as regressors, as long as one or more right-hand side variables are not strictly

[11] In this ARDL model, the log of GVA is regressed on p–1 lags of the dependent variable and on p lags of the independent variables: $\text{Log}(y_{it}) = a_i + \sum_{l=1}^{p} \phi_l y_{i,t-l} + \sum_{l=0}^{p} \beta_l \boldsymbol{x}_{i,t-l} + \varepsilon_{it}$, where y_{it} is the log of the real GVA of region i in year t, and $\boldsymbol{x}_{i,t}$ is the vector of controls including GIs and patents. The number of lags p has been set equal to 1, given the quite short timeframe of our panel.

exogenous, as could ultimately be the case with our GI and patent variables.

5. Results

5.1. A preliminary look at the data

Descriptive statistics and correlation matrices are presented in Tables 1 and 2. As the data show, the GVA in the food sector (920 million euros) is higher on average than the GVA in agriculture (663 million euros). The average number of GIs is 0.31 per NUTS-2 region.

The countries with the highest number of PDO (771) and PGI (859) products registered are France (371 registered GI products), Italy (351 registered GI products), Spain (198 registered GI products), Germany (165 registered GI products), and Portugal (157 registered GI products). The most important GI producer regions in the period analysed are Rhône-Alpes (FR71 with 49 GIs), Alentejo (PT18 with 49 GIs), Norte (PT11, with 46 GIs), Emilia-Romagna (ITH5 with 49 GIs), Centro (PT16 with 37 GIs), Veneto (ITH3 with 36 GIs), Andalucía (ES61 with 35 GIs), Midi-Pyrénées (FR62 with 30 GIs), Lombardia (ITC4 with 30 GIs), and Sicilia (ITG1 with 30 GIs).

The panel dataset includes approximately 16,800 food patents and 25,460 agricultural patents in 265 NUTS-2 regions. For food patents, Germany is the most innovative country with approximately 4,120 patents, followed by the Netherlands with about 3,480 patents, France with roughly 1,937 patents, Italy with around 1,545 patents, and the United Kingdom with approximately 1,360 patents. In the domain of agriculture patents, Germany leads again with about 10,510 patents, followed by France with roughly 2,860 patents, the Netherlands with about 2,520 patents, the United Kingdom with approximately 2,200 patents, and Italy with around 1,610 patents. The NUTS-2 regions with the highest activity in food-related technology are Zuid-Holland (NL33) with 1,216 patents, Hovedstaden (DK01) with 932 patents, Ile-de-France (FR10) with 820 patents, Oost-Nederland (NL42) with 697 patents, and Greater London (UKI1) with 593 patents. For agriculture-related technologies, Düsseldorf (DEA1) is the top NUTS-2 innovator with 2,420 patents, followed by Rheinhessen-Pfalz (DEB3) with 2,086 patents, Weser-Ems (DE94) with 987 patents, Zuid-Holland (NL33) with 985 patents, and Ile-de-France (FR10) with 835 patents.

Our explanatory variables tend to be significantly and positively correlated with both dependent variables (food GVA and agricultural GVA) (Table 2). The correlation values among the independent and control variables are, in general, quite low, i.e., below the cut-off point of 0.50 (Hair et al., 2010, p. 189). The only exceptions are the correlations between food patents and agricultural patents, suggesting that technological innovations within the two sectors are not interdependent. Note, however, that the two variables do not enter the model simultaneously.

We check for the existence of multicollinearity issues by measuring the variance inflation factors (VIFs) for each regression with pooled data that are lower than the threshold of 5 suggested by O'Brien (2007) and found that multicollinearity was not a problem.

5.2. Results and discussion

Table 3 shows the results of the panel regression analysis related to the food industry in the EU regions. As discussed above, we use a fixed effects estimator, controlling for observed (and unobserved) heterogeneities at the regional level and time fixed effects to control for idiosyncratic shocks, common to all EU regions (see Models 1a, 2a, 3a, 4a 5a).

