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Latent relationships between environmental impacts of cultivation practices and land market: Evidences from a spatial quantile regression analysis in Italy

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A B S T R A C T

Several economic approaches can be carried out for managing the environmental impacts in agriculture, i.e. property and bargaining rights, economic incentives, ecological fees, etc. These approaches can be mainly applied to the cultivation phase or to the markets of the agricultural commodities. However, a further ambit in which the regulatory systems could be useful to trigger sustainable cultivation practices is the farmland market. Hence, this study contributes to the setting of market mechanisms based on incentives or fees related to the environmental impacts of farming practices for reducing the pressures of the production processes on the environmental components.

The study, through a hedonic pricing method based on a spatial quantile regression and integrated by an environmental analysis, highlights different trends of land value determinants along the quantiles of the selling prices as the intensity of the cultivation system varies. The results show that the most important value determinants of the vineyards cultivated through the semi-extensive production system are related to the quality of grapes. Conversely, in presence of the intensive production system, the most important value determinants are related to the high yields, which also generate high greenhouse gas emissions, in contrast with the "polluter pays" principle.

The results allow the assessment of the implicit marginal prices concerning the impact of the environmental indicator on land value per cultivation system, so as to favour the setting of regulatory monetary strategies able to foster farmers towards cleaner agricultural practices.

1. Characteristics of farmland market

Land is the most important part of the capital invested in farm, and its availability can generate economies of scale capable of increasing the efficiency of the production processes, as well as the productivity of machineries and labour. In general, land demand consists of (Povellato, 1997): i) professional farmers attracted by land on the extent of which it is able to generate income, so that this demand is highly selective towards natural (fertility, slope, etc.) and production (access to irrigation water, production system, etc.) characteristics, is strongly linked to the market of the agricultural products, and is affected by the agricultural policies that support income; ii) non-farmers, which consider also alternative uses of land mainly in the urban fringe areas, where the agricultural characteristics of land are marginal, while the accessibility, the presence of buildings and the distance from non-agricultural production areas are the most important factors that affect its value. Thus, the land value determinants can be classified as: i) intrinsic and closely related to land productivity and territorial elements, i.e. environmental and landscape characteristics (Randall, 1987; Pearce and Markandya, 1989); ii) inherent to the socio-economic aspects of the economic operators involved in the trading; iii) concerning the economic, political and social forces during the trading. On this last point, the role of the economic trends is important, with particular reference to the alternatives of investment in the urban real estate market and to financial markets. In this case, a central role is played by the inflation trend, so that when land is considered a "shelter good", its value mainly depends on inflation expectations rather than on its profitability (Zuccolo, 1993), with consequent speculative effects by non-farmers. Land value is also influenced by

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monetary (through the interest rates) (Grillenzoni and Bazzani, 1995) and fiscal policies (Povellato, 1997), as well as by social factors (Sillani, 1994) concerning the quality and quantity of services related to land ownership, extra-agricultural profitability and the absence of the land rental market. Finally, also urban and territorial planning affect land market dynamics, since urban, landscape and environmental plans influence directly and indirectly land uses, often through law restrictions.

Concerning the assessment of the farmland value, land quality, i.e. the set of chemical, physical and biological characteristics able to ensure adequate qualitative and quantitative production, is the most important determinant. Therefore, the discounting of the expected income flow is one of the most widely used approach (Alston, 1986; Featherstone and Baker, 1987), which, however, can generate incorrect short-term estimates due to the exclusion of other use and non-use values, in particular the existence and bequest values (Awasthi, 2014). In addition, in the long run, the approach does not consider market conditions capable of influencing land value (Falk and Lee, 1998), i.e. cyclical fluctuations (Awasthi, 2014), financial bubbles (Featherstone and Baker, 1987), risk aversion and transaction costs (Chavas and Thomas, 1999; Just and Miranowski, 1993). The analysis of the hedonic price, on the other hand, is an assessment method belonging to the macro-category of the revealed preference methods, and uses regression techniques in order to infer the implicit marginal prices of the land features. The approach allows to explore further factors, such as soil (Patton and McErlean, 2003; Choumert and Phélinas, 2015), climatic and orographic (Mendelsohn et al., 1994; Maddison, 2000) characteristics, proximity to agricultural markets (Merry et al., 2008; Choumert and Phélinas, 2015), size of plots (Jayne and Wineman, 2018), but also aspects not closely connected to the agricultural configuration of land, such as the presence of energy infrastructure (Sardaro et al., 2018a, 2019), the proximity to urban centres (Plantinga et al., 2002; Guiling et al., 2009; Sklenicka et al., 2013) and the distance from natural elements (Ma and Swinton, 2011).

The literature highlights that the studies on the influence of the environmental impacts from farming on land value are absent (land market failure), as well as on the economic instruments to correct the related distortions. Indeed, in recent decades, agriculture has been affected by a massive intensification of the production processes in order to improve yields, therefore land profitability. This result can be obtained through one or more of the following strategies: intensive conversion of land use (from fallow or annual crops to permanent crops, from dry to irrigation systems, etc.); greater use of production factors and inputs (machineries, labour, irrigation water, pesticides, fertilizers, power, etc.); use of more productive plant varieties; monoculture (Martin et al., 2018). The main reasons for the adoption of the intensive production systems lie both in the significant growth of the food demand by 2050 and in the change of the future food preferences in terms of increase in caloric and protein content (Tilman et al., 2011). Therefore, the intensive production systems play a crucial role in future development strategies (Rockström et al., 2017; DeClerck et al., 2016). However, despite these reasons, the benefits from the intensive agricultural systems are often related to negative environmental impacts on local and global scale (Pe'er et al., 2014; Hertel et al., 2014). In addition, the intensification of production for food purposes clashes with the land demand for the conservation of biodiversity (protected areas) and the energy security (biofuels), with consequent pressures on land properties. Thus, the agricultural production systems are characterized by different levels in the use of production factors and inputs per unit area, which can affect the duration of the life cycle of plants and their sanitary status, as well as the yields and the production quality. In particular, in the intensive areas, vigorous plants and high yields are important determinant of land value, mainly in the presence of permanent crops, i.e. orchards, olive groves and vineyards. These characteristics are favoured by a high soil fertility, but mainly through the massive use of inputs. On the contrary, in the extensive areas, land value is chiefly affected by determinants able to ensure the quality of production.

