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The Announcement Effect of Undergrounding High Voltage Overhead Transmission Lines: Quasi-Experimental Evidence from Rural France

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Abstract

In the tradition of studies in environmental and urban economics, house sale prices are used to evaluate the external net price premium of being located close to specific infrastructures. This paper estimates the announcement effect of the decision to underground a high voltage overhead transmission line in rural France. We propose a difference-in-differences method based on a quasi-experimental approach comparing house sale prices at different distances from existing pylons, before and after the announcement. In line with previous literature, the net price premium is found to be locally concentrated within less than 200 m. The statistical analysis indicates that the implied environmental costs of proximity to high voltage pylons are substantial and their reduction is internalized into house prices as soon as the decision is announced. The results also show that undergrounding transmission lines provides a positive benefit-cost ratio in about 85% of the different scenarios proposed.

Key words:

Transmission Line; Perception; House Values; Difference-in-Differences Estimator; Policy Analysis.

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1- Introduction

In Europe, investment of around €150 billion is needed for the installation of 48,000 km of new or upgraded transmission lines by 2030 (ENTSO-e, 2014) in order to include more renewable power in the energy mix. Renewable power generation sites are being built faster than the infrastructure needed to transport and connect the source of production of energy to the distribution centres (Rious et al., 2011). However, the installation of new electricity transmission infrastructure (ETI) frequently meets with opposition from local host communities (Battaglini et al., 2012; Cohen et al., 2016). Such resistance generates costly delays and may interrupt or at least slow the transition to a low-carbon or carbon-free power system.

A familiar explanation for local opposition to infrastructure projects, first proposed in the literature on social psychology, is the "Not In My Back Yard" (or NIMBY) syndrome. While people are globally in favour of the energy transition, they are reluctant to bear alone the costs of infrastructure projects (Devine-Wright, 2013). Visual obstructions related to ETIs – especially high voltage overhead transmission lines (HVOTLs) – have been identified as the main reason for people living close to such infrastructures speaking out against them (Cohen et al., 2014). Visible power lines, pylons, and transformers affect local residents' perceptions of the loss of ecological and aesthetic values of the landscape (Soini et al. 2011; Cain and Nelson 2013; Lienert et al., 2018). Local residents are also concerned about health risks from exposure to electromagnetic fields (Wadley et al., 2019).

Estimations of the local economic impact of HVOTLs help in identifying the external costs for the electricity supply industry to improve both efficiency in electricity pricing and fairness in defining host community compensation provision (Tobiasson and Jasmab, 2016). Hedonic pricing models provide an empirical framework in which to make an economic valuation of the visual impacts of energy infrastructure as reflected by variations in real-estate market prices (Gibbons, 2015). As people choose their residential location according to their preferences and aversions (Tiebout, 1956), the hedonic price approach, formally developed by Rosen (1974), provides a theoretical and methodological framework for retrieving the implicit price of – or willingness-to-pay (WTP) for – environmental characteristics that do not have a specific market price. In principle, this empirical process is straightforward. In practice, there are a number of major modelling issues to be considered, such as the choice of appropriate instruments for measuring environmental amenities and the selection of an econometric specification by which to identify and interpret their impact on welfare more easily (Bishop et al., 2020).

In the literature, one way to assess the possible impact of HVOTL infrastructure on house prices is to introduce a variable for the distance between individual houses and the transmission line pylons. Colwell (1990) was one of the first to show that the further away a house is from an ETI the higher the property's sale price. Subsequent studies measure visual nuisance more precisely using indicators that supplement distance to the infrastructure with the visibility of the line, and even more so of a pylon. Hamilton and Schwann (1995) mobilize the sale prices of individual houses (N=12,907) in Vancouver (Canada) and show that the value of a house located 100 m from a power line is 6.3% lower if the line or at least one tower is in the field of vision. For houses located more than 200 m away, the reduction in property values is around 1%. Des Rosiers (2002) uses information on 507 transactions in a southern suburb of Montreal (Canada) to suggest that it is the view of the pylons that is negatively correlated with property prices, with a premium ranging from -5% to -20%. He suggests that the effect is highly local, varying from 50 m to 100 m from the pylon. Beyond 150 m, the effect appears to be insignificant. Sims and Dent (2005) adopt the same methodology to study 664 transactions near Glasgow (Scotland) and find that properties located within 100 m of power lines are associated with a 6% to 17.7% lower sale price or thereabouts. The actual view of a pylon is associated with a 7.1% to 14.4% lower sale price.

So far, most applications have been based on a correlational approach, which may differ from a causal analysis. A causal approach in hedonic pricing models usually relies on the application of quasi-experimental approaches to environmental valuation to address inefficiencies associated with externalities (Greenstone and Gayer, 2009). It is essential for transmission system operators to develop reliable estimates of the external costs of the presence of HVOTLs if they are to conduct informed negotiations about compensatory mechanisms with host communities. Using the conventional hedonic approach to capture the external cost of infrastructure might confound the estimate of HVOTLs' externalities with other non-observable neighbourhood effects that are correlated with those externalities (Kuminoff et al., 2010). Thus, the impact being measured may be correlational and not causal (Parmeter and Pope, 2013).