Concerning the effects of the control variables, the presence of local scientific universities has a positive, although not significant, impact on the food GVA. This result suggests that the educational services and structures in a region do not play a crucial role in the growth of regional competitiveness in the food industry. Indeed, although the effect is positive, the region's capacity to promote and support the development of relational and innovation-related skills is not a significant driver of competitiveness. In line with our expectations, the effect of a manufacturing specialization, measured as the employment rate in manufacturing activities, is positive and statistically significant ($p < 0.01$) across all specifications. Agglomerations of related regional industrial activities are cost-efficient spatial configurations and can respond to the increasing demand for rapid knowledge transfer between firms and organizations. Product and process innovations, new forms of governance, or new expertise are largely gained through interactive processes within regional industrial systems (Malmberg and Maskell, 1997).

It is surprising, but consistent with other recent research, that the density of the population has a negative and significant effect ($p < 0.01$)

Table 3
Fixed effect panel regression model results on GVA in the food sector.

Dependent variable:	Log (GVA Food Industry)				
	(Mod. 1a)	(Mod. 2a)	(Mod. 3a)	(Mod. 4a)	(Mod. 5a)
Food Patents		−0.0011*		−0.0011*	−0.0010*
		(0.0006)		(0.0006)	(0.0006)
GIs			0.0111***	0.0111***	0.0119***
			(0.0024)	(0.0024)	(0.0027)
GIs × Food Patents					−0.0003
					(0.0003)
Scientific universities	0.0049	0.0046	0.0044	0.0044	0.0044
	(0.0046)	(0.0046)	(0.0046)	(0.0046)	(0.0046)
Population density	−0.4995***	−0.4794***	−0.4832***	−0.4803***	−0.4807***
	(0.0925)	(0.0933)	(0.0932)	(0.0929)	(0.0930)
Manufacturing specialization	2.6410***	2.6249***	2.6428***	2.6367***	2.6382***
	(0.4371)	(0.4373)	(0.4312)	(0.4312)	(0.4309)
Log (GFCF)	0.1586***	0.1599***	0.1584***	0.1582***	0.1583***
	(0.0236)	(0.0223)	(0.0222)	(0.0222)	(0.0222)
NUTS-2 fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	4,770	4,505	4,505	4,505	4,505
Regions	265	265	265	265	265
Years	17	17	17	17	17
Adjusted R^2	0.9868	0.9874	0.9875	0.9875	0.9875

Notes: Clustered standard errors at the NUTS-2 level are in parentheses.
$*p < 0.1$; $**p < 0.05$; $***p < 0.01$.

(Dijkstra et al., 2013, 2015; McCann, 2013). Even though urbanisation is expected to leverage regional competitiveness, in largely populated areas, negative externalities may stem from unskilled workers rather than talents, labour oversupply, insufficient infrastructure investments and higher costs of living and doing business (Marrocu et al., 2013; De Noni et al., 2018). As expected, the effect of gross fixed capital formation (GFCF) on regional competitiveness is positive and significant ($p < 0.01$) across all models, highlighting the positive influence of the acquisition of new and existing regional assets on the efficiency and effectiveness of production processes in the food industry.

Focusing on our key explanatory variables, we can observe some interesting findings. The number of food patents, introduced as an independent variable in Model 2a, is significant ($p < 0.10$) and negatively correlated with the outcome in every regression. Hence, contrary to our expectations, an increase in the (lag) number of regional food-related patents does not lead to an increase in the GVA of the food industry. This negative correlation might reflect two different aspects. First, it could highlight the maturity and stability of the food processing-related activities, which rely mostly on incremental product and process innovations that do not leverage competitiveness, at least in the short run, due to the high costs of producing and protecting them (Blay-Palmer and Donald, 2006). Second, another possible explanation could be linked to the Neo-Schumpeterian approach to innovation. In specific, Aghion et al. (2005) in his theoretical approach demonstrate that the distance of the firms or sectors to the technological frontier explain, together with the level of competition, the behaviour towards the adoption of innovation activities. In this case, the adoption of innovation is almost to be attributed to 'laggard regions', i.e. regions where the agri-food sector is not competitive and show a reduced regional value added. These two different possible interpretations should be empirically validated in future analysis by considering other variables of innovation like, for example, new trademarks, new products or process activities within local economies. Indeed, patents, while generally considered a good proxy for technological progress in a region, are only a part of the story, as they represent innovation inputs (Apa et al., 2018). Also, the consideration of the level of regional competitiveness could be useful to add clarity on the mechanisms surrounding the adoption of innovation in the agri-food sector and long-term regional growth.