That said, the study was aimed at the assessment of the influence of farming environmental impacts on the selling price in presence of cultivation systems with different intensity. In particular, the real estate study was integrated through an environmental analysis focusing on the estimation of an indicator concerning the greenhouse gas emissions related to the quantities of inputs used in the cultivation practices. The results shed light on how the intensity of different cultivation systems, interpreted in environmental terms, affected the farmland value. This approach favours the calibration of specific policy interventions for land market aimed at mitigating the negative externalities of the agricultural production processes, and at efficiently allocating the positive ones (Kroeger and Casey, 2007).

2. Materials and methods

2.1. Study area

The study concerns the vineyards for the production of wine grapes located in the northern Apulia, namely in the following municipalities: Andria, Barletta, Bisceglie, Canosa di Puglia, Minervino Murge, San Ferdinando di Puglia, Trani and Trinitapoli, in the province of Barletta-Andria-Trani; Cerignola, Ortanova, Stornara and Stornarella, in the Province of Foggia (Fig. 1). In these territories, winegrowing is the second most important agricultural sector behind olive growing, characterised by 40% of the farms and 30% of the utilised agricultural area (UAA) (Istat, 2010).

The natural and heterogeneous characteristics of this area influence the intensity of use of production factors (mainly machineries and labour) and inputs (fertilizers, pesticides, irrigation water, power, fuel, etc.), thus two cultivation systems for winegrowing are widespread (Table S1):

a) the semi-extensive "*Espalier*" system, based on two vine-shoots per vine that ensure medium-low yields (9–16 t ha^{-1}) and characterised by a low use of inputs, also for the presence of local varieties; it is mainly widespread in the inner and hilly territories, and is often related to the production of Protected Designation of Origin (PDO) wines;
b) the intensive "*Tendone*" system, based on several vine-shoots per vine (even more than four) and able to ensure sizeable yields per hectare (even four/five-fold than the semi-extensive one) by higher quantities of inputs and more productive varieties; it is widespread in the flat and fertile territories, and is often related to the production of table wine.

2.2. Variables and data collection

Between September 2017 and June 2019, two samples of vineyards traded between January 2012 and April 2019 were gathered, corresponding to a relatively stable period in the local farmland market. In particular, the samples concerned the intensive "*Tendone*" system ($n = 187$) and the semi-extensive "*Espalier*" system ($n = 158$) (Table 1), whose data were gathered through 50% of both lawyers and real estate agencies located in each considered municipality, so that half of the total land properties traded in the considered period were likely included in the analysis.

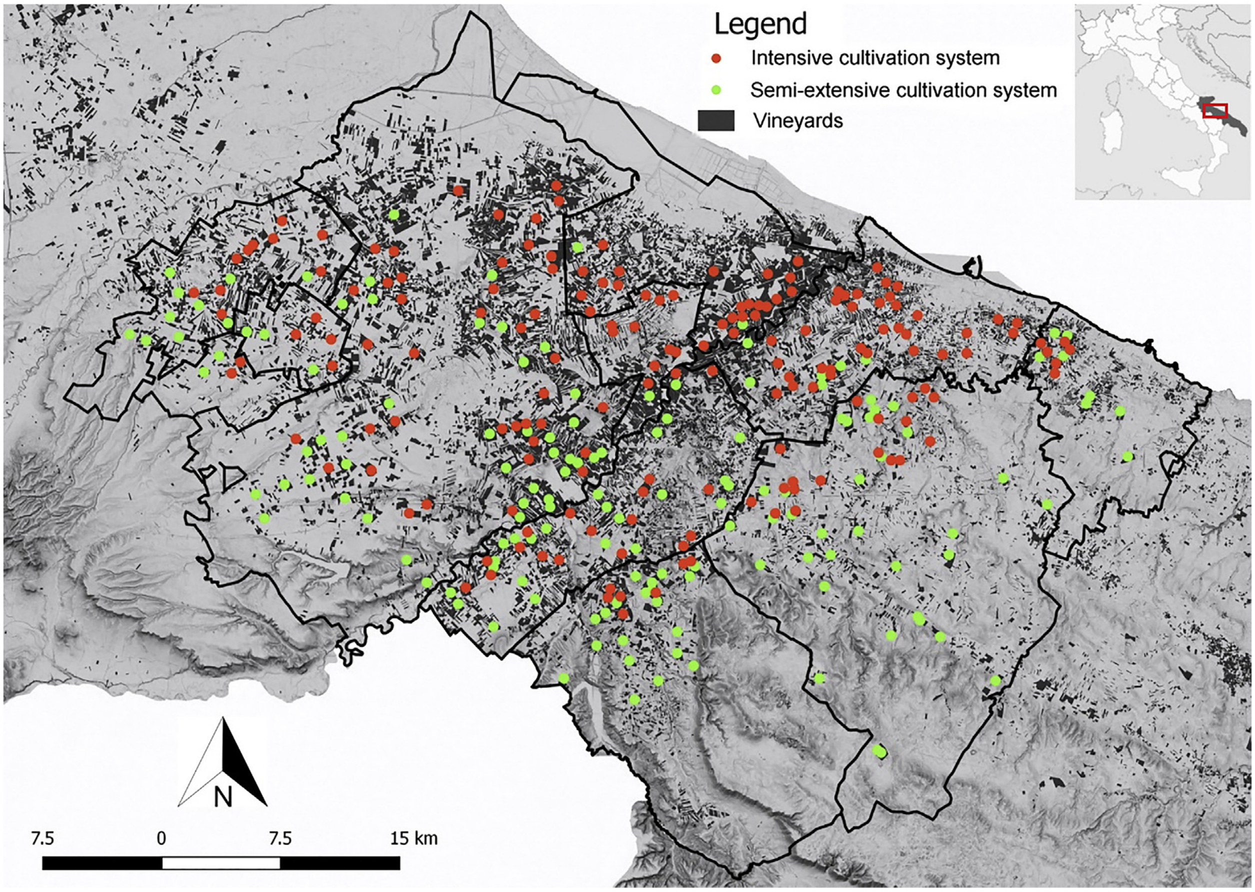

Fig. 1. Study area and traded vineyards.

Table 1
Agronomic characteristics and inputs of the traded vineyards, per cultivation system.