A recent empirical study by Tang and Gibbons (2021) analyses the effects of new HVOTL installations on home values for England and Wales, i.e. with more than 1.4 million transactions from 1995 to 2018. The analysis is based on a difference-in-differences approach where price changes around neighbourhoods that are close to overhead powerlines before and after the construction of new lines are compared to other transactions not involving any major visual changes. As compared to the previous literature, they assume that proximity to pylons and lines can affect the prices of properties up to 1200 m away. Their analysis suggests that new overhead power lines may reduce prices by 4% on average.

The present paper contributes to the literature on evaluating the impact of HVOTLs by using a quasi-experiment that takes a different perspective. In making causal inferences about the perception of the market, two conditions are important: (i) economic agents (buyers and sellers) must be aware that a change will occur, and they must know where and when it will occur; and (ii) it must be possible to confine the nuisance under study to some specific distance. In this case study in rural France, about 70% of the buyers had their previous residence in one of the municipalities in the target area. Moreover, about 30% of homebuyers bought a property in the same municipality as their previous dwelling. It can be thought, then, that the economic agents were sufficiently informed to be able to anticipate the impact of the change.

The paper is original in three ways. First, the study takes advantage of the announcement about the replacement of an existing transmission line, where it was decided that part of it was to be undergrounded, to evaluate the impact of the prospect of the removal of the HVOTL, i.e., before the transformation actually occurred. Working on the assumptions of rational expectations and full information, the results of a difference-in-differences comparison concerning the announcement of an undergrounding project could be interpreted as the anticipated net impact of HVOTLs on environmental amenities in the study area.

Second, assuming, as in most of the literature, that the impact is concentrated locally, the methodological framework adequately isolates for potential omission variable bias by limiting the selection of both treatment and control transactions within 1000 m of the existing pylons. This choice greatly reduces the sample size for the estimations, while controlling both for spatially unobservable characteristics and spatial autocorrelation among residuals.

Third, the estimation results are used to investigate a cost-benefit analysis using a Monte Carlo experiment approach. This exercise aims to limit the impact of a large confidence interval when investigating the profitability of a public project. It indicates a probability of profitability regarding the estimation of benefits and costs instead of relying on a single point estimation.

The analysis is based on single-family home transactions between 2003 and 2014 (construction start date) in the municipalities concerned by the “2-Loires” project to upgrade a 225 kV line linking Saint-Privat-d’Allier to Saint-Etienne in France. It is assumed that the announcement of the upgrading plan, in 2009, might have affected public perception of a forthcoming change in the nuisances caused by the HVOTLs in place. Importantly, the announcement of the upgrading project did not mark a change in the footprint of the infrastructure, thus expectations about the environmental benefits of removing the pylons and undergrounding the power line are the only things that changed.

The results show that the negative impacts of HVOTLs may result in a price depreciation of about 40% for houses located within a strip of 200 m of the existing pylons. While the number of observations for comparison is small, a series of robustness checks suggests that the conclusions are consistent as regards the choice of control transactions. The results of the difference-in-differences approach indicate that the net impact of HVOTLs on house values may be much higher than previously reported in the hedonic literature. Furthermore, a benefit–cost ratio analysis for the undergrounding project, similar to stated-preference estimates (Navrud et al., 2008; Tempesta et al., 2013), is conducted to investigate the profitability of such actions. From a public policy perspective, the results suggest that opting for underground transmission lines may be a valuable tool, if not necessarily a panacea, for optimizing social welfare as well as global economic benefit as a Monte Carlo experiment suggests that the ratio is positive in about 85% of cases.

The paper consists of six sections in all. Section 2 sets out the methodological framework. Section 3 outlines the data used for the analysis. Section 4 shows the results and sensitivity tests. Section 5 presents a benefit-cost analysis. The final section concludes.

2- Methodological Framework

According to the hedonic pricing model (Rosen, 1974), the sale price of a complex good i at time t, stacked in the vector $\mathbf{y}_{it}$, can be expressed as a function of all its characteristics, including individual and spatial ones, synthesized in the matrix $\mathbf{X}_{it}$. The coefficients related to the independent variables, $\boldsymbol{\beta}$, can be used to retrieve the implicit (or hedonic) prices of each individual characteristic (equation 1).

$$\ln(\mathbf{y}_{it}) = \boldsymbol{\iota}\alpha + \mathbf{D}_{it}\boldsymbol{\delta} + \mathbf{X}_{it}\boldsymbol{\beta} + \boldsymbol{\varepsilon}_{it} \quad (1)$$