Second, and more interesting, we find a strong and positive effect of GIs on regional growth, namely, GI diffusion appears to spur regional competitiveness. The number of GI products was highly statistically significant ($p < 0.01$) in all regressions, consistently having a positive coefficient. Thus, the food industry in European regions gains from the protection and valorisation of products and such policy measure have a positive effect on the competitiveness of local food systems. Such a result adds to Cei et al. (2018) and Raimondi et al. (2018) by giving quantitative insight at the European level into the performance effects of GIs on regional economies, and they expand the findings of Bouamra-Mechemache and Chaaban (2010) by confirming a positive impact of GIs not only in specific agri-food sectors but also on the overall agri-food supply chain. Regarding this last aspect, the results also highlight that GIs have a robust pro-competitiveness effect, especially in the food industry.

To answer our second crucial research question, in Model 5a we add to the specification the interaction term 'GI × Food PAT' to study the extent to which the diffusion of GI dampens or spurs the impact of innovation activities on competitiveness. Its estimated coefficient is negative, suggesting the existence of some substitution relationship between GIs and patenting, but it is not significant at the conventional statistical level. Quantitatively, our estimated GI and patent effects, being semi-elastic, suggest that a new GI (or patent) in the market increases GVA in the food industry by approximately 1% (−0.1%), not a small effect from an economic point of view.

Notwithstanding this quantitative evidence, we can draw some qualitative insights from these results. The negative coefficient could indicate that the more registered GI products a region has, the lower the number of food patents it has, and vice versa. Thus, it might seem that the regions tend to opt for products with a strong origin recognition or on innovation. In other terms, it might be that those regions focusing on GI products are less driven to innovate because they focus mostly on the valorisation of cultural heritage of food products and on traditional use of the *terroir*, rather than investing in new processes, at least when measured through patents. However, it should be considered that the competitiveness effect of the agri-food innovation process may be differently distributed across industries within the region, not only condensed in the agri-food industry. The development of agri-food technologies often involves universities and other research institutions, which are not classified within the agri-food technologies (Cardamone et al., 2018; Rodríguez-Pose and Ganau, 2022). The same may apply to firms that manufacture machinery for food, beverage, and tobacco processing, as well as non-manufacturing industries such as food retail, wholesale, transportation, storage, and beverage service

Table 4
Fixed effect panel regression model results for GVA in agriculture.

Dependent variable:	Log (GVA in Agriculture)				
	(Mod. 1b)	(Mod. 2b)	(Mod. 3b)	(Mod. 4b)	(Mod. 5b)
Agricultural Patents		0.0002		0.0002	0.0002
		(0.0005)		(0.0005)	(0.0005)
GIs			0.0050*	0.0050*	0.0079**
			(0.0026)	(0.0026)	(0.0031)
GIs × Agricultural Patents					−0.0006***
					(0.0002)
Scientific universities	−0.0054	−0.0049	−0.0051	−0.0051	−0.0049
	(0.0054)	(0.0055)	(0.0055)	(0.0055)	(0.0055)
Population density	−0.8530***	−0.7630**	−0.7647**	−0.7633**	−0.7639**
	(0.3249)	(0.3702)	(0.3700)	(0.3703)	(0.3701)
Manufacturing specialization	−0.6549	−0.5578	−0.5523	−0.5510	−0.5398
	(0.6076)	(0.6134)	(0.6113)	(0.6116)	(0.6112)
Log (GFCF)	0.0286	0.0304	0.0296	0.0296	0.0298
	(0.0288)	(0.0269)	(0.0269)	(0.0269)	(0.0269)
NUTS-2 fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	4,824	4,556	4,556	4,556	4,556
Regions	265	265	265	265	265
Years	17	17	17	17	17
Adjusted R^2	0.9646	0.9661	0.9662	0.9662	0.9662

Notes: Clustered standard errors at the NUTS-2 level are in parentheses.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 5
Fixed effect panel regression model results for PDO and PGI.