Variables	U. m.	Intensive cultivation system (n = 187)					Semi-extensive cultivation system (n = 158)					*t*-test sign.
		Min.	Max.	Mean	Std. dev.	Expec. sign.	Min.	Max.	Mean	Std. dev.	Expec. sign.	
Agronomic characteristics												
Price	€ ha^{-1}	43,775.10	76,873.38	61,830.66	25,472.04		33,654.01	69,673.81	54,888.52	33.561.77		***
Area	ha	1.14	16.83	2.59	5.40	+	0.72	29.18	3.79	9.60	+	**
Yield	t ha^{-1}	165.18	39.55	28.59	21.62	+	8.70	16.02	10.24	10.51	+/−	***
Age	Years	6	19	15.18	11.27	−	4	26	18.42	12.66	−	***
Slope	%	0	5.46	2.76	3.04	−	0	6.31	3.67	4.95	−	***
Distance [a]	km	1.76	23.18	12.49	13.62	−	3.19	17.28	9.82	14.25	−	**
Road	No/Yes	0	1	0.22	0.26	+	0	1	0.14	0.29	+	**
PDO	No/Yes	0	1	0.25	0.14	+/−	0	1	0.48	0.18	+	***
Inputs [b]												
Vines	n	1,600	2,000	1,852.19	148.39		3,080	5,000	4,178.23	787.19		***
Chemical fertilizers	kg ha^{-1}	331.00	589.00	411.53	193.84		141.15	368.00	283.12	103.52		***
Manure	t ha^{-1}	–	–	–	–		1.16	5.38	2.21	4.90		-
Herbicides	kg ha^{-1}	0.80	1.60	1.38	0.77		–	–	–	–		-
Fungicides	kg ha^{-1}	11.6	26.9	15.53	16.91		4.39	11.26	6.17	4.39		***
Insecticides	kg ha^{-1}	1.12	2.84	1.83	1.90		0.45	1.49	0.77	0.72		***
Irrigation water	m^3 ha^{-1}	2,216.71	3,742.44	2,773.29	1,058.02		827.16	1,966.83	1,353.06	668.72		***
Power	MJ ha^{-1}	0	8,521.33	5,759.17	5,101.34		0	4,670.20	2,284.71	3,390.56		***
Fuel	kg ha^{-1}	261.18	753.41	577.22	498.39		173.25	436.61	369.71	388.66		***

* Sign. 10%; ** Sign. 5%; *** Sign. 1%.

[a] the distance was measured between the centroid of the vineyard and the nearest peripherical edge of the nearest urban centre.

[b] the values are the medians of the inputs' quantities used during the three years before the sale.

Furthermore, a power analysis indicated a minimum sample size of 142 (power 0.80, Bonferroni-adjusted alpha 0.034, R-sqr-change 0.025). The cultivated varieties were: Sangiovese, Lambrusco, Trebbiano and Garganega for the intensive system; Montepulciano, Uva di Troia, Bombino Bianco and Pampanuto for the semi-extensive one.

Direct interviews to lawyers (4), brokers (7) and winegrowers (22) allowed to identify several agronomic variables able to affect the selling price of vineyards, namely (Acciani and Sardaro, 2014): the farm area (coded as *Area* and expressed in hectares), related to economies of scale of labour and capital; the yield (*Yield* – tonne hectare^{-1}), which influences revenues; the age of the vineyard (*Age* - Years), which affects the quality of grapes; the land slope (*Slope* - %), related to the type and to the efficiency of the mechanized practices; the distance between the vineyard and the nearest urban centre (*Distance* - kilometres), which indicates a faster transfer of commodities to/from markets, as well as an easier accessibility to schools, hospitals, etc., and possible advantages from future land urbanization; the location along highways or provincial roads (*Road* - Yes/No), which further increases the previous advantages; the location in a PDO territory (*PDO* – Yes/No), which indicates the quality and value of grapes. The variable concerning the irrigation water was not considered in the analysis as this natural resource was always available in the traded vineyards of both samples. Finally, in order to assess the environmental impact of the cultivation practices on farmland market, the quantities of the inputs used were collected and referred to the last three years before the sale. The expected signs of the relationship between each variable and the selling price are showed in Table 1. In general, the variables that enhance yields have positive effects on the value of the intensive vineyards, while the predictors able to ensure the quality of grapes are crucial for the value of the semi-extensive vineyards.

Data concerning the selling price and the area were collected through real estate transfer acts (76%) and real estate agencies (24%). *Yield*, *Age*, *PDO* and inputs variables were collected at four agricultural assistance centres through face-to-face based questionnaire interviews of approximately 70 min to the sellers of the traded vineyards. Finally, the *Slope* variable was measured through the territorial information system of Apulia Region (http://www.sit.puglia.it/), while the *Distance* and *Road* variables were detected by Google Maps. The missing data of 17 vineyards were gathered by direct inspections on the properties.

2.3. *Carbon footprint analysis*

In order to investigate how farmland market is indirectly affected by the environmental impacts of the cultivation practices, the inputs' variables were used to calculate a synthetic indicator (carbon footprint - CF) for each traded vineyard. The choice of this indicator was due to the strong relationship between agriculture and anthropogenic greenhouse gas (GHG) emissions. In particular, CO_2 emissions by the primary sector amount to about 11% and can be mostly attributed to fossil fuel combustion and land use change, while CH_4 and N_2O emissions account for 60% and 70% of anthropogenic ones, respectively, and are mainly attributed to livestock and fertilizers (Adewale et al., 2019; Yan et al., 2015). Consequently, mitigation measures for the agricultural sector can contribute to stabilize the global anthropogenic GHG emissions, and their quantification is a widely accepted approach for addressing both the impact of efficiency of farming practices (Jradi et al., 2018) and the environmental hotspots in the product value chains in the most efficient way (Bartocci et al., 2017; Dubey and Lal, 2009; Soode et al., 2015). As a result, quantification of GHG emissions from the agricultural sector is crucial for setting climate change policy (Adewale et al., 2019), and the use of CF allows to furnish information for effective policy and decision-making. Thus, the appropriateness of CF is related to its direct relationship to global warming and to its capacity in representing other underlying environmental impacts linked to energy use (Rugani et al., 2013; Navarro et al., 2017b; Weidema et al., 2008).

CF belongs to the Life Cycle Assessment (LCA) approach, measures CO_2 emissions directly and indirectly caused by an activity or accumulated during the lifecycle of a product or service (Wiedmann and Minx, 2007), and is expressed in kg CO_2-equivalent (CO_2-eq) per functional unit of the product (e.g. one kg of grapes, a bottle of wine, 1 ha of vineyard, etc.), depending on the boundaries of the system and on the aim of the analysis.

