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High-voltage overhead transmission lines and farmland value: Evidences from the real estate market in Apulia, southern Italy

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ABSTRACT

The construction of high-voltage overhead transmission lines on farmland implies a permanent easement, involving expropriation of land and depreciation of the remaining farm area. The Italian system operator should pay compensation for both aspects, but recognizes only the former. Therefore, landowners often appeal to the law courts and claim compensation for the depreciation of the entire non-occupied area, often obliging the system operator to pay substantial amounts. This delays the provision of new power lines and increases their respective costs.

In order to verify the correctness of the *modus operandi* by the system operator and landowners, a study was carried out into the impact of several characteristics of power lines on farmland value in northern Apulia, south Italy. The results highlighted that the area occupied by plinths and cabins, the height of towers and the type of intersection were the main sources of depreciation, which varies depending on the crop. Moreover, depreciation on the residual area exists, but only involves two narrow strips of land on either side of infrastructure. Finally, it is not constant, but tends to decrease rapidly as the distance from the infrastructure increases, and zeroes at 30–70 m from the power line.

1. Introduction

The Italian national electricity grid has a total of 71,000 km of lines, consisting of 49,000 km of 150 kV-lines and 22,000 km of 220–380 kV-lines (High-Voltage Overhead Transmission Lines - HVOTLs), with a density of 0.23 km per km^2 (Terna, 2015). Terna S.p.a. is the national transmission system operator, which owns and manages the power lines, together with their planning and development. Between 1992 and 2015, 220-kV lines decreased by 23%, but 150- and 380-kV lines increased by 15% and 20%, respectively. In Apulia Region, southern Italy, the energy demand has increased by 18% over the last twenty years (Regione Puglia, 2014), thus requiring modernization and improvements to the regional HVOTL grid, including new infrastructures, especially on extra urban areas.

The construction of HVOTLs on cultivated land implies several problems: occupation of land by the plinths of towers, electric cabins, etc.; disturbance of agricultural activities for inspection and maintenance; visual and landscape impacts; damage to crops during installation phase; reduced farm profitability; influence on future land uses; depreciation of farmland. Therefore, the assessment of suitable compensations related to these issues is necessary and usually refers to two aspects, namely land expropriation for occupation by power line components and depreciation of the residual (i.e. unoccupied) farmland. The Italian transmission system operator considers only the former, which is calculated as the sum of the following economic items: 100% of the market value of the occupied areas; 25% of the market value of the area of cable projected onto the ground; 7% of the market value of the respect areas. Additional returns are recognized in the case of direct management of farm by the landowner and of voluntary acceptance of the compensation calculated.

However, the construction of HVOTLs often also causes depreciation of the remaining farm area. Hence, the following questions:

a) does the depreciation concern the entire residual area, or only a part of it?
b) does the effect of depreciation remain constant over the affected area, or does it progressively decrease to zero at a certain distance?

Answering these questions is crucial for fair compensation mechanisms. For example, the impact of power lines on the value of residential properties tends to decrease rapidly as the distance from the power lines increases (Colwell and Foley, 1979; Hamilton and Schwann, 1995), so that only a part of the total area is affected and should be compensated. Nevertheless, as said, the Italian system

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operator does not include this further effect in assessment of total compensation, so that landowners often appeal to law courts claiming that the entire residual farm area has decreased in value, entitling them to the maximum level of compensation. Finally, the system operator uses subjective criteria to assess the compensation related to land expropriation and does not consider the depreciation of the remaining farmland; landowners, however, subjectively claim the highest compensation on the residual area, forcing the system operator to make substantial payments. This clash of interests causes difficulties in siting (Vajjhala and Fischbeck, 2007), delays in the provision of new power lines, and considerably increases the cost of these infrastructures (Buijs et al., 2011; Cotton and Devine-Wright, 2013; Jay, 2004).

Only the real estate market of farmlands can provide useful information capable of resolving this conflict, hence the need for accurate studies able to measure the influence of power lines on the value of these properties. Therefore this paper: a) investigated the influence of HVOTL characteristics on farmland value; b) assessed the coefficients related to the impacts of power line characteristics on farmland value, in order to apply them to quantify total compensation for the construction of new HVOTLs; c) studied the extent and trend of depreciation on the residual farmland. In other terms, the paper detects real-estate market-based criteria for the assessment of proper compensations in the presence of HVOTLs on farmland, and at the same time checks the consistency of the economic behaviours by the system operator and landowners. The analysis focused on northern Apulia (southern Italy), and referred to the region's three most important crops (durum wheat, olives and vines).

The paper contributes to the literature in two ways. Firstly, no applied economic study has investigated the impact of HVOTL characteristics on farmland value in Italy, or focused on different crops. Secondly, this research helps stakeholders and decision makers with suitable compensation criteria for the construction of new power lines on private farms. Moreover, the findings allow the definition of useful indicators for grid development plans and related strategic environmental assessment.