The hedonic pricing model is usually based on a logarithmic transformation of the dependent variable, $\ln(\mathbf{y}_{it})$, to better control for heterogeneity. The vector of the dependent variable is of dimension ($N_\tau \times 1$), where N_τ is total number of observations collected over time period t ($\tau = 1, \ldots, T$).[1] The matrix of independent variables, $\mathbf{X}_{it}$ is a matrix of dimension ($N_\tau \times K$), $\mathbf{D}_{it}$ is a matrix of time (year) fixed effect variables of dimension ($N_\tau \times (T-1)$), $\boldsymbol{\iota}$ is a vector of dimension ($N_\tau \times 1$) of elements equal to 1, and $\boldsymbol{\varepsilon}_{it}$ is an error term, assumed to be independent and identically distributed of dimension ($N_\tau \times 1$). The vector of parameters $\boldsymbol{\delta}$, of dimension ($(T-1) \times 1$), captures the nominal change in the house price over time, the vector of

1 The total number of observations is given by $N_\tau = \sum_t N_t$.

parameters $\boldsymbol{\beta}$, of dimension (K × 1), is the vector of implicit prices of the individual characteristics, while the scalar parameter α is the constant term.

While it is a straightforward matter to estimate the equation price model, causal inference cannot be estimated in such a cross-sectional specification. To make such estimations, standard methods have been developed (Antanokis et al., 2010), including the difference-in-differences (DID) approach. The DID approach is a simple extension of the hedonic pricing model where two additional variables are accounted for.

The first variable serves to isolate the transactions recorded before or after a specific (exogenous) change ($DT_{it} = \{0,1\}$). The variable takes a value of zero if the transaction is recorded before a certain date ($t < t^*$), while it takes a value of one if the transaction is observed on or after that date ($t \geq t^*$).

The second variable expresses the relative location of the transactions ($DD_{it} = \{0,1\}$). The variable takes a value of one if a given house is located within a specific zone liable to be impacted by the change (treatment area). This zone is located within a specific distance, $d_{ip} \leq d_c$, with d_{ip} being the distance between a transaction i and a pylon p, and d_c being a critical distance cut-off value identifying the within/outside (treatment) zone. It takes a value of 0 if it is located further away ($d_{ip} > d_c$).

Introducing both variables, as well as the cross-product of the variables, into the original price model equation allows us to obtain the DID specification (equation 2). This equation enables us to retrieve the causal effect of the change under study when the treatment and control groups are adequately identified, with $\mathbf{DD}_{it}$ a vector of dimension (N × 1), $\mathbf{DT}_{it}$ another vector of dimension (N × 1), and ○ the Hadamard (term-by-term) matrix product.

$$\ln(\mathbf{y}_{it}) = \boldsymbol{\iota}\alpha_0 + \mathbf{D}_{it}\delta + \mathbf{X}_{it}\boldsymbol{\beta} + \mathbf{DT}_{it}\eta + (\mathbf{DD}_{it} \circ \mathbf{DT}_{it})\theta + \boldsymbol{\varepsilon}_{it} \qquad (2)$$

The scalar parameter δ controls for any differences there might be between the transactions within each year, the scalar η controls for differences that might occur for both groups after the change, while the scalar θ controls for the difference that occurs for the treatment group after the change occurs. It is the parameter θ that allows us to isolate the effect of the treatment on house prices.

Description of the project under study

The study concentrates on the project to replace an existing transmission line between Saint-Privat-d'Allier and Saint-Etienne in the Auvergne-Rhônes-Alpes region of France. The original 25 kV line was built in 1941 and was in need of major investment to reduce the risk of shut down. To avoid such a situation, it was decided, on 19 March 2009, to rebuild the line. It was decided to replace the entire length of the power line. The construction was split into three separate phases.

The official announcement of the technical solution, which included undergrounding a part of the line, was set for February 2010. At this time, *Réseau de transport d'électricité* (Rte), the public network operator responsible for electricity transmission in France, opted to reconstruct the line as a double (instead of a single) circuit. The new transmission line was to feature about 250 pylons and three underground sections. It was to cross 23 municipalities (*communes*) for a total investment of about €132.7M under the conditions prevailing in 2012. Of this total investment, about €21M was earmarked for compensating, on a voluntary basis, local authorities for expected damage.

The route was finalized during the period 2012–2013, and the final public announcement was made in June 2014. While the details about the exact location of the new pylons were not entirely determined at that time, it had already been decided that a short section of the line would be undergrounded to bypass the main town along the line. The total length of the underground line was about 8 km out of a total 87 km. The replacement work began officially in 2015 and the line was officially brought into service on 1 December 2017, although the old line was only fully dismantled in March 2018.

The analysis focuses on the period during which the public consultation about the upgrading project was carried out, i.e., right after the announcement regarding the decision to rebuild the transmission line, and just before actual construction began. This period was essentially given over to delineating the route of the new high voltage transmission line. Studying this period means we can evaluate the impact of the prospective change, as opposed to the actual change. The paper concentrates on the shift in market expectation, as data on transactions after the project was completed are unavailable.