Dependent variable:	Log (GVA) Food industry		Log (GVA) Agriculture	
	(Mod. 1a)	(Mod. 2a)	(Mod. 1b)	(Mod. 2b)
Food (Agricultural) Patents	−0.0011*	−0.0010	0.0002	0.0002
	(0.0006)	(0.0006)	(0.0005)	(0.0005)
PDO	0.0130***		0.0121**	
	(0.0037)		(0.0056)	
PGI		0.0174***		0.0055
		(0.0042)		(0.0043)
PDO × Food (Agricultural) Patents	0.0000		−0.0006	
	(0.0004)		(0.0004)	
PGI × Food (Agricultural) Patents		−0.0006*		−0.0008***
		(0.0004)		(0.0003)
Scientific universities	0.0045	0.0045	−0.0050	−0.0048
	(0.0046)	(0.0046)	(0.0055)	(0.0055)
Population density	−0.4813***	−0.4789***	−0.7646**	−0.7632**
	(0.0934)	(0.0927)	(0.3703)	(0.3700)
Manufacturing specialization	2.6368***	2.6292***	−0.5423	−0.5509
	(0.4319)	(0.4351)	(0.6106)	(0.6134)
Log (GFCF)	0.1586***	0.1594***	0.0293	0.0306
	(0.0222)	(0.0223)	(0.0268)	(0.0269)
NUTS-2 fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	4,505	4,505	4,556	4,556
Regions	265	265	268	268
Years	17	17	17	17
Adjusted R^2	0.9874	0.9874	0.9662	0.9662

Notes: Clustered standard errors at the NUTS-2 level are in parentheses.
*p < 0.1; **p < 0.05; ***p < 0.01. Only results from the full models are reported in this Table.

activities. Therefore, interindustry learning, knowledge spillovers, and research collaboration are crucial for the food industry's competitiveness (Strøm-Andersen, 2020).

In Table 4, we study the effect of GIs and technology upstream of the food supply chain, i.e., in the agricultural sector, using the same battery of regressions. If we analyze the results of the control variables on the GVA in agriculture, we can observe similar impacts to those reported in Table 3, but with weaker statistical significance. The only significant difference is related to the effect of manufacturing specialization on the competitiveness of local agricultural systems. As expected, in regions with a high employment share in manufacturing activities and with larger industrial agglomerations, the competitiveness of the agricultural sector is lower.

Additionally, the effect of the presence of scientific universities is negative, although not significant. This could suggest a disconnection between the scientific/academic world and agricultural activities in the various European territories compared to food industry-related activities.

Regarding the effects of our key explanatory variables on agricultural GVA, we find similar signs that we found with the food industry, although the level of significance is somewhat lower. First, innovation, as measured by agricultural patents, has a positive effect on agricultural GVA, although its estimated coefficient is small and not statistically insignificant. A possible interpretation of this small effect of patents on agricultural GVA, is that by starting with an already high rate of technological adoption in agriculture, regional economies are experiencing decreasing returns to scale. Therefore, a variation in the number of patents with respect to the regional average has no significant effect on improvement in local system competitiveness or that most agricultural innovations do not turn into real product or process innovation capable of improving regional performance in terms of GVA.

We confirm the significant and positive effect (*p*-value <0.05 in the full model 5b) of GI products on the competitiveness of local systems. This means that the impact of GIs is relevant not only in supporting competitiveness downstream in the agri-food supply chain but also in leveraging the value of raw materials, intermediate inputs, and agricultural products, which are very sensitive to international competition from non-EU countries. However, note that quantitatively, the magnitude of the GI effect on agricultural competitiveness is approximately half of the food industry effect, *ceteris paribus*.

Model 5b in Table 4 adds the interaction term between GIs and patents. Its estimated coefficient is negative and statistically significant at 1%. This result is in line with the negative effect discussed above, suggesting that in agriculture, more than in the food industry, GIs and innovations tend to be substitutes in affecting competitiveness, *ceteris paribus*. The results could be interpreted by taking into consideration the level of technology advancement of regions and the level of competition of agricultural firms in the different EU regions. Indeed, findings could suggest that in those regions with a high presence of GIs the level of competition of firms is low and their innovation capacity as a consequence. Such argument could be in line with the neo-Schumpeterian literature which takes into consideration competition, regulation, and innovation performance (Arrow, 1962; Aghion et al., 2005).

To add insights to our analysis, in Tables 5 and 6 the effect of GIs has been split in PDOs and PGIs effect (Table 5) and also considering the main GI product categories (Table 6). Table 5 reveals a positive impact of PDOs both on agricultural and food industry value added. Also, it reveals a positive relationship of PGIs with the value added of the food industry, but not, as expected, in agriculture.