2. Literature review

Electricity transmission via HVOTLs can produce many negative externalities. They include: landscape and visual impacts (Tempesta et al., 2014; Devine-Wright and Batel, 2013); health risks associated with electrical and magnetic fields (Bickel and Friedrich, 2005); damage to the environment and wildlife (Sumper et al., 2010); damage to scientific, historical and cultural areas; reduced profitability of productive activities; land use conflicts (Doukas et al., 2011); decreased property values (Furby et al., 1988). The academic literature about the land depreciation is generally dated and mainly focused on residential areas (Chalmers and Voorvaart, 2009). In particular, when negative impacts are evident, studies have highlighted a discount between 1% and 10% of property value (Pitts and Jackson, 2007; Des Rosiers, 2002), which decreased rapidly as the distance from the power line increased, and usually disappeared at 60–90 m from the HVOTL (Colwell, 1990). No significant effect was found on the selling prices of vacant residential land with future potential residential use (Blinder, 1979; Kinnard and Mitchell, 1988; Mitchell and Kinnard, 1996).

The effects on the value of properties in rural areas were also uncertain. Several authors (Brown, 1976; Chalmers, 2012) found no effects, even where land use was recreational (for example, with a high level of environmental amenity) and rural-residential. On the contrary, Woods (1981) found some effect in a few percentage points, but perhaps related to the fact that these farms would soon become residential areas. Ball (1989) highlighted a 2% reduction, while Jackson and Pitts (2010) assessed a depreciation of 1–2.5%, although this was considered too small to be statistically significant and attributable to the presence of the line alone.

The above studies, which were mostly carried out in the US, highlighted that the impacts of power lines on farmland value are varied and difficult to measure (Pitts and Jackson, 2007), giving conflicting results. Therefore, it is very difficult to generalise, since these studies involve a wide variety of property type and size, market segment, configuration and location, type of power lines and towers, as well as type and quality of the statistical approaches used (Wyman and Worzala, 2013). Moreover, many of these independent studies were not actually independent, but were financed by power line companies (Kinnard, 1990; Kroll and Priestly, 1992), who obviously have an interest in demonstrating a negligible impact on property value.

3. Materials and methods

3.1. Data and variables

The study focused on farmlands in the Municipalities of Ortanova, Foggia, Lucera, Troia and San Severo, in Apulia Region, southern Italy. Over the last decade, there has been significant expansion of HVOTLs in this area, raising issues concerning the payment of unfair compensation and generating conflictual siting, as well as delays in planning and construction of power lines.

The most common crops in the area are durum wheat (46.7% of the utilized agricultural area - UAA), olives for oil production (9.8%), and vine (5.4%) (Istat, 2017). Hence, the analysis referred to these crops, characterized by very different quantities of productive factors involved, i.e. land, labour and capital. In particular, durum wheat is characterized by large properties, and small use of labour and capital. Olive groves are related to medium-size properties and moderate recourse to labour and capital. Finally, vineyards have opposite characteristics compared to durum wheat fields.

The study was based on a comparison of properties with and without HVOTLs (Table 1), so that two samples were assembled, per crop. Data, collected from real estate transfer acts (62%) and estate agencies (38%), referred to transactions from 2011 to 2016, corresponding to a relatively stable period in the local land market. Using direct interviews with lawyers, brokers and landowners, several variables were identified as influencing the selling price of properties without power lines: the farm area (coded as *Area* and expressed in hectares), able to exploit economies of scale related to labour and capital and directly correlated to the selling price; the yield (*Yield* - tonne hectare^{-1}) for durum wheat fields and vineyards, which influenced revenues and was directly correlated to the selling price; the age of plant (*Age* - Years) for olive groves, which influenced revenues and was directly correlated to the selling price; the orthogonal distance from the farm centre to the nearest HVOTL on nearby properties (*Proximity* - Metres), considered as an indicator of the influence of power lines on surrounding farms, and assumed to be directly correlated to the selling price; the distance between the urban residence of the landowner and its property (*Distance* - Kilometres), indicating more rapid movement to and from the workplace and assumed to be inversely correlated to the selling price; the location of the farm along highways or provincial roads (*Road* - Yes/No), which was an indicator of a faster and easier transport of commodities to and from market places, and was assumed to be directly correlated to the selling price. Finally, the effect of irrigation was not analysed, as it was always present in the olive groves and vineyards, but never in the durum wheat fields, regardless of HVOTLs.

The following additional variables were considered for properties with HVOTLs. The ratio between the area occupied by the infrastructure components (plinths, electric cabins, etc.) and the total farm area (*Occupied area* - Percentage) was an important indicator related to the expropriation of land, with further possible implications for farm layout (e.g. changes to farm roads) and managerial strategies (i.e. increased cultivation costs, variations in agronomic practices, etc.). The increase in this ratio was assumed to be directly related to the

Table 1
Descriptive statistics of the samples, per crop.