For the remainder of the paper, it is assumed that the decision to rebuild the power transmission line resulted, from the real-estate market perspective, in an exogenous shock, especially the decision to include the underground segments. This is so because the public network plan (2010–2020) to rebuild the line did not become public information until the official announcement was made. Moreover, while discussions were going on about the new route for the line, Rte had already decided on the location of the underground segments. This provides a quasi-experimental design to focus on the perception of the negative impact of the line by testing whether the market internalizes this major change through higher sale prices after the announcement.

The anticipation effect related to announcements about projects is familiar enough when it comes to implementing and developing new transport infrastructure (Devaux et al., 2017; Murray and Bardaka, 2021) but also energy infrastructure (Boslett et al., 2016). Thus, the changes in the perception of proximity to/view of such infrastructure is based on a real situation, and not on a survey, where the agent does not necessary feel that the change is for real. Thus, anticipation is measured from a different perspective based on actual transaction data where it is already known that a public intervention is to take place. The change thus measures perception from the perspective of actual experience.

3- **Transaction data**

The information about single-family home transactions was provided by the *Notaires de France* information system (also called *Perval*). The full set of transactions covers the period between January 2000 and December 2016 for a total of 3583 single-family house sales for the whole region under study (Figure 1).

INSERT FIGURE 1 HERE

While the reconstruction of the transmission line may affect many municipalities, the literature recognizes that the nuisance impact, of transmission lines is closely concentrated around the pylons. In the case of the “2-Loires” project, it was decided to concentrate most of the reconstruction within 50 m of the existing pylons. Usually, the presence of a power line commands a restriction on land use within 100 m on either side and the new line itself is some 20 m wide. Some studies suggest that the negative effect is closely related to the encumbrance of the pylon (Des Rosiers, 2002) and is usually inexistant beyond 150 m, but there remained some uncertainty regarding the exact location of the pylons along the new line. For those reasons the treatment area was defined using a 200 m distance to the existing pylons (and not the distance to the line).

Moreover, to ensure that the perception effect is related to a major change, the analysis focuses explicitly on the area in which it is proposed to underground the new line. For this part of the project, and to avoid potential problems of violation of the stable unit treatment values assumption (SUTVA),[2] the control group is defined by a zone twice as wide as the treatment group using transactions located within 300 m and 700 m. This leaves a 100 m distance between the treatment and control groups. This local approach is also designed to control for high heterogeneity in the spatial amenities that might otherwise bias the analysis.

Filters are applied to the data set. First, as the study focuses on the anticipation (and adjustment) effect related to the announcement of the modification, transactions in 2015 and 2016 are discarded. Second, a filter on the final sale price and the size of land lot, based on interquartile statistics, is used to remove the extreme values that might influence the estimation results, especially when limiting the analysis to a small sample size. Finally, to make sure that the number of transactions before and after the announcement is not highly unbalanced, it is proposed to keep transactions recorded between 2003 and 2014 in the analysis. In the end, the total sample size available for the analysis is fixed at 125 transactions (Figure 2).

INSERT FIGURE 2 HERE

The number of transactions within the treatment area is small. A total of 24 transactions was observed in the period 2003–2014. Of this total, 17 transactions were observed before the announcement and 7 transactions after.[3] The number of transactions within the control area is greater (101 transactions), but a similar pattern is observed with more transactions (72) before the announcement than after (29). For both areas, about 30% of transactions are observed after the announcement (Table 1).

A quick look suggests that the mean sale price rose more in the control area (an increase of about €19,699) than in the treatment area (increase of about €9,872). However, this comparison hides the fact that the values are in nominal terms, as well as the fact that the characteristics of the houses may be different.

Focusing on the descriptive statistics of the transactions, the characteristics of the transactions used for the analysis (N_τ = 125) are not statistically different from the characteristics of the transactions for the period 2000–2014 (N_τ = 152). The only statistical difference is in the sale price and the sale year (Table 1). However, these differences can easily be explained by the larger span of the time period. The mean sale price is about €132,405 for a mean land lot size of about 886 m^2. The houses have about 4 rooms, 1 bathroom, a parking space, and most of the transactions involve detached single-family houses.

INSERT TABLE 1 HERE

On the one hand, limiting the analysis to a specific area obviously limits the sample size. However, the investigation is spatially concentrated on transactions that will undergo a marked change, i.e. the dismantling of the existing pylons and the undergrounding of the transmission line. Thus, it is in this area that any sizeable influence on sale prices might occur. Moreover, the selection of the sample does not influence the mean statistics of the selected transactions (Table 2).

INSERT TABLE 2 HERE

On the other hand, limiting the analysis to municipalities (*communes*) affected by the undergrounding of the transmission lines helps limit the possible omission bias related to

2 Which is related to the spatial spillover effect.

3 Adding the information from the construction period (2015–2016) has only a slight influence on the size of the groups and on the results. It adds three observations to the treatment group after the announcement. To be consistent, the analysis is based on the announcement period only so as to avoid any undesirable cross-effects between specific periods. However, analysis with the transactions confirms the estimation results.

spatial characteristics. The municipalities affected have about the same population size and the spatial characteristics and amenities are similar within the small municipalities.[4] The inclusion of distance to the nearest major town (St-Etienne) is designed to control for specific differences within the municipalities. Limiting the extension of the spatial area covered also limits possible problems related to spatial autocorrelation among residuals.