Such finding confirms the strategic role of PDOs for both agriculture and the food industry. The strict rules associated to the area of production and processing for such indication lead to the overall growth of the regional agri-food system and from a policy perspective gives quantitative evidence of the efficacy of such normative instrument for rural development and local competitiveness. Such evidence confirms existing qualitative studies dealing with the socio-economic effect of PDOs on local economies (Schimmenti et al., 2021; Donati et al., 2021; Vakoufaris, 2010) and, more generally, the literature dealing with the role of territory on the economic competitiveness throughout different organizational forms, i.e. industrial districts, local agri-food systems, and other existing interbranch organizations (Arfini et al., 2019; Sforzi and Mancini, 2012). As expected, the adoption of PGIs has an effect only

Table 6
Fixed effect panel regression model results for different categories of GIs.

Dependent variable:	Log (GVA Food Industry)					Log (GVA in Agriculture)				
	(Mod. 1a)	(Mod. 2a)	(Mod. 3a)	(Mod. 4a)	(Mod. 5a)	(Mod. 1b)	(Mod. 2b)	(Mod. 3b)	(Mod. 4b)	(Mod. 5b)
	Meat	Dairy	Oil	Fruit &Veg.	Others	Meat	Dairy	Oil	Fruit &Veg.	Others
Food (Agricultural) Patents	−0.0010*	−0.0010*	−0.0011*	−0.0010*	−0.0011*	0.0002	0.0002	0.0002	0.0002	0.0003
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0004)
GIs (by category)	0.0101***	0.0284***	0.0258**	0.0074	0.0333***	0.0047	0.0116	0.0392***	0.0167**	0.0024
	(0.0037)	(0.0059)	(0.0101)	(0.0080)	(0.0103)	(0.0046)	(0.0090)	(0.0120)	(0.0072)	(0.0130)
GIs × Food (Agricultural) Patents	−0.0000	−0.0007**	−0.0009	−0.0003	−0.0000	−0.0002	−0.0005	−0.0026***	−0.0017***	−0.0021***
	(0.0005)	(0.0003)	(0.0012)	(0.0007)	(0.0014)	(0.0005)	(0.0005)	(0.0009)	(0.0004)	(0.0007)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NUTS-2 fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,505	4,505	4,505	4,505	4,505	4,560	4,560	4,560	4,560	4,560
Regions	265	265	265	265	265	265	265	265	265	265
Years	17	17	17	17	17	17	17	17	17	17
Adjusted R^2	0.9874	0.9875	0.9874	0.9874	0.9874	0.9661	0.9661	0.9662	0.9662	0.9662

Notes: Clustered standard errors at the NUTS-2 level are in parentheses. * p<0.1; **p<0.05; ***p<0.01.Only results from the full models are reported in this table. Control variables are included in all the models, though not displayed due to space limitations. Meat (469) = Class 1.1. Fresh meat + Class 1.2. Meat products; Dairy (438) = Class 1.3. Cheeses + Class 1.4. Other products of animal origin; Oil (142) = Class 1.5. Oils, fats + Class 3.2. Essential oils; Fruit & Vegetables (410) = Class 1.6. Fruit, vegetables; Other (245) = All the other categories (e.g. bread, pastry, pasta, fresh fish, seafood, beer).

on the GVA of the food industry because such indication relates mainly to products with a processing phase, whereas GIs impacting on agricultural value added refer mostly to unprocessed food.

Interestingly, the adoption of PGIs has a stronger impact on the value added of the food industry than PDOs. Even if for PGIs it is mandatory that only one phase of the processing phase takes place within the protected geographical area, the results seem to suggest that many productions probably carry out all the processing phases within the certified area as for PDOs. As consequence, many products are PGI certified even if they are substantially like PDOs. The decision to rely upon the PGI certification could be related to the willingness of firms to maintain a higher flexibility in case of changing inputs market and/or institutional conditions. Also, even if the authorization process and the rules applied for PGIs are softer than for PDOs, consumers tend to give the same market value to GIs without giving a precise difference between PDOs and PGIs. This is due to a lack of consumer awareness of these labels (Grunert and Aachmann, 2016; Likoudis et al., 2016). Generally, consumers link these two certifications with quality, valorisation of the product origin and protection of producers without distinguishing among the rules to be applied for PDOs and PGIs (Dias and Mendes, 2018).