Variable	Unit	Code	Durum wheat fields								
			Without HVOTL (n = 71)				With HVOTL (n = 59)				t-stat sign.
			Min.	Max.	Mean	S. d.	Min.	Max.	Mean	S. d.	
Selling price	€ ha^{-1}	Price	22910.70	31031.26	26832.15	11820.48	21346.08	27721.04	25192.17	9032.48	**
Farm area	ha	Area	3.62	126.26	18.23	14.39	4.12	138.91	20.47	11.98	**
Yield	t ha^{-1}	Yield	2.85	4.12	3.42	1.76	2.78	3.96	3.7	1.53	
Age of plants	Years	Age	–	–	–	–	–	–	–	–	–
Proximity	m	Proximity	222	1136	318.60	396.00	–	–	–	–	–
Distance from urban residence	km	Distance	5	13	8.80	5.90	6	13	12.06	7.67	**
Highway or provincial roads	Yes/No	Road	0	1	0.40	0.49	0	1	0.38	0.28	
Occupied area/total farm area	%	Occupied area	–	–	–	–	0.84	5.55	4.81	2.43	–
Height of towers	m	Height	–	–	–	–	18.00	50	32.55	9.23	–
Intersection	Shannon-Wiener index	Intersection	–	–	–	–	0.12	0.43	0.22	0.28	–
Distance from boundary	m	Boundary	–	–	–	–	36.04	319.63	125.68	66.63	–
Variable	**Unit**	**Code**	**Olive groves**								
			Without HVOTL (n = 56)				**With HVOTL (n = 42)**				**t-stat**
			Min.	**Max.**	**Mean**	**S. d.**	**Min.**	**Max.**	**Mean**	**S. d.**	**sign.**
Selling price	€ ha^{-1}	Price	26338.04	45481.26	36529.03	130372.88	28193.13	37718.90	33160.83	24779.35	***
Farm area	ha	Area	0.77	9.13	2.94	3.60	1.01	12.36	3.13	2.58	*
Yield	t ha^{-1}	Yield	–	–	–	–	–	–	–	–	–
Age of plants	Years	Age	50.17	85.10	71.00	41.40	54.13	91.49	68.88	29.03	
Proximity	m	Proximity	108	1452	214.29	338.18	–	–	–	–	–
Distance from urban residence	km	Distance	2.11	15.6	9.29	3.82	4.91	14.02	12.46	6.91	**
Highway or provincial roads	Yes/No	Road	0	1	0.27	0.17	0	1	0.26	0.20	
Occupied area/total farm area	%	Occupied area	–	–	–	–	1.72	9.81	3.14	3.20	–
Height of towers	m	Height	–	–	–	–	18	50	20.2	18.07	–
Intersection	Shannon-Wiener index	Intersection	–	–	–	–	0.11	0.37	0.26	0.16	–
Distance from boundary	m	Boundary	–	–	–	–	65.39	172.4	100.57	112.09	–
Variable	**Unit**	**Code**	**Vineyards**								
			Without HVOTL (n = 49)				**With HVOTL (n = 41)**				**t-stat**
			Min.	**Max.**	**Mean**	**S. d.**	**Min.**	**Max.**	**Mean**	**S. d.**	**sign.**
Selling price	€ ha^{-1}	Price	39420.22	57851.03	45119.92	18032.10	31482.55	52992.48	38660.21	26794.35	***
Farm area	ha	Area	1.86	11.65	4.90	2.43	2.13	10.47	4.12	3.66	*
Yield	t ha^{-1}	Yield	14.37	36.28	19.51	11.74	12.57	35.18	18.83	12.62	
Age of plants	Years	Age	–	–	–	–	–	–	–	–	–
Proximity	m	Proximity	217	1361	440.82	476.01	–	–	–	–	–
Distance from urban residence	km	Distance	3	18	14.63	12.95	5	21	16.22	10.05	*
Highway or provincial roads	Yes/No	Road	0	1	0.44	0.31	0	1	0.51	0.25	
Occupied area/total farm area	%	Occupied area	–	–	–	–	0.09	13.25	2.15	3.62	–
Height of towers	m	Height	–	–	–	–	18	50	29.69	12.18	–
Intersection	Shannon-Wiener index	Intersection	–	–	–	–	0.13	0.32	0.19	0.20	–
Distance from boundary	m	Boundary	–	–	–	–	18.04	236.52	113.96	83.17	–

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

depreciation of property. The height of towers (*Height* - Metres) was a characteristic of power lines related to the operators' perception of disturbance during their agricultural activities, and was assumed to be positively correlated to land depreciation. The intersection of infrastructure (*Intersection* – Central/Lateral) with farm area was another element of disturbance generated by HVOTLs. In particular, in the interviews landowners considered a central intersection more invasive than a lateral one due to its negative impact on farm layout and cultivation practices. When processing this variable, we assumed that a power line divides a property into two parcels of the same area if the intersection is perfectly central, but of different sizes if the intersection is lateral, thus causing maximum and minimum depreciation, respectively. Therefore, we used the Shannon-Wiener index[1] (Shannon, 1948) in order to characterize the diversity of the parcel areas generated by the intersection of the property with the power line. The basic idea was that the more similar the areas of the parcels, the higher the entropy index H, calculated as:

$$H = (p_1, ..., p_s) = -\sum_{i=1}^{s} p_i \log_2 p_i \quad (1)$$

where s was the number of parcels and p_i was the percentage share of the area of the i^{th} parcel compared to the total farm area. In this study, we considered only traded properties intersected by just one infrastructure, excluding farms with two or more power lines (only two survey cases), so that s was always equal to two and $p_1 + p_2$ was the total farm area. The Shannon-Wiener index assumed nominal values between zero (absence of entropy), indicating a power line on the boundary, and ½ (maximum entropy) for a central power line dividing the total area into two equal parcels. Therefore, this variable was assumed to be positively correlated to land depreciation. Moreover, this approach was considered more accurate than the use of a dichotomous variable, as the attribution of discrete values (0 or 1) would have been