The winemaking process consists of the agricultural (vineyard planting and grape production) and industrial (vinification, bottling, packaging, distribution and waste management processes) phases. Several studies applied the LCA methodology in order to evaluate the environmental performance of the entire process (e.g. Notarnicola et al., 2003; Aranda et al., 2005; Ardente et al., 2006; Pizzigallo et al., 2008; Gazulla et al., 2010; Point et al., 2012; Vázquez-Rowe et al., 2012a,b; Benedetto, 2013; Neto et al., 2013), also focusing on CF (e.g. Colman and Päster, 2009; Smyth and Russell, 2009; Cholette and Venkat, 2009; Bosco et al., 2011; Pattara et al., 2012; Rugani et al., 2013; Vázquez-Rowe et al., 2013; Pattara et al., 2017; Navarro et al., 2017a). However, only a few studies focused on CF related to the sole agricultural phase (Kavargiris et al., 2009; Venkat, 2012), whose results highlighted that the cultivation practices contribute from 17% (Rugani et al., 2013) up to 40% (Benedetto, 2013; Neto et al., 2013) to greenhouse gas (GHG) emissions of the entire winemaking process.

In particular, fertilizers, fuel and pesticides are the main sources of GHG emissions (Marras et al., 2015; Bosco et al., 2011; Benedetto, 2013; Rugani et al., 2013; Fusi et al., 2014; Point et al., 2012), and synthetic fertilizers are the most carbon-intensive chemicals because of the sizeable amounts of energy required for their production and worldwide transportation (Litskas et al., 2013). On the contrary, the use of organic fertilizers ensures lower GHG emissions (Hillier et al., 2011; Pattara et al., 2017) and higher carbon sequestration in the soil (IPCC, 2014; UNFCCC, 2015; Marras et al., 2015). The frequency of tillage influences the organic matter decomposition and the related CO_2 loss to the atmosphere (Brunori et al., 2016; Eldon and Gershenson, 2015), besides the cultivation of landraces ensures a lower use of inputs (Litskas et al., 2013). In general, intensive winegrowing releases greater amounts of GHG per unit area (Vasquez-Rowe et al., 2013) and consequently generates higher CF, whose decrease is related to the use of sustainable practices for increasing carbon sequestration in the soil and for reducing the use of inputs.

In this study the functional unit (FU) is one kg of grapes ready for winemaking, and is based on a system boundary cradle-to-gate, i.e. from the extraction of the resource to the winery door, so excluding the winemaking process, the distribution, and the wine consumption. Hence, the analysis focused on the cultivation practices, namely: tillage, fertilization, pest control, irrigation, pruning, harvesting, transportation of the inputs into the vineyard, transportation of the grapes to the winery, daily trips of farmer from the residence to work place. The calculation of GHG emissions was carried out through the online Cool Farm Tool (www.coolfarmtool.org), a tool based on the framework provided in IPCC (2006), and considered the best available in the public domain (Whittaker et al., 2013). In particular, the following GHG emissions were considered (Litskas et al., 2017): 1) emissions from production and use of fertilizers; 2) direct N_2O emissions from N additions to soils (synthetic or organic fertilisers and manure) and N mineralisation of organic matter caused by soil management and cultivation change (e.g., forest land or grassland converted to cropland); indirect N_2O emissions from both volatilisation of N (as NH_3 and oxides of N (NO_x)) caused by the application of synthetic and organic N fertilisers, and leaching and runoff from land of N derived from fertiliser additions, crop residues and mineralisation of N associated with loss of soil Carbon for land-use change or management practices; 3) emissions from pesticide production; 4) emissions from crop residue management, related to soil Carbon stocks and non-CO_2 greenhouse gas emissions from biomass burning; 5) emissions from the degradation of organic matter and related to soil Carbon stocks; 6) emissions from energy use for irrigation; 7) combustion and evaporative emissions from fuel use both in off farm transports of inputs/harvest from market/farm to farm/winery and in the annual trips of winegrower from residence to farm; 8) emissions from human labour for assessing the relationship between production and human labour (HL). Emissions from waste disposal were omitted since their amount was not significantly relevant. The respective factors used to calculate the CF are presented in Table S2.

N_2O, NO and NH_3 emissions from the use of nitrogen fertilizers and manure were assessed through the model of Bouwman et al., 2002 (Hillier et al., 2011), based on the following equation:

$$N_2O = e^{c+\sum_1^{n=i} F(i)} \tag{1}$$

where c is a constant and $F(i)$ concerns several agronomic, soil and climatic factors, i.e. crop type fertilizer type, fertilizer application rate, soil texture, soil organic carbon, soil pH, climate type, etc. (Table S2). Equation (1) was used for the estimation of NO emissions too, while the NH_3 emissions were calculated through the following equation:

$$NH_3 = F \times e^{c+\sum_1^{n=i} F(i)} \tag{2}$$

where F is the quantity of fertilizer used. NO and NH_3 emissions were converted to N_2O by the factor 0.01 (IPCC, 2006). Emissions from the management of the pruning residue into the soil, as well as the carbon stock changes in the soil, were calculated by the approaches described in Hillier et al. (2011). The emissions from pesticide applications were estimated through the approach of Hillier et al. (2011), based on a value of 20.5 kg CO_2-eq/ha per product application. Emissions from fuel used by machineries were estimated through the model of the American Society of Agricultural and Biological Engineers technical standards (ASABE, 2006, 2006), while the emissions from power grid were taken from the GHG protocol (http://www.ghgprotocol.org/). The emissions related to transports and trips were calculated through the emission factors from Hillier et al. (2011) and FIVS (2016). Finally, for the emissions related to human labour, i.e. human respiration, a factor of 0.46 kg CO_2 h^{-1} (Rugani et al., 2012) was used (http://www.engineeringtoolbox.com/co2-persons-d691.html).

2.4. Real estate assessment

Real estate studies are usually based on the ordinary least squares (OLS) regression, which allows the assessment of the conditional means of property prices given a set of explanatory variables. However, the impacts of these predictors may vary along the conditional distribution of prices (Nilsson and Johansson, 2013), so that the estimates based on their conditional mean may be inadequate (März et al., 2016). On the contrary, the investigation of the upper and lower tails of the conditional distribution of price can shed light on its possible segments, which range from the more to the less expensive properties.

Conditional quantile regression allows to reach this goal, so as to catch potential heterogeneity of the estimated covariate effects across the conditional distribution of property prices (Koenker, 2005). Previous studies highlighted the validity of this approach (Kostov, 2009; Mishra and Moss, 2013; Nilsson and Johansson, 2013). On the housing sector, scholars focused on the square footage and the number of bathrooms (Zietz et al., 2008), on the school proximity and the scenic view (Kim et al., 2015), as well as on the proximity to environmental externalities (Kuethe and Keeney, 2012). On the farmland market, instead, despite its rarer use, quantile regression allowed investigating, along the distribution of farmland prices or rental rates: different market segments in Northern Ireland (Kostov, 2009); the effect of seasonal homes and accessibility as proxies for rural amenities (Nilsson and Johansson, 2013); the influence of off-farm income, direct farm payments, and farm location in metropolitan counties (Mishra and Moss, 2013); the closeness to urban centre and the location along the transport network in the United States (McMillen, 2015); the effects of livestock density, share of rented agricultural land, and share of rented arable land in Germany (März et al., 2016); the impact of soil contamination on Belgian farmland (Peeters et al., 2017); the determinants of high price levels in Germany (Lehn and Bahrs, 2018a and 2018b).