Table 6 reveals that the certified product categories that positively contribute to the value added of the local food industry are mainly meat, dairy, oil, and other products. For agricultural value added the oil and fruit and vegetables categories has a positive and significant effect. For all the categories considered the interaction between GIs and patent is confirmed to be always negative, even though it is statistically significant only for Dairy in the food industry and for Oil, Fruit and Vegetables and the residual Other categories in agriculture.

Overall, these findings confirm an important role of the largest categories of agricultural products and food stuffs under GIs in terms of sales value also for the growth of regional economies. Indeed, cheeses represent more than one third of the total EU28 sales value for GIs agrifood products, meat products (including fresh, cooked, salted, smoked, etc.) represent the 28% of the total sales value, fruits and vegetables account for the 8% of the total value (European Commission, 2021). Interestingly, the oils category appears to affect positively the value added of both the agricultural sector and the food industry even if it is not among the important categories for its economic value at European level (it represents around the 2% of the GI value). This is mostly related to the specificities of this category in terms of soil and climate conditions which are necessary for the production. Also, it refers to small business with relative low production quantities, that do not register high sales value like in other sectors, such as, for example, for meat or dairy sectors. However, the findings clearly indicate a positive contribution of such category for the development of local economies, both for the agricultural sector and the food industry.

The interaction between GIs and patents is confirmed to be negative but statistically significant for some categories both in agriculture and in the food industry. This result could suggest that innovation plays a conflicting role in the mature and low-tech agri-food industry, where incumbents have little prior knowledge on how to exploit innovation opportunities (such as the transition towards the bioeconomy), resulting in a diffidence towards the investment and radical technological development needed to enhance industry competitiveness. From this perspective, it is fair to point out that, in recent decades, the food industry has been supported by the increasing entry of smaller companies able to challenge the dominant agri-food mainstream model and to potentially introduce novelty and more disruptive innovations (for instance, supporting the development of new distribution channels such as home delivery, trade shows, or community-shared agricultural buying groups). However, despite such opportunities, these new smaller companies complain of multiple constraints and restrictions stemming from the reluctant and protectionist behaviour of larger incumbents and outdated policies (Blay-Palmer and Donald, 2006). These constraints and barriers might become even stronger in regions characterized by a large presence of GIs because of the desire to protect local products and cultural heritage.

5.3. Robustness check

Table 7 reports some robustness checks based on the ARDL model, estimated with both a standard fixed effects model and the half-panel jackknife fixed effects (xtspj) estimator, to address Nickell bias in a dynamic panel with a large N/T. As discussed above, a crucial property of the xtspj estimator is its consistency in the presence of regressors that are not strictly exogenous, such as the GIs and patents in our model. In addition, the autoregressive term will account for the model dynamics, controlling for time-varying omitted variable bias.

Overall, the results from the dynamic panel model confirm, with some minor changes, the results discussed above. First, according to Chudik et al. (2018), when the model is run with the xtspj estimator (columns 2 and 4), the magnitude of the estimated coefficients is normally higher and more significant, confirming that Nickell bias is

Table 7
Robustness checks: results from the dynamic panel model.

Dependent variable:	Log (GVA) Food industry		Log (GVA) Agriculture	
	xtreg	xtspj	xtreg	xtspj
Log (GVA) t-1	0.8525***	0.8824***	0.6298***	0.7114***
	(0.0113)	(0.0073)	(0.0281)	(0.0112)
Food (Agricultural) Patents	−0.0002	−0.0001	−0.0000	−0.0001
	(0.0002)	(0.0003)	(0.0002)	(0.0005)
GIs	0.0019**	0.0039***	0.0021	0.0029
	(0.0008)	(0.0011)	(0.0015)	(0.0026)
GIs × Food (Agricultural) Patents	−0.0001	−0.0002	−0.0002**	−0.0002
	(0.0001)	(0.0002)	(0.0001)	(0.0003)
Scientific universities	0.0007	−0.0003	−0.0014	−0.0010
	(0.0011)	(0.0010)	(0.0023)	(0.0020)
Population density	−0.0669***	−0.0470**	−0.2160	−0.1398***
	(0.0233)	(0.0208)	(0.1819)	(0.0469)
Manufacturing specialization	0.0752	0.2471***	−0.1904	−0.0828
	(0.0744)	(0.0592)	(0.1863)	(0.1293)
Log (GFCF)	0.0088	0.0151***	0.0054	0.0039
	(0.0059)	(0.0041)	(0.0112)	(0.0084)
NUTS-2 fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	4,505	4,505	4,556	4,556
Regions	265	265	268	268
Years	17	17	17	17
Adjusted R^2	0.7981	n.a.	0.4346	n.a.