[1] The Shannon-Wiener index, based on the concept of entropy, is a diversity index that reflects how many different types (in this case the farmlands) there are in a dataset, and simultaneously takes into account how evenly the entities (in this case the areas of the parcels generated by the intersection with the power line) are distributed among those types.

affected by high subjectivity. On the contrary, through the continuous index used, we objectively measured the level of intersection within properties.

Finally, in order to examine the spatial trend of depreciation across the residual area, we calculated the orthogonal and greatest distance from the central point of the line to the opposite boundary (*Boundary* - Metres). In this case, it was assumed that the longer the distance, the smaller the depreciation.

For the variables concerning the intrinsic characteristics of the properties, i.e. *Area*, *Yield*, *Age* and *Road*, data were collected through the real estate sources already mentioned, while the *Distance* and the *Proximity* variables were measured using Google Maps, from February to October 2016. The variables related to the characteristics of the power lines (*Occupied area*, *Height*, *Intersection* and *Boundary*) were calculated via overlapping between the cadastral maps and the respective Google Maps in ArcMap 10.4, between November 2016 and April 2017. Any missing data (often concerning the yield, the age of plants and the height of towers) was supplied by direct inspections on properties.

3.2. The model

The analysis was based on the hypothesis (Lancaster, 1966; Rosen, 1974) that the selling price of farmland without HVOTLs was only influenced by its intrinsic characteristics (*Area*, *Yield* or *Age*, *Proximity*, *Road*, *Distance* and *Proximity* variables). In the presence of HVOTLs, instead, the selling price was also affected by additional factors related to power lines (*Occupied area*, *Height*, *Intersection* and *Boundary* variables).

A linear form of the model based on the ordinary least squares (OLS) (Wooldridge, 2012) was assumed, except for the *Boundary* variable. In this last case, we assumed the maximum depreciation next to the HVOTL, rapidly decreasing down to zero as the distance from the power line increased, so that a reciprocal relationship was used (Colwell, 1990). Hence, the following model was implemented:

$$\ln SP_i = \beta_0 + \sum_{j=1}^{n} \beta_j x_{ij} + \sum_{l=1}^{m} \beta_l z_{il} + \beta_B (1/Boundary_i) \tag{2}$$

where: SP_i was the selling price of the *i*th property and *ln* was its natural log; x_{ij} was the *j*th characteristic (Area, Yield or Age, Proximity, Distance, Road and Proximity variables) of the *i*th property; z_{il} was the *l*th characteristic (Occupied area, Height and Intersection variables) of the HVOTL in the *i*th property; *Boundary* was the distance between the power line and the boundary of the *i*th property; β_0, β_j β_l and β_B were the unknown coefficients to be estimated.

We used the semilog functional form, from which, if the assumptions of the classical linear regression model are fulfilled,[2] the OLS method allows us to estimate the parameters (Gujarati and Porter, 2009). In particular, the OLS estimators $\hat{\beta}$s obtained will be best linear unbiased estimators of βs. Moreover, the percentage variation in *SP* for an absolute change in each regressor can be calculated by multiplying the relative change in *SP* by 100. That is, $\hat{\beta}$s x 100 gives the variation rate in *SP*. This model allowed the direct assessment of the depreciation rates related to the characteristics of HVOTLs, thus providing practical information for stakeholders and policy makers, in order to evaluate compensation for landowners due to the construction of new power lines.

The choice of this functional form was verified by the MacKinnon's J-test. Firstly, the null hypothesis that the hedonic form was linear against the log-linear alternative hypothesis was tested. In a first step, the log-linear model was estimated and the predicted values were calculated. In the second step, the linear model was estimated, with the predicted values from the first regression included as extra regressors. The t-statistic for the predicted values, i.e. the test statistic for the J-test, was 11.36, so that the null hypothesis of a linear functional form was rejected. The analogous test for the log-linear functional form against the linear functional form provided a t-statistic of 1.63, hence the null hypothesis of a log-linear functional form was accepted.

A preventive multicollinearity analysis based on the correlation coefficient was also carried out in order to identify possible overlap effects among the independent variables.

Finally, in regression analysis, the selection of informative variables able to explain the obtained model is crucial, since too many regressors may lead to non-robust parameter estimates and non-interpretable models. In this study, we performed the OLS-lasso (least absolute shrinkage and selection operator) regression (Efron et al., 2004; Tibshirani, 2011, 1996), i.e. a variable shrinkage based on a penalty approach for improving OLS. The lasso model is interpretable like the subset selection method, and is as stable as ridge regression (Hastie et al., 2009). Moreover, the lasso regression is a tolerant method for reducing the sensitivity of regression parameters to multicollinearity.