In formal terms, the analysis was framed in the hedonic pricing model approach (Palmquist, 1991; Ready and Abdalla, 2005), which assumes farmland price defined by a set of agronomic and non-agronomic determinants (Lancaster, 1966; Rosen, 1974), so that the following stochastic equation can be formulated:

$$SP_i = \beta_0 + \sum_{j=1}^{l} \beta_j A_{ij} + \sum_{m=1}^{n} \beta_m E_{im} + \varepsilon_i \qquad i = 1, \ldots, r \tag{3}$$

where: SP_i was the selling price of the ith vineyard; A_{ij} was the jth agronomic characteristic of the ith vineyard; E_{im} was the mth environmental characteristic of ith vineyard; β_0, β_j and β_m were the unknown coefficients to be estimated; ε_i was the error term.

In this study, the variation of the implicit prices of the vineyards' characteristics across the conditional distribution of the selling prices was assumed, hence a quantile regression was carried out (Koenker and Bassett, 1978; Koenker and Hallock, 2001). Unlike OLS, which estimates a conditional mean function by minimizing the sum of the squared residuals, the quantile regression estimates a conditional quantile function by minimizing the sum of asymmetrically weighted absolute residuals for any quantile in the range $0<\tau<1$, except for the median ($\tau = 0.5$), for which symmetric weights are used. Quantile regression avoids truncation problems deriving from the splitting approaches of samples according to the unconditional distribution of the response variable (Heckman, 1979). Besides, it allows a better handling of heteroscedasticity, outliers, and unobserved heterogeneity (Koenker and Hallock, 2001; Koenker, 2005). Thus, given any vineyard characteristic x, the objective function of the quantile regression model can be written as:

$$\widehat{\beta}(\tau) = \min_{\beta \in R^k} \left[\sum_{i \in \{i : y_i \geq x_i \beta\}} \tau |y_i - x_i \beta| + \sum_{i \in \{i : y_i < x_i \beta\}} (1-\tau)|y_i - x_i \beta| \times \right] \tag{4}$$

About the functional form, several functions were tested through the Box-Cox transformation. The respective tests rejected the linear and reciprocal forms, and allowed the selection of the semilog functional form, by which natural logarithm of farmland value per hectare is regressed on the vectors of the untransformed independent variables. This functional form assesses the percentage variation in selling price given an absolute change in each regressor by multiplying the relative change in selling price by 100. That is, $\widehat{\beta}$s x 100 gives the variation rate in selling price. Hence, the equation (3) becomes:

$$\ln SP_i = \beta_{0\tau} + \sum_{j=1}^{l} \beta_{j\tau} A_{ij} + \sum_{m=1}^{n} \beta_{m\tau} E_{im} + \varepsilon_{i\tau} \qquad i = 1, \dots, r \tag{5}$$

where τ represents the quantile, and ln is the natural log of the selling price.

However, the quantile regression model in equation (5) does not account for spatial effects that may be present in the data, i.e. spatial dependence and spatial heterogeneity. Spatial dependence can occur in the dependent variable due to spill over effects, namely when the selling price of a vineyard can be influenced by the prices of vineyards located in neighbouring territories. This effect is a consequence of both competition among buyers for land within a radius around their farms and the use of reference prices by sellers and buyers in the same region (Maddison, 2009). Therefore, the selling prices of geographically nearby vineyards tend to be similar because of the spatial dependence of properties (Anselin, 1988; LeSage and Pace, 2009) that, if neglected, can cause issues of inefficiency and biased estimators. At present, several studies concerning the farmland market have identified spatial effects (Patton and McErlean, 2003; Huang et al., 2006; Dillard et al., 2013; Hüttel and Wildermann, 2015; Lehn and Bahrs, 2018a and 2018b).

Thus, in this study, spatial lag model, namely a spatial quantile regression, was used. To this aim, the spatial autocorrelation was tested through the Moran's I test, whose positively significant value indicates similarity between the selling price of each vineyard and the selling prices of the nearby vineyards (Anselin and Hudak, 1992). The Moran's I test confirmed the existence of spatial autocorrelation in both samples (Moran's I = 0.747 P < 0.000 for the intensive vineyards; Moran's I = 0.651 P < 0.000 for the semi-extensive vineyards), and the robust version of the Lagrange multiplier (LM) test indicated the need to consider the spatial dependence in the dependent variable (LM = 153.19, P < 0.000 for the intensive vineyards; LM = 129.40, P < 0.000 for the semi-extensive vineyards). Therefore, the equation (5) become (LeSage and Pace, 2009):

$$\begin{gathered} \ln SP_i = \rho_\tau W_1 SP_i + \beta_{0\tau} + \sum_{j=1}^{l} \beta_{j\tau} A_{ij} + \sum_{m=1}^{n} \beta_{m\tau} E_{im} + \varepsilon_{i\tau} \qquad i = 1, \dots, r \\ \varepsilon_{i\tau} = \lambda_{i\tau} W_2 \varepsilon_{i\tau} + u_{i\tau} \\ u \sim N\left(0, \sigma^2\right) \end{gathered} \tag{6}$$

where W_1 is a spatial weight matrix relating to the relevant neighbourhood of each vineyard and ρ is a spatial autoregressive estimation parameter (spatial lag coefficient). The error term ε includes a spatial error coefficient λ indicating the spatial autocorrelation of the residuals, a spatial weight matrix W_2 and an error term u. No distinction was made between the weight matrices W_1 and W_2 and the respective weights were the inverse distances between the vineyards. Consequently, the strength of the relationships among the neighbour vineyards decreased with distance. In this context, a cut-off distance within which the neighbouring prices influenced each other was set. The Moran's I spatial correlogram suggested significant spatial correlation among observations within 6.1 km and 8.3 km for the intensive and semi-extensive vineyards, respectively. Thus, two inverse distance weighting matrices with cut-off points of 6 km and 8 km from the centroid of each vineyard was generated for the two cultivation systems.