Two conditions must be met for changes in home sale prices to reflect environmental disamenities. The first is that potential buyers (and sellers) should be aware of the existence of infrastructure in the vicinity of their future purchase and the dismantling of the infrastructure and therefore take this information into consideration when making an offer for a house. This seems to be the case: more than 70% of them already had their previous residence in one of the municipalities of the area targeted by the "2-Loires" project.

The second condition is that the market should perceive the proximity of the infrastructure as a nuisance. About 30% of homebuyers bought a property in the same municipality as their previous dwelling. In other words, we can comfortably assume that, before buying the house, the great majority of purchasers knew about the presence of the HVOTL near their future residence.

4- Estimation Results

Before turning to the estimation, a brief remark is called for about the small sample size. First, since the number of observations in the treatment area (within 200 m of the existing pylons) is small, it is impossible to formally test for the parallel trend assumption. However, as the transactions are spatially highly concentrated, the assumption appears to be quite realistic, as the price within a distance of 1400 m (radius of 700 m) within a rural community is likely to share the same trend. Second, since no transactions occur between January and March 2009, the vector $\mathbf{D}_{it}$ is perfectly correlated with the vector $\mathbf{DD}_{it}$ (see equation 2). For this reason, one of the terms in the original equation is deleted in the estimation process.

The models are estimated using Stata software. All models are corrected for a robust variance-covariance matrix.[5] The estimation results suggest that the basic hedonic price equation is able to explain more than 60% of the variance in the sale price (in log). The model is globally significant, while the coefficients related to the individual and spatial characteristics are consistent with theoretical expectations: houses with better amenities sell for higher prices (Table 3 – column 1). No spatial autocorrelation is detected among the residuals of the models, as suggested by the non-significant Moran's I index.

INSERT TABLE 3 HERE

A few specific points are called for about the interpretation of the results for the base model. First, many characteristics are not statistically significant. This is the case for the number of rooms, the number of bathrooms, the number of parking spaces, and the number of floors. This situation can be partly explained by the fact that the area under study is rural, where goods might be more homogenous. Second, it appears that lot size is one of the most important factors in explaining the final sale price. Lot size appears to be the characteristic that accounts for most of the heterogeneity in the goods in such areas. Third, larger houses, as captured by the variable *Pavillon* (single-family house) are associated with higher sale prices. Fourth, the year dummy variables are globally significant, suggesting a rise in nominal price over time.

4 The number of dwellings was about 2032 in 2018 in Saint-Just-Malmont (the closest town to St-Etienne), while it was 1762 for Saint-Didier-en-Velay and 794 in La-Séauve-sur-Sermène.

5 With the `robust` option.

Focusing on the second model with the original DID specification (Table 3 – column 2), the results suggest that the announcement of the removal of the pylons and the undergrounding of the transmission lines positively and significantly affected sale price. While the price was about the same before the announcement after controlling for the characteristics of the houses, as suggested by the non-significant coefficients related to proximity to the old pylons, the price premium related to the announcement of the project was about 40%. The positive price premium for the houses located close to pylons before the announcement can be explained by the fact that those houses are located in the centres of the small municipalities.

Based on the mean sale price of houses located close to the pylons before the announcement, i.e. about €172,555, the price premium represents a rise of about €68,912 in nominal value, which is considerable. Of course, the size of sample is small, which results in large standard errors. The confidence interval of the estimated parameter suggests that the price premium lies between €3,660 and €158,327. Thus, while the numbers seem high, we might be cautious about extrapolating the estimated price premiums according to the sample size. Nevertheless, the main conclusion is that the announcement of the removal of the pylons was positively perceived by the real-estate market.

To check the robustness of the results, six complementary analyses were conducted. The first one used the same time period (2003–2014) but confined the control area to within 300 to 600 m. This reduced the sample size of the control area. The results show that the estimated coefficient of interest is similar to the main specification, and that the effect remains statistically significant (Table 3 – column 3).

The second complementary analysis took the same time period but used transactions recorded between 300 and 800 m as the control area. This increased the sample size for the control area in both absolute and relative terms. The results are, once again, similar to the original specification. The estimated coefficient of interest suggests a price premium of about 39% and is statistically significant (Table 3 – column 4). In this second robustness analysis, the gap in the confidence interval appears to be less pronounced than that regarding the original and the previous specifications.

The other set of robustness check analyses includes the transactions concluded between 2000 and 2003 for the control and treatment areas. With this sample, three separate models are estimated: (i) one with the control area defined by the 300 to 700 m area; (ii) one with the control area defined within 300 to 600 m of the existing pylons; and (iii) one with the control area extended to include transactions within 300 to 800 m of the existing pylons. In each case, only the number of transactions within the control area changed.