Generally, in addition to the sum of squares error minimization, the lasso model considers L_1 norm constraint on the sum of the absolute value of the regression coefficients, so that some of these latter shrink to exactly zero and are excluded from the analysis. OLS estimates have low bias but high variance of the predicted response, which decreases following removal of predictors from the full model, although the bias increases as trade-off (Miller, 2002). Therefore, OLS accuracy can be improved by shrinking or setting some coefficients to zero, so that this bias–variance trade-off often allows better predictions. The approach is also useful if some predictors are highly correlated, as the lasso model picks only one of them and shrinks the others to zero.

In formal terms, **X** denotes the *n* x *p* matrix of predictors, whose elements are centred and scaled to have unit standard deviation and mean zero, and **y** denotes the *n* x 1 response vector, whose elements have mean zero. If $\boldsymbol{\beta}$ is a *p* x 1 vector of regression coefficients, for a given parameter λ, the lasso regression coefficients are the solution to the constrained optimization problem:

$$\hat{\boldsymbol{\beta}}_{Lasso} = \underset{\boldsymbol{\beta}}{\operatorname{argmin}} ||\mathbf{y} - \mathbf{X}\boldsymbol{\beta}||^2 \text{s.t.} \sum_{j=1}^{p} |\beta_j| \le \lambda \tag{3}$$

where $\lambda \ge 0$ is a tuning parameter controlling the amount of shrinkage, and, provided that it is small enough, some regression coefficients will be exactly zero, thus allowing the automatic selection of the most informative predictors (i.e. the ones with nonzero regression coefficients). In other terms, the parameter λ tunes estimate results through a trade-off between accuracy in prediction and number of predictors, so that lasso selects a subset of regression coefficients for each value of λ.

In order to select the proper λ, thus ensuring an accurate and interpretable model, the lasso solutions for different values of λ are tested by model selection optimality criteria. i.e. *k*-fold cross validation (CV) (Efron et al., 2004), or information criteria, namely AIC or BIC (Zou et al., 2007; Tibshirani and Taylor, 2012). However, in our experience of real estate assessment, also confirmed in other research fields (Mauerer et al., 2015), BIC and CV identify the most and least sparse model, respectively. AIC, instead, allows a desirable compromise, therefore we preferred this optimality criterion. The appropriate model for each crop was selected on a grid of 100 λ-values, and the best was

[2] The following assumptions were verified using appropriate tests, selected from those reported in literature also according to the small size of the samples (Gujarati and Porter, 2009):.

1) Normality of residuals: Shapiro–Wilk test (H_0: residuals are normally distributed);

2) Homoscedasticity of residuals: Breusch-Pagan test (H_0: residuals have constant variance);

3) No autocorrelation of residuals: Durbin–Watson test (H_0: residuals are not autocorrelated, if $d_U < d < 4 - d_U$).

The assumptions concerning the multicollinearity among predictors and the functional form of the model were tested and commented in the text.

chosen according to the AIC-criterion. Standard errors were computed via bootstrap based on 500 bootstrap samples. In turn, approximate *p* values based on simple, two-sided *t*-tests were calculated by the bootstrapped standard errors.

The variance inflation factor (VIF) was calculated to further verify the presence of multicollinearity among the predictors. Firstly, we ran the lasso regression in which each nonzero regressor in the Eq. (2) was a function of all the other nonzero covariates. Then, we calculated the VIF factor through the following formula (Wooldridge, 2012):

$$VIF = \frac{1}{1 - R_i^2} \tag{4}$$

where R_i^2 was the coefficient of determination of the regression equation calculated in the first step.

4. Results

4.1. Sample characteristics

The descriptive statistics (Table 1) highlighted that the presence of HVOTLs on farmland influenced selling prices, with depreciations of 6.3% for durum wheat fields, 9.3% for olive groves and 14.4% for vineyards. Moreover, durum wheat fields were much larger than olive groves and vineyards, as expected. Finally, significant differences emerged also between farm surface area, distance from urban residence and HVOTLs, so that the power lines were located far from cities, i.e. in areas where farms are larger, mainly due to a reduced level of land fragmentation.

4.2. Lasso results

The multicollinearity analysis indicated correlation coefficients between 0.03 and 0.18, highlighting the absence of a notable overlap among the independent variables, for each crop. The absence of multicollinearity was also confirmed by the VIF values (Table 2), which, for the nonzero predictors, were much lower than the thresholds commonly used by analysts, namely 5 or even 10, according to Snee (1973) and Marquandt (1980), respectively. Regarding the other assumptions, the respective tests indicated normal, homoscedastic and uncorrelated residuals. All the estimated models (Table 2) had adjusted R^2 from 74% to 86%, and the significance of the F-tests was 1%, indicating good general fittings. All selected predictors had high significance (at 1% and 5%), except for the *Road* variable in durum wheat fields with power lines.