Notes: The table reports results from the ARDL models, where the log of GVA is regressed on p–1 lags of the dependent variable and the p lags of the independent variables: $\text{Log}(y_{it}) = a_i + \sum_{l=1}^{p} \phi_l y_{i,t-l} + \sum_{l=0}^{p} \beta_l \boldsymbol{x}_{i,t-l} + \varepsilon_{it}$, where y_{it} is the log of real GVA of region i in year t, and $\boldsymbol{x}_{i,t}$ is the vector of controls, including GIs, patents and their interaction term. The number of p lags has been set equal to 1. The figures in the table refer to short-run coefficients. The long-run coefficients discussed in the text are calculated from the short-run coefficients as follows: $\beta^{LR} = \phi^{-1}\beta^{SR}$ with $\phi^{-1} = 1 - \phi$.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$; robust standard errors clustered within regions are in parentheses.

present in the fixed effects counterpart (columns 1 and 2). The autoregressive terms are, not surprisingly, strongly significant, with a magnitude generally larger than 0.7, suggesting that in the food industry, and less so in agriculture, competitiveness is a persistent feature in European regions. In the dynamic model, the effect of patents, although still negative, is no longer ever statistically significant in either the food industry or agriculture sector. This suggests that the static model results could be affected by problems of reverse causation. The estimated effect of GIs on competitiveness is positive as before in both the food industry and agriculture. However, only in the food industry is the coefficient estimated with great precision, confirming that the diffusion of GIs affects competitiveness mainly in the food sector. Note that this result is not surprising when one realizes that more than 70% of GIs are indeed classified as processed food and that in recent decades, there has been an explosion in PGIs, which tend to have a weaker link with the local agricultural sector than PDO products. The long-run effect of GIs on food industry competitiveness, when estimated with the half-panel jackknife fixed effects model, is equal to 0.033 (=0.0039/(1–0.882)). Interestingly, this estimated effect is more than three times larger than the coefficient of the static model (see Table 3, column 5), suggesting that the endogeneity of GIs to competitiveness tends to create a downward bias on the estimated effect. Putting this number into context, it means that quantitatively, a new registered GI, on average, induces an increase in the regional competitiveness of approximately 3.3 percentage points, which is not an irrelevant economic effect.

Finally, turning to the key research question of the paper, namely, the extent to which GIs and innovations interact at the regional level, in affecting competitiveness, the results from the dynamic panel model confirm the previous evidence discussed above. We find only some weak evidence that a sort of substitutability between GIs and patents could eventually be present at the regional level. Indeed, the estimated effect of the interaction between GIs and patents, although always negative in the dynamic models, is statistically significant only for agriculture sector when the fixed effects dynamic model is considered, but not with the half-panel jackknife fixed effect estimator.

6. Concluding remarks

The set of research hypotheses investigating the impact of GIs and innovation on regional competitiveness offers interesting insights into the existing literature concerning the effectiveness of regional food policies. A first consideration emerges directly from the positive relationship between GIs and the GVA of the agricultural sector and, particularly, of the food industry at the regional level.

Following a robust quantitative analysis, the findings confirm that such a policy measure can be considered a tool that can not only legally protect products in the international market but also foster competitiveness at the regional level within European regions. This is in line with the characteristics of GIs, which are present within the European territory. Indeed, almost 70% of GIs are processed food, and there has been a huge expansion of PGIs in recent years, which weakens the link with regional agriculture and, consequently, their effect on agricultural performance at the territorial level.

The present findings show also negative relationship between innovation and competitiveness at regional level, highlighting that innovation activities proxied by patents do not significantly affect regional competitiveness both in agriculture and the food industry. The negative relationship could be attributed to the low level of innovations in the mature and stable sectors, like food industry (Blay-Palmer and Donald, 2006), where there is a high cost of implementation and a time lag between investment costs and returns.