The additional three robustness check analyses show a positive and significant coefficient related to the variable of interest (Table 4 – column 1). While the value of the coefficient is a little larger (0.3715 instead of 0.3360), the estimated impact lies within a similar confidence interval. Similar conclusions are obtained when the analysis is narrowed to the 300 to 600 m ring around the existing pylons (Table 4 – column 2), and when it is extended to include transactions within 300 and 800 m control area (Table 4 – column 3). In all cases, the mean price premium is estimated to be between €75,218 and €79,152.

INSERT TABLE 4 HERE

The final robustness check analysis is based on a permutation test to calculate the significance of the parameter of interest in the original specification. This allows us to develop a non-parametric test to calculate the pseudo p-value for the parameter of interest. The idea is to permute the variable of interest (here the treatment variable) randomly for the before and after time periods and to re-estimate the model. The original parameter is significant if it is distinct from the one estimated using the permutation. Stated otherwise, the original parameter must be far enough from the distribution of the parameters based on their fictive status to be significant. The test is based on 9999 permutations and the rank of the original parameter is calculated to obtain the pseudo p-value. The results suggest that the parameter is statistically significant, with a pseudo p-value of 0.0493 (Figure 3). In the end, the statistical conclusion appears to provide a robust impact coefficient, even if the sample size used to make the analysis is small.

INSERT FIGURE 3 HERE

5- Evaluating the (partial) economic impact of the undergrounding project

One way to avoid the negative impact of high voltage transmission lines is to opt for a fully underground line. In such a case, the negative nuisance of the line is almost non-existent (Navrud et al., 2008; Menges and Beyer, 2014; Lienert et al., 2018). While this solution appears to be suitable for avoiding many downsides, it is sometimes deemed too expensive. For example, a project initiated in 2003 for a new transmission line between Spain and France through the Pyrenees Mountains was finally turned into an underground line after discussions with the local population. The original project for an overhead transmission line aroused strong opposition and it took about eight years of consultation to finally propose the underground solution (Ciupuliga and Cuppen, 2013). The line was put into service in 2015 and the final cost of the 33 km line was €357M, including an additional cost of €257M related to the choice of undergrounding.[6]

As the statistical analysis suggests, there is an individual and economic cost to living close to an overhead transmission line, at least for people directly exposed to the infrastructure. The availability of estimates of the causal effect of the presence of overhead transmission lines can be used to develop a partial cost-benefit approach to undergrounding schemes based on the resident household’s willingness-to-pay to have an energy infrastructure-free landscape.

On the one hand, the marginal WTP, evaluated between €3,660 and €158,327 from the analysis, can be used to estimate the environmental net benefit values, as the sample is representative of the entire geographical area (Bateman et al., 2006). A total of 650 single-family residences, generally owner-occupied, were located within 200 m of the source of the nuisance, which amounted to about 2000 inhabitants.

On the other hand, the cost per km of an underground high voltage line varies from project to project. In the case of the “2-Loire” project, the cost is estimated at between €1M and €2.8M. Based on those intervals, it is possible to evaluate the net benefit of undergrounding the transmission line.

A first and simple analysis consists of taking the mean value of the estimation of the benefit and the cost to calculate the (partial) net benefit. In such a case, the benefit clearly outweighs the construction cost. The net benefit is about €29.59M. It would have been equal to zero if the total number of houses located within 200 m of the pylons had been 221, representing about 1/3 of the total housing stock. However, this estimation relies on a point estimate only and might suffer from the lack of observations related to the treatment group after the change occurs.

Another way to take the analysis is to use the extreme values of the intervals for the estimated benefit and the building cost of the different scenarios. On the one hand, the results

6 Which represents a rough estimation of about €7.79M/km.

suggest a total benefit that varies between €2.4M and €102.9M. On the other hand, the actual cost of building the infrastructure, for the 8 km stretch, suggests that the cost varied between €22.4M and €8.0M. In the worst-case scenario, i.e. when the estimated benefit is about €3.7K/house and the construction cost is €2.8M/km, the net benefit is estimated to be about -€20M (Table 5). In such a case, the minimum number of houses affected by the presence of the pylons should be 6119 to reach a zero net benefit. In the best-case scenario, i.e. when the estimated benefit is about €158.3K/house and the construction cost is €1.0M/km, the net benefit is estimated to be about €94.9M. In this case, the presence of only 51 houses located close to the existing pylons is necessary to ensure a zero net benefit (Table 5).

INSERT TABLE 5 HERE

Another way to deal with the analysis is to conduct a Monte Carlo experiment using the confidence interval regarding the benefits and the costs.[7] Using 1000 simulations by randomly changing the value of the benefit and cost, the (partial) cost-benefit analysis reveals the distribution of the net benefit is mainly positive (Figure 4). The analysis suggests that less than about 15% of the net benefit is negative, which in turn suggests that the decision to bury the transmission line results in a positive impact for about 85% in the different scenarios.