The lasso estimates pointed out a different influence of regressors on selling prices. In particular, in the absence of HVOTLs, the farmland size positively influenced durum wheat fields and vineyards, due to benefits related to economies of scale, mainly related to mechanization. However, this variable had no effect for the olive groves, probably because of the family management of this crop in the territory considered, and the consequently small size of the farms (under three hectares). The variables related to profitability (yield for durum wheat fields and vineyards, and age of plants for olive groves) had the expected positive effect, while the distance from the urban residence of the landowner negatively influenced the selling price of olive groves and vineyards, but was irrelevant for durum wheat fields. Indeed, the wheat cultivation system involves extensive practices, which imply a low intensity of capital and labour, so that the variable *Distance* did not affect the agronomic practices and then property value. Closeness to principal roads positively influenced the property value for all crops, due to faster and easier transportation of commodities, whereas the proximity of farms to HVOTLs on nearby properties did not affect the selling price. This could be due to the relatively large average distances in the samples, namely 319 m for the durum wheat fields, 214 m for the olive groves and 441 m for the vineyards. Some effect might have emerged with smaller distances, but would probably not have been significant.

In the presence of power lines, the significance of the variables related to the intrinsic characteristics of farmlands generally decreased, and some of them often exited from the models. In any case, their impact respected the expected signs. In particular, among the intrinsic characteristics of properties, the selling price for durum wheat fields and olive groves was affected only by the variables related to production, namely *Yield* and *Age*. The *Area* variable remains in the model for vineyards, however, indicating the great importance of economies of scale generated by the predictor for this crop.

On the contrary, selling price was mainly influenced by HVOTL characteristics, but always in negative way, thus generating depreciation. The type of intersection was the most influential variable, causing a fall in property values from 10% for the durum wheat fields to 27% for vineyards, per each unit value of the Shannon-Wiener index. The occupied areas by power line components reduced the selling price of 1% for all the considered crops, depreciation corresponding to the market value of land, and the height of towers influenced the value of properties between 0.03% and 0.07% per metre. The negative impact of the *Boundary* variable on selling price was between 6% for durum wheat fields and 15% for vineyards, per each reciprocal value of distance (1/Boundary).

Finally, the analysis highlighted the following findings. In general, the presence of power lines sensibly reduced the influence of the agronomic variables (farmland area, yield, age of plants, distance from the urban residence of landowner and proximity to principal roads) on property value, above all in case of extensive crops (Durum wheat). However, their expected signs remain. Furthermore, the area occupied by plinths and cabins, the height of towers and the type of intersection were the main causes of depreciation. Specifically on the first aspect, which generates land expropriation, the depreciation was assessed equal to 1%, i.e. to the market value of land, so that the first part of the criterion used by the system operator is valid. However, the other compensations recognized, namely 25% of the market value of the area of cable projected onto the ground and 7% of the market value of the respect areas, were devoid of economic justification. Other items, instead, should be considered, namely the compensations related to the height of towers and to the type of intersection. Therefore, the total depreciations resulting from both the land expropriation and the characteristics of power lines are depicted in Table 3.

On the residual farmland, the analysis highlighted the presence of depreciation, which however was not constant over the whole property. Considering the specific functional form, the impact of HVOTL on the unoccupied area zeroed at approximately 30 m for durum wheat fields, 40 m for olive groves and 70 m for vineyards (Fig. 1). This tendency was due to the increasing use of capital and labour factors which durum wheat fields, olive groves and vineyards respectively request. In particular, the presence of HVOTL increases the negative perception of risk for winegrowers, who spent over 400 h/hectare/year on the agronomic activities (compared to 300 h/hectare/year for olive groves and only 30 h/hectare/year for durum wheat fields). In addition, the presence of HVOTLs on vineyards makes it more difficult to perform mechanized agronomic activities, while the construction of new power lines creates difficulties because it necessitates changes in the structure of these cultivation systems. These issues, however, were less important for olive groves and almost insignificant for durum wheat fields, so that the impact of power lines on these last production systems was smaller and less extensive. In any case, the influence of HVOTLs was confined to each property and, therefore, power lines did not affect the neighbouring farmland (*Proximity* variable).

These findings could be used for fair criteria to assess the depreciations for landowners. In this connection, authorities could apply schedule percentage values based on the marginal effects assessed.

Table 2
Results from the lasso analysis.