Finally, the Two Stage Quantile Regression (2SQR) (Kim and Muller, 2004; Liao and Wang, 2012) was used for the assessment of quantile regression into spatial econometric modelling. Its advantage in estimating the spatial lag model is the computation efficiency, compared to Instrumental Quantile Regression (IVQR) (Chernozhukovm and Hansen, 2006). However, unlike ordinary least squares, parameter estimates contain spatial lags of the dependent variable, so that they cannot be directly interpreted as marginal effects, and the change effect of the characteristic c on the vineyard price at quantile τ is not $\widehat{\beta}_{\tau,c}$. Indeed, a characteristic change of the vineyard i affects also the prices of i's neighbouring properties, which may further influence other vineyards, so that the model has feedback effects in $\rho_\tau W_1 SP_i$. Therefore, the change effect of the characteristic c is the ith diagonal element of the matrix $\widehat{\beta}_{\tau,c}[I - \widehat{\lambda}_\tau W]^{-1}$, whose values, however, are not identical as properties are influenced by the spatial proximity of other vineyards. Hence, with reference to the average direct impact (LeSage and Pace, 2009), i.e. the average of the diagonal elements of the matrix, the following formula was used:

$$[I - \widehat{\lambda}_\tau W]^{-1} \approx I + \sum_{v=1}^{V} \widehat{\lambda}_\tau^{v} W^{v} \tag{7}$$

where V is the order of approximation. In this study a second-order approximation performed well compared with higher-order approximations, hence we used it to interpret the percentage of price change. Standard errors of the coefficient estimates were obtained by using 500 bootstrap replications (Gould, 1993, 1998; Liao and Wang, 2012; Zhang and Leonard, 2014).

3. Results

3.1. Characteristics of the traded vineyards

The descriptive statistics in Table 1 provided trade and management information relating to the considered cultivation systems, which appear highly differentiated according to the agronomic determinants of value and to the inputs' quantities used per unit area, as shown by the *t*-test. In addition, the correlation matrices based on the Bravais-Pearson coefficient allowed further considerations (Table 2). In particular, the intensive cultivation system was mainly located in the fertile and flat areas so as to ensure higher yields, which were also strictly related to the vines' age. The largest traded vineyards were the most distant properties from the urban centres, due to the high incidence of land fragmentation in the peri urban areas. In any case, yields tended to decrease if the vineyards were located in PDO territories, where the land slope is higher. Therefore, the selling price was positively correlated to the vineyard area, for the economies of scale; to yield, which entails higher revenues; to the location along highways, due to the easier transportation of production factors, inputs and products. On the contrary, an inverse correlation concerned: the vines' age, due to the decreasing production performance over time; the distance from the nearest urban centre, due to logistic issues; the land slope, for the greater difficulty to carry out the mechanized practices.

The semi-extensive cultivation system, instead, was based on different dynamics. The correlation between selling price and yield was almost absent, while the aspects related to the production quality were crucial, such as the location inside PDO territories. Conversely, an inverse correlation emerged in relation to the vines' age (although less accentuated than the intensive system), the land slope, and the distance from the nearest urban centre.

Table 2
Correlation matrices, per cultivation system.

Variables	Price	Area	Yield	Age	Slope	Distance	Road	PDO	CF
Price	1.00								
Area	0.17 **	1.00							
Yield	0.81 ***	−0.05	1.00						
Age	−0.75 ***	0.03	−0.76 ***	1.00					
Slope	−0.38 ***	−0.25 **	−0.30 ***	0.12 *	1.00				
Distance	−0.48 ***	0.29 ***	0.17 **	−0.06	0.06	1.00			
Road	0.52 ***	0.11	0.02	0.02	0.03	−0.14 *	1.00		
PDO	0.12 *	0.05	−0.14 **	0.07	0.27 ***	0.11	0.04	1.00	
CF	0.54 ***	−0.10	0.68 ***	−0.55 ***	−0.26 ***	0.06	0.02	−0.14 **	1.00

Intensive cultivation system

Variables	Price	Area	Yield	Age	Slope	Distance	Road	PDO	CF
Price	1.00								
Area	0.19 ***	1.00							
Yield	0.11 **	0.02	1.00						
Age	−0.19 ***	0.01	−0.35 ***	1.00					
Slope	−0.46 ***	−0.31 ***	−0.36 ***	0.13 **	1.00				
Distance	−0.49 ***	0.20 ***	0.07	0.07	0.04	1.00			
Road	0.15 *	0.02	0.03	0.02	0.03	0.02	1.00		
PDO	0.61 ***	0.14 **	−0.28 **	0.16 ***	0.35 **	−0.13	0.01	1.00	
CF	0.11 ***	0.02	0.38 ***	−0.29 ***	−0.25 **	0.01	0.05	−0.30 ***	1.00

Semi-extensive cultivation system

* Sign. 10%; ** Sign. 5%; *** Sign. 1%.

3.2. Environmental impacts of the traded vineyards

The GHG emissions concerning the cultivation practices and the related inputs totalled 1.01 and 0.65 kg CO_2-eq kg^{-1} of grape, for the intensive and semi-extensive production system, respectively, with significant differences for all the considered emissions' categories (Table 3). The intensive cultivation system had the highest CF for the higher use of fertilizers (ammonium nitrate and urea), pesticides, fuel for mechanized practices, transportation and trips, and power for irrigation, in order to achieve the highest possible yield and profit. These results are in line with other studies that analysed GHG emissions during the grape production phase, though they were based on different management practices, boundary systems and CF methodologies. In particular, in these studies, GHG emissions ranged from 0.20 to 0.67 kg CO_2-eq kg^{-1} of grape in Venkat (2012) and Vázquez-Rowe et al. (2012a). Litskas et al. (2013) estimated the average CF for Xynisteri grapes at 0.15 kg CO_2-eq kg^{-1} of grapes, Vasquez-Rowe et al. (2013) reported a CF range from 0.11 to 1.61 kg CO_2-eq kg^{-1} of grapes for vineyards in Luxembourg, Italy and Spain, while Litskas et al. (2017) assessed a CF for Xynisteri, Cabernet Sauvignon and Soultanina in the Cyprus island to 0.28, 0.57, and 0.85 kg CO_2-eq kg^{-1} of grapes, respectively. Other studies, referred to 0.75 L wine bottle as functional unit, found values of 0.30 (Bosco et al., 2011), 0.50 (Gazulla et al., 2010) and 0.80 kg CO_2-eq (Point et al., 2012) during the agricultural phase.