INSERT FIGURE 4 HERE

In the end, the analysis returns similar results to those reported by two earlier stated-preference studies (Navrud et al., 2008; Tempesta et al., 2013) conducted in Norway and Italy. Even for sparse rural areas, it appears that the benefits from burying high voltage power lines do exceed the costs. Of course, the analysis is only partial since more benefits and costs could be included in a more complete scheme. However, the benefit/cost ratio yields some interesting insights for developing public policies about the future development of transmission lines.

6- Conclusion

This study contributes to evaluation of the impact of electricity transmission infrastructures on housing prices, as they produce disamenities (mainly visual effects, and potential electromagnetic field emissions) for residents living close by. The analysis is based on the effects associated with the announcement of a project to upgrade a high voltage (225 kV) line in a rural area around the town of Saint-Etienne in France. More specifically, the announcement of the burial of a portion of the line (8 km) serves as a quasi-natural experiment with which to investigate the perception of the electric transmission pylons on house prices. As the analysis is based only on the impact after the announcement, and not on the final market adjustment, the paper aims at singling out the market reaction to a political decision of the kind.

To do this, the statistical analysis draws on difference-in-differences (DID) estimators using a hedonic pricing model for three municipalities affected by the decision to switch from overhead to underground high voltage transmission lines. The selection of single-family home transactions located within 200 m of the pylons of the old line as the treatment group enables us to compare a situation with and without the presence of the infrastructures, for the same localities. Such an approach avoids confusion between the impact of the infrastructure and the effect of other environmental variables.

The results suggest that there is a negative and significant impact related to the presence of pylons on single-family house prices. The results show that the announcement of

7 The `Stata` code used for the analysis can be found in the appendix. See Elariane and Dubé (2019) for a full discussion of this exercise.

the intention to replace the transmission line is reflected by a rise of about 40% in the price of a house located within 200 m of existing pylons. For the area under study, this impact represents a price premium of about €68,912 in nominal value.

The large disparities in properties on the real-estate market in rural areas means that the price premium can also vary quite considerably, from €3,660 to €158,327. Based on these estimations and on the estimation of the additional cost of undergrounding a power line (between €1M and €2.8M/km), a cost-benefit analysis is conducted. To investigate the robustness of the analysis, a Monte-Carlo simulation based on different combinations of the cost and benefit is developed to build a distribution of the potential net benefits. The analysis suggests that about 85% of the point estimates return a positive net benefit, emphasizing the economic potential related to the undergrounding of transmission lines.

The paper is original in three ways. First, it uses a quasi-experimental approach based on an exogenous announcement about undergrounding a high voltage transmission line to investigate the causal effect related to such actions. The analysis relies on the expected effect of the proximity of pylons on single-family house prices since it is based on the announcement period alone. To our knowledge, this is one of the first research papers to take advantage of such public decisions to investigate the impact on expectation. Second, the local application of the before/after investigation using a DID hedonic pricing model allows us to adequately control for the omission of spatial variable bias, as well as controlling adequately for spatial autocorrelation within residuals. Finally, a global cost-benefit analysis to investigate how such public action can result in a net positive impact from an aggregated perspective reveals interesting features regarding the potential net impact of burying high voltage lines.

The analysis has also its limitations. First, the analysis is based on the expectations about the real-estate market, which could overestimate the final impact after a market adjustment process. It clearly shows that the presence of electricity transmission lines does entail a local cost that is borne by a few individuals. Second, the analysis relies on a relatively small number of transactions. This raises questions about the external validity of the estimation, as it is conducted in a specific region and in a limited number of municipalities. However, most analyses involving rural areas necessarily face such constraints since transactions there are sparse.

From a public policy perspective, while several authors (Mueller et al., 2019; Lienert et al., 2018) have shown that undergrounding is not a panacea for limiting protests by local populations, or for modifying their perception of the risks, the results suggest that, in some situations, the undergrounding of transmission lines might prove a useful way to limit negative local perceptions. The results suggest that if the local population demands underground technology despite its cost, the global economic impact might be efficient from a social welfare standpoint, at least in some areas.

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Figure 1: Spatial distribution of transactions in the region under study