However, it is important to recognize that patents are only a part of the technological path of innovations, as discussed by Apa et al. (2018). According to Ruiz et al. (2018), firms producing GIs introduce innovation to respond to changing market demand for the quality characteristics of food products through variations in amendments that mostly relate to production processes. However, most of these innovations are not patented although they produce positive effects on firm competitiveness, as underlined by Marescotti et al. (2020), Mancini et al. (2019) and Guerrero et al. (2009).

This logic can also partially explain the relation between GIs and patents, which is only weakly supported by the present study. Our models show only weak evidence that GIs interact with innovation incentives in affecting GVA in agriculture. Such a finding is also partially confirmed for the food industry, which shows a negative but nonsignificant interaction effect between GIs and patents, at least when estimated aggregating GI products. However, the lack of significance may also suggest that there are regions and or specific GI sectors where this matching potentially exists, as showed for the dairy sector, but it is not the general rule. From this perspective, future research should also take into consideration other kinds of innovations to test whether such results are confirmed or if it is possible to reveal strong interaction effects between GI adoption and different innovation strategies, as suggested by Moerland (2019) and Josling (2006).

Our work also offers some interesting insights from a policy perspective. The positive relationships between GIs and the GVA in the agricultural sector and food industry, empirically demonstrate that the European GI policy framework is successful in supporting not only rural development but also the overall competitiveness of agri-food supply chains. Moreover, quantitatively, our results reveal that a new GI entering the market contributed, on average, 1% growth in GVA for the food industry and 0.5% for agriculture, highlighting the strategic role of such policy interventions in fostering regional economies. From a policy perspective, the interaction between innovation and such normative intervention remains a crucial aspect to understand and further investigate, especially considering the forthcoming implementation of the European farm-to-fork strategy. Indeed, the achievement of the green goals of European agri-food policy calls for process innovation at the supply chain level that will be able to support its transformation towards environmentally sustainable production processes and achieve its carbon neutrality goal for the food system. Within such policy options, the GI policy needs to be evaluated in depth and eventually reframed in line with such normative targets.

All these considerations illustrate the need for local policies to promote knowledge transfers in the agri-food sector according to an open innovation perspective that is far from completely exploited yet and to the need for sector-specific instruments that promote the transition from invention to innovation and can help overcome the European paradox, which is particularly evident in the agri-food industry. In this light, local governments should define new policies to foster the entry and growth of new innovative firms that can increase industry dynamism by inspiring and exploiting radical innovation opportunities. Moreover, despite the weak interactive effect between patenting and GIs, matching tradition and innovation should not be thought of as a conflictual linkage but as an auspicious opportunity to further increase the competitiveness of GIs and, in turn, the competitiveness and the sustainability of the whole agri-food sector.

This study has different limitations that should be highlighted. First, while agri-food patents are a good proxy of innovation performance in regions, they are only one component of the possible indirect effects of GIs on the economic growth of local economies. Apart from regional innovation performances, there are other variables which can be considered, such as the presence of activities producing goods similar to GIs in the same geographical area which contributes to the increase of the agri-food value added, or the presence of existing interbranch organizations related to GIs which strengthen local economic relationships and foster the stability of economic activities and the preservation of agricultural labour within a certain territory (Dentoni et al., 2012).

Second, the lack of reliable regional data on the food industry's competitiveness led to the use of proxy measures that call for caution in results interpretation. Third, the analysis does not consider the characterization of innovation, in terms of size, value, type, and quality of innovation and this limits the exploration in depth of present findings. Therefore, the study suggests that further investigation is needed to explore the relationship between the regional competitiveness of the agri-food sector and the quality and types of innovation, including the differentiation between incremental, radical, and breakthrough inventions using backward and forward patent citations. This approach could provide a better understanding of the insignificant impact of technologies on regional competitiveness and the negative impact of their interaction term with GIs. Additionally, future research should examine how GIs in the wine sector, which exhibit unique characteristics, influence the innovation activities of local systems, and enhance their competitiveness.

CRediT authorship contribution statement

Stefanella Stranieri: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Luigi Orsi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation. **Federico Zilia:** Writing – review & editing, Software, Methodology, Formal analysis. **Ivan De Noni:** Software, Methodology, Data curation. **Alessandro Olper:** Writing – review & editing, Writing – original draft, Supervision, Software, Formal analysis, Conceptualization.

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.

Data availability

Data will be made available on request.

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