The main processes responsible of the GHG emissions during the agricultural phase, respectively for the intensive and semi-extensive production systems, were: fertilization (0.27 and 0.24 kg CO_2-eq); N released by soil tillage (0.26 and 0.17 kg CO_2-eq); fuel (0.21 and 0.10 kg CO_2-eq); power for irrigation (0.12 and 0.06 kg CO_2-eq). All these emissions categories presented significant differences between the two production systems. This is in line with the literature (e.g. Bosco et al., 2011; Point et al., 2012; Knudsen et al., 2014), for which fertilizer use, soil tillage and fuel were the carbon hotspots in vineyard. However, noteworthy is the different impact of these emission categories on the global carbon budget, since, for example, soil tillage affects the N emissions and the organic carbon stored into the soil (i.e. roots, pruning residues, etc.) so to trigger a relatively fast turnover (about one year), while fuel affects the global carbon reservoirs representing an additional source of CO_2 emissions. In general, higher values emerged compared to Vázquez-Rowe et al. (2012a), Bosco et al. (2011), Point et al. (2012), Marras et al. (2015), Fusi et al. (2014), Neto et al. (2013) and Venkat (2012), mainly due to variations in local climate conditions, soil characteristics, grapes' variety and agricultural practices (Rugani et al., 2013). The use of pesticides contributed with 0.07 and 0.03 kg CO_2-eq to CF for the intensive and semi-extensive production system, respectively. On this concern, the higher use of

Table 3
GHG emissions from the agricultural phase.

GHG emissions	Intensive cultivation system				Semi-extensive cultivation system				*t*-test sign.
	Min.	Max.	Mean	Std. dev.	Min.	Max.	Mean	Std. dev.	
Fertilizers' prod.	0.1182	0.4914	0.2708	0.2501	0.1756	0.2910	0.2382	0.1625	***
N_2O	0.2058	0.3425	0.2646	0.1844	0.1388	0.2207	0.1700	0.1032	***
Pesticides	0.0492	0.0980	0.0651	0.0294	0.0206	0.0317	0.0269	0.0107	***
Crop residues	0.0512	0.0883	0.0685	0.0339	0.0317	0.0838	0.0539	0.0347	***
Power	0.0704	0.1882	0.1242	0.0536	0.0382	0.0775	0.0571	0.0327	***
Fuel	0.1000	0.3140	0.2063	0.1602	0.0632	0.1599	0.1031	0.0758	***
Human work	0.0034	0.0126	0.0076	0.0044	0.0032	0.0086	0.0055	0.0027	***
CF	0.5881	1.5492	1.0071	0.7207	0.4815	0.8763	0.6547	0.4286	***

* Sign. 10%; ** Sign. 5%; *** Sign. 1%.

pesticides for the intensive system was mainly due to the vineyard structure, which was characterised by a higher density of shoots and leaves, so as to favour a greater susceptibility to pests' attacks and consequent damage to grapes. Finally, emissions from crop residues were less than 10% of the total GHG emissions for both the cultivation systems, while human work only contributed for less than 1%, in line with Marras et al. (2015).

3.3. Real estate results

The correlation analysis and the investigation of the environmental impacts highlighted, mainly for the intensive cultivation system, a strong relationship between yield, vines' age and CF. Therefore, this latter was a proper indicator able to encompass both the environmental impact of the cultivation practices and the production performance. Consequently, CF was used in place of the variables related to yield and vines' age in the real estate analysis, in order both to gain information about the mechanism by which the farmland market unconsciously and indirectly values the environmental impacts generated by the cultivation practices, and to avoid the collinearity problems among the covariates.

The OLS results remarked the findings from the descriptive statistics and the correlation coefficients (Table 4), so that, for the intensive cultivation system, the selling price increases of 2.7% for each further hectare of land traded, decreases of 3.2% for each unit increase in the land slope, decreases of 1.1% for each additional kilometre of the distance between the vineyard and the nearest urban centre, increases of 18.5% if the property is located along highways, and increases of 6E-04% for each additional kg CO_2-eq produced during the cultivation phase. On the other hand, the semi-extensive cultivation system is negatively affected by the land slope too, but the effect is more accentuated than the intensive system. In addition, the selling price is positively affected by the land area and by the location of the vineyards in PDO territories. Conversely, the location along highways and the distance from the nearest urban centre do not influence the response variable (Acciani and Sardaro, 2014; Sardaro et al., 2020). Finally, the CF influences the selling price of both cultivation system.

The quantile regression allowed a deeper investigation concerning the variation rates of the implicit marginal prices along the quantiles of the response variable. For the intensive system, the absolute values of the estimates related to the land slope, the distance from the nearest urban centre and the location along highways on the selling price increase for the most valued vineyards, while the area's coefficient decreases. For the semi-extensive system, instead, the absolute values of all the significant coefficients increase. Finally, the CF coefficient rises along quantiles for the intensive cultivation system, while decreases for the semi-extensive one. Thus, in general, results highlight that the influence of the considered determinants is low for the cheaper properties, while is maximum with the most expensive ones.

4. Discussion and conclusions

The study on the farmland market highlighted how the cultivation practices interpreted in environmental terms significantly affect land value depending on the cultivation system used. In particular, the value determinants of the semi-extensive cultivation system mainly concern agronomic and management characteristics able to improve the production quality. Yields, instead, are considered on the extent of which are able to ensure the necessary quality standards. In other words, farmers prioritize the natural productive potential of land, and their assessments concern those property characteristics able to ensure a good set of chemical and biological parameters of grapes, so as to obtain quality wines. Concerning the CF, it is characterized by a positive but moderate effect on the dependent variable, and mainly increases at the highest quantiles of the selling price (0.75 and 0.90). On the contrary, the farmers that use the intensive cultivation system are particularly attentive to yields since, according to them, the profit obtained by enhancing the production quality can be gained also by a massive use of inputs and production factors per unit area. Therefore, in this case, the environmental indicator, as related to the use of productive factors and inputs, is one of the main price predictors, and tends to increase at the highest quantiles.