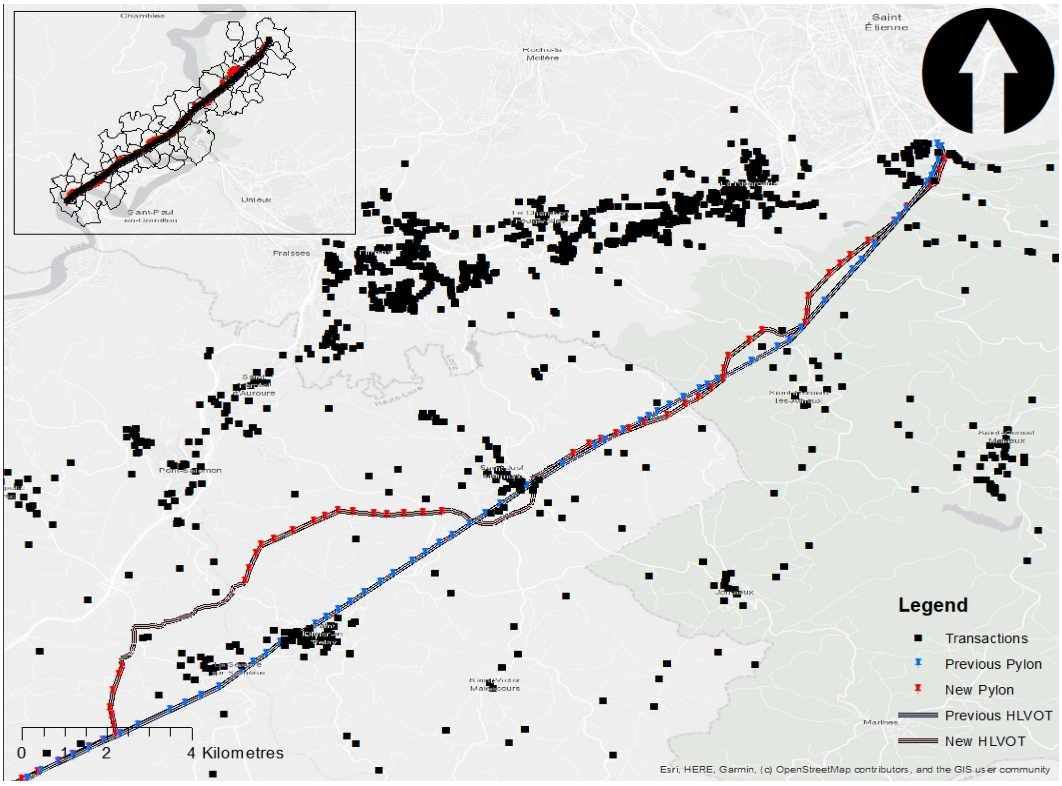


Figure 2: Identification of the transactions under study

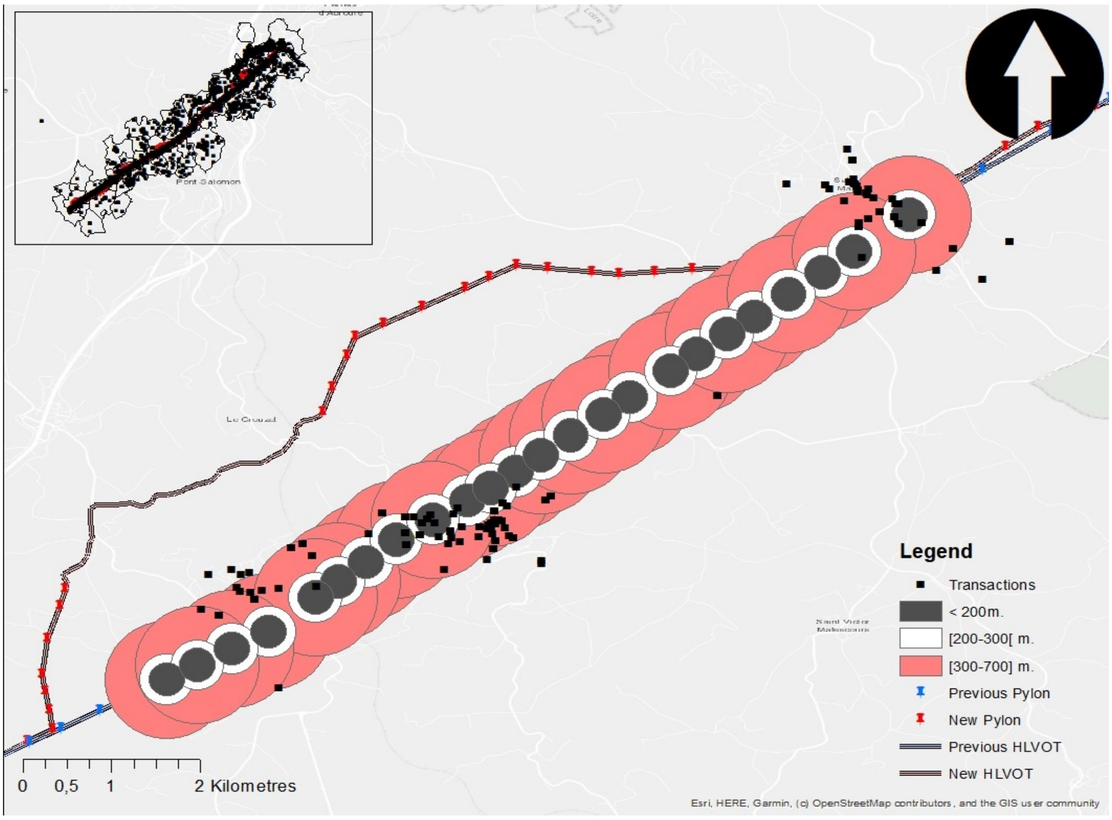