	Durum wheat fields						Olive groves						Vineyards					
	Without HVOTL			With HVOTL			Without HVOTL			With HVOTL			Without HVOTL			With HVOTL		
Variable	Coeff.	*P* value	VIF	Coeff.	*P* value	VIF	Coeff.	*P* value	VIF	Coeff.	*P* value	VIF	Coeff.	*P* value	VIF	Coeff.	*P* value	VIF
Intercept	10.0867	0.000	0	10.1154	0.000	0	9.9865	0.008	0	10.1898	0.005	0	10.1739	0.000	0	10.3184	0.002	0
Area	0.0014	0.021	1.1332	0			0			0			0.0062	0.003	1.3406	0.0055	0.015	1.1216
Yield	0.0113	0.002	1.0557	0.0090	0.038	1.0602	–	–		–	–		0.0116	0.004	1.1009	0.0114	0.036	1.0332
Age	–	–		–	–		0.0053	0.001	1.0048	0.0052	0.002	1.0068	–	–		–	–	
Distance	0			0			−0.0006	0.028	1.1875	0			−0.0056	0.030	1.2715	0		
Road	0.1275	0.003	1.1095	0.0720	0.085	1.1140	0.0617	0.032	1.1932	0			0.1489	0.017	1.0098	0		
Proximity	0			–	–		0			–	–		0			–	–	
Occup. area	–	–	–	−0.0105	0.004	1.1631	–	–	–	−0.0117	0.000	1.1418	–	–	–	−0.0119	0.000	1.1805
Height	–	–	–	−0.0003	0.033	1.2285	–	–	–	−0.0004	0.016	1.2055	–	–	–	−0.0007	0.002	1.2147
Intersection	–	–	–	−0.1015	0.000	1.0716	–	–	–	−0.1629	0.000	1.1184	–	–	–	−0.2694	0.000	1.0596
Boundary	–	–	–	−0.0578	0.019	1.1322	–	–	–	−0.1020	0.041	1.1705	–	–	–	−0.1468	0.000	1.1742
R^2	0.8415			0.8225			0.7882			0.7719			0.8726			0.8352		
R^2 adj	0.8291			0.8054			0.7666			0.7393			0.8574			0.8110		
F-value	22.90	0.000		18.49	0.000		27.88	0.000		18.31	0.000		28.70	0.000		19.90	0.000	
N.	71			59			56			42			49			41		
Shapiro–Wilk test	W = 0.9477			W = 0.9623			W = 0.9304			W = 0.9682			W = 0.9641			W = 0.9816		
	Pr < W = 0.6289			Pr < W = 0.8517			Pr < W = 0.6813			Pr < W = 0.5119			Pr < W = 0.7750			Pr < W = 0.9480		
Breusch-Pagan test	chi2 = 2.22			chi2 = 1.63			chi2 = 3.82			chi2 = 1.94			chi2 = 3.20			chi2 = 3.17		
	Pr > chi2 = 0.357			Pr > chi2 = 0.739			Pr > chi2 = 0.550			Pr > chi2 = 0.824			Pr > chi2 = 0.419			Pr > chi2 = 0.362		
Durbin–Watson test	d_L = 1.525 d_U = 1.703			d_L = 1.372 d_U = 1.808			d_L = 1.452 d_U = 1.681			d_L = 1.230 d_U = 1.786			d_L = 1.378 d_U = 1.721			d_L = 1.175 d_U = 1.854		
	D = 1.935			D = 1.877			D = 1.729			D = 1.944			D = 1.763			D = 1.921		

Table 3
Depreciations per characteristic of HVOTL and crop.

	Ref. values		Durum wheat fields		Olive groves		Vineyards	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Occupied area	–	–	−1.00%	−1.00%	−1.00%	−1.00%	−1.00%	−1.00%
Height (m)	18	50	−0.54%	−1.50%	−0.72%	−2.00%	−1.26%	−3.50%
Intersection (S.-W. index)	0	0.5	0.00%	−5.07%	0.00%	−8.14%	0.00%	−13.47%
Total			**−1.54%**	**−7.57%**	**−1.72%**	**−11.14%**	**−2.26%**	**−17.97%**

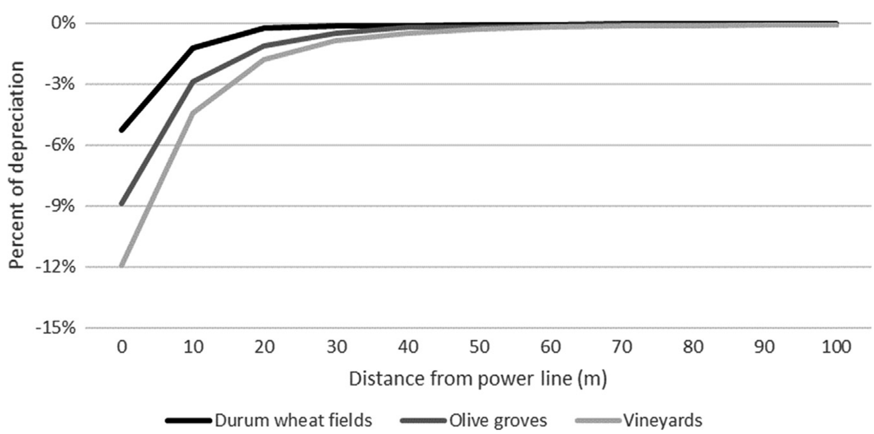

Fig. 1. Percentage of depreciation based on the distance from the power line.