The study suggests the need of a wider analysis of the farmland market dynamics, which goes behind the classic interpretation of the real estate determinants. Indeed, the use of environmental indicators related to the use of productive factors and inputs allows to bring out negative hidden mechanisms of farming, whose detection can favour the setting of policies for regulating the land market and triggering sustainable cultivation practices and cleaner production. In this connection, the analysis highlighted that the intensive production system is characterized by greater environmental impacts and boosts higher selling prices of farmland, with serious repercussions on environment and public goods, and in contrast with the "polluter pays" principle. In particular, public goods are able to supply externalities, but society fails to internalize their value (Pattanayak et al., 2010), thus proper strategies aimed to internalize the negative externalities of the cultivation practices in farmland market could be set through a Pigouvian tax (Turner et al., 1993). Such approach removes the gap between the private benefits from the farming process and the social cost it generates, and makes the farmer's decision at the margin consistent with the maximization of the aggregate welfare (Janmaat, 2005). Thus, the pollution tax can correct the market failure by being set equal to the marginal cost of the negative externalities. Concerning the semi-extensive cultivation system, instead, the presence of positive externalities could boost the setting of a Pigovian subsidy, namely cash payments or tax-credits granted by a public authority to farmers for encouraging them to generate positive externalities to society. Due to the involvement of ecosystem services (ES) in farming, the study also allows the assessment of Payments for Ecosystem Services (PES), basically defined as a voluntary transaction between a buyer and an ES supplier (Wunder, 2005), and more practically involving governmental intervention and public payment schemes (Schomers and Matzdorf, 2013; Farley and Costanza, 2010). In particular, this approach is based on incentives aimed at remunerating farmers or public subjects for the preservation and/or the providing of ecosystem services through compensations related to the income losses or to the higher costs for their supply (Teeb, 2008). Furthermore, the assessment of CF related to land market can be used for adjusting fees payed for land trade (in Italy, register, mortgage and cadastral fees), as well as for evaluating the possibility by farmers to obtain public (i.e. EU structural funds) or private (credit and insurance) aids in order to buy land.

Beyond the use in land market, the assessment of CF can also be used for a "farming green accounting" to define PCR (Product Category Rules) and, consequently, EPD (Environmental Product Declarations). This last tool could improve environmental communication between producers (business to business) or distributors and consumers (business to consumers), as required by EU environmental policies, and in particular by the standards of the ISO 14020 series. In addition, it could be used to improve communication between producers and institutions by certifying the sustainability of the production processes and the compliance to the conditionality defined by the common agricultural policy.

Finally, noteworthy is the possibility of extent the environmental analysis through the assessment of other indicators used in

Table 4
OLS and quantile estimates, per cultivation system.

Variables	OLS				Quantile regression														
					0.10			0.25			0.50			0.75			0.90		
	Coeff.	Std. Err.		VIF	Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.	
Intercept	9.82643	4.44635	**	0	9.77025	1.78615	***	9.82549	2.42605	***	9.88341	1.92659	***	9.92643	1.60882	***	9.73421	1.73207	***
Area	0.02644	0.01180	**	1.1418	0.02883	0.01270	**	0.02782	0.01100	**	0.02529	0.00973	**	0.01950	0.00515	***	0.01916	0.00819	**
Slope	−0.03255	0.01334	**	1.2179	−0.01367	0.01111		−0.02941	0.01191	**	−0.03703	0.01323	**	−0.05176	0.01998	**	−0.05284	0.02056	***
Distance	−0.01088	0.00173	***	1.1105	−0.00463	0.00096	***	−0.00548	0.00132	***	−0.01184	0.00283	***	−0.01391	0.00423	***	−0.01955	0.00334	***
Road	0.18471	0.08173	**	1.1426	0.10471	0.06627		0.11885	0.11212		0.15562	0.04485	***	0.18501	0.04805	***	0.19743	0.05454	***
PDO	0.01844	0.01190		1.3185	0.01543	0.01002		0.01603	0.01262		0.01943	0.01461		0.01743	0.00838	*	0.01472	0.00694	*
CF	0.000006	0.000001	***	1.1706	0.000005	0.000001	***	0.000005	0.000001	***	0.000006	0.000001	***	0.000008	0.000001	***	0.000013	0.000002	***
Adj. R-sqr	0.7968																		
F-test	27.51																		

* Sign. 10%; ** Sign. 5%; *** Sign. 1%
Intensive cultivation system

Variables	OLS				Quantile regression														
					0.10			0.25			0.50			0.75			0.90		
	Coeff.	Std. Err.		VIF	Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.		Coeff.	Std. Err.	
Intercept	9.97386	2.33034	***	0	9.93620	1.62889	***	9.45210	1.52208	***	9.48328	1.82021	***	9.67355	1.79472	***	9.70416	2.52713	***
Area	0.01272	0.00503	**	1.1264	0.00654	0.00436		0.01148	0.00557	*	0.01253	0.00499	**	0.01429	0.00598	**	0.01602	0.00651	**
Slope	−0.08038	0.01441	***	1.2268	−0.06581	0.02654	**	−0.07419	0.02887	**	−0.08618	0.02374	***	−0.09161	0.02610	***	−0.10137	0.02696	***
Distance	−0.01615	0.01282		1.1163	−0.01036	0.00724		−0.01174	0.00699		−0.01193	0.01037		−0.01274	0.00930		−0.01205	0.00861	
Road	0.05672	0.04975		1.2754	0.02843	0.02090		0.02953	0.01834		0.03771	0.03017		0.03801	0.03221		0.08032	0.05501	
PDO	0.39272	0.09007	***	1.1592	0.28430	0.06643	***	0.30120	0.06368	***	0.36900	0.08849	***	0.40206	0.07762	***	0.41104	0.06535	***
CF	0.000003	0.000001	**	1.2249	0.000004	0.000002	**	0.000004	0.000002	**	0.000003	0.000001	***	0.000001	0.000000	**	0.000001	0.000000	***
Adj. R-sqr	0.7155																		
F-test	25.48																		

* Sign. 10%; ** Sign. 5%; *** Sign. 1%
Semi-extensive cultivation system

the LCA methodology (Guinée et al., 2002; Hoekstra and Chapagain, 2006), such as: the water footprint, defined as the total volume of fresh water to produce goods or services in the farm; the potential acidification, related to the emissions of acid substances into the atmosphere that subsequently return to soil or water; the depletion of abiotic resources; the ecotoxicity; the eutrophication; the toxicity of production processes for humans; the reduction of the ozone layer; the photochemical pollution, i.e. the production of pollutants through chemical-physical transformations of primary pollutants (directly emitted into the atmosphere) in combination with the natural components of the air (for example, the reactions that occur between nitrogen oxides and hydrocarbons in the presence of sunlight); etc. The single or joint use of such indicators can provide additional knowledge about the relationship between land value and environmental impacts of the cultivation practices. It could ensure a better setting of regulatory market mechanisms for the environment preservation, as well as for the sustainable development of the agricultural productive sector and the territorial planning (Petrillo and Sardaro, 2014; Sardaro et al., 2018b).

CRediT authorship contribution statement

Ruggiero Sardaro: Conceptualization, Methodology, Project administration, Investigation. **Gianluigi De Pascale:** Formal analysis. **Carlo Ingrao:** Writing - review & editing. **Nicola Faccilongo:** Conceptualization, Methodology, Project administration, Investigation.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123648.

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