5. Discussion and policy implication

The study pointed out a considerable impact of HVOTLs on farmland, differentiated per crop. Earlier hedonic studies[3] showed that the presence of lines on urban properties negatively affected land value (−1% to −10%). In the present study, the depreciations were sizeable, considering the agricultural use of the properties analysed. These high percentages could be the combined effect of several aspects, namely visual impact, perception of health risk due to electrical and magnetic fields and to noise, in addition to farm management issues. The results concerned power lines already on farmland, but they can also be applied to the construction of new HVOTLs, which leads landowners to claim very high levels of compensation, mostly for depreciation of the residual farmland. This attitude could be explained by several strategic behaviours, including the "Not-In-My-Backyard" (NIMBY) reaction, concerning public opposition to the siting of HVOTLs (Kyle, 2013; Cain and Nelson, 2013). Another more rigorous scientific behaviour is "place attachment", i.e. the sense of affiliation toward the physical location where people live or work (Joe et al., 2016; Aas et al., 2014; Cotton and Devine-Wright, 2013; Devine-Wright, 2013). In this case, opposition to siting HVOTLs is related to demographic factors, i.e. gender, age and education, but above all to specific characteristics of the project, i.e. positive or negative impacts, procedural justice, trust in the developer, etc. These aspects, together with risk perception, noise and farm management issues, could lead landowners to request sizeable compensation for the construction of new HVOTLs on their properties (Acciani and Sardaro, 2014), especially for the residual farm area. However, this analysis, which was based on land market, and therefore on the actual behaviour of operators, has demonstrated that when HVOTLs are already present on farmland, the depreciated area consists of just two narrow strips of land (30–70 m depending on the crop) on either side of the power line. Hence, landowners' claims for the maximum amount of compensation concerning the entire remaining area are unjustified. However, the modus operandi of the system operator also appears unfair, as some depreciation on the remaining farmland should be recognized in any case.

These findings have highlighted that the approach of landowners differs before and after construction of a HVOTL. This could be explained by the time factor, since several studies (Chalmers and Voorvaart, 2009; Pitts and Jackson, 2007) have reported that the impact of recent power lines built on private properties was initially significant, but quickly diminished over time.

The compensatory mechanism in the planning process for power lines should be based on the real estate market, which reflects the true attitudes of landowners. Keeping in mind this assumption, the analysis showed a large degree of inconsistency between their claims during the siting phase and their actual behaviour on the real estate market regarding farmland with pre-existent HVOTLs. On the other hand, depreciation of a part of the remaining area should be recognized by the system operator.

The investigation of real-estate characteristics of farmlands with HVOTLs is a crucial element for fair and quicker planning process, therefore these findings should be considered in negotiations concerning land use rights. On the contrary, the absence of real-estate surveys for HVOTL siting can increase the risk of project failure and/or additional costs. These issues could stem from a range of factors: lack of trust in the public or private agencies responsible for siting, construction and management of lines (Ceglarz et al., 2017; Jenkins-Smith et al., 2009; Schively, 2007); implementation of non-optimal technological solutions (Lienert et al., 2015); lack of information and notification (Lienert et al., 2018); a sense of exclusion from decisional process by people (Gross, 2007); a negative institutional context (Friedl and Reichl, 2016; Devine-Wright, 2009), and a lack of simplified and standardised regulatory frameworks (Battaglini et al., 2012). In other words, it is necessary to deal with issues related to societal, market and political acceptance (Devine-Wright et al., 2017). By ensuring open participation, as well as collaborative and coordinated planning supported by economic findings, conflicts can significantly reduce (Ritchie

[3] A hedonic study assumes that the good being valued is composed by constituent parts, each of which is valued by market. The contributory value of each characteristic is determined through hedonic models based on regression analysis. Hedonic models are commonly used in real estate economics and Consumer Price Index calculations.

et al., 2013), enabling greater trust and better policy outcomes (Steinbach, 2013; Beierle and Konisky, 1999). The transmission system operator should implement well-structured and clear processes involving transparent communication (Ciupuliga and Cuppen, 2013). This approach could improve participants' knowledge and their sense of procedural fairness, benefiting from the effects of "procedural justice" and "social trust" (Schively, 2007; Mohanty and Tandon, 2006; Roussopoulos, 2005).

6. Conclusions

Real estate studies on the influence of HVOTL characteristics on farmland value can facilitate transmission line planning, construction and management outside urban centres in Italy. This research pointed out three important aspects. The first one concerns the Italian system operator, which should resort to assessment criteria based on scientific findings. Therefore, the compensation to landowners should concern land expropriation, height of towers, type of intersection and depreciation of a part of the unoccupied area. The remaining two aspects concern landowners. During the siting phase, based on individual sentiment, social interaction and political context, they claim sizeable compensations on the total unoccupied area, so to conflict with the system operator. However, this study revealed that, when landowners trade properties with pre-existent power lines, the impact of HVOTL is strongly reduced, above all on the residual area. Hence, landowners claim compensations which are not supported by the real estate mechanisms which themselves trigger. These findings can enhance the regulatory frameworks and improve the energy supply to community by involving public cooperation based on impartial and transparent information.

However, real estate analyses in Italy are difficult to carry out, for lack of transparency of real estate market, scarce vivacity of land transactions, and absence of a public agency in charge of the gathering and management of the trade information. Moreover, these analyses also request multidisciplinary data concerning the characteristics of power lines and their location, which however are not made available by institutions. Finally, to date, only direct and lengthy (in this case more than one year) surveys make possible the assessment of fair compensations. On the contrary, the creation of a single agency in charge of the collection and management of real estate and power-line information on the national territory is desirable, thus allowing also a periodical data updating for the increase of the quality of valuations over time.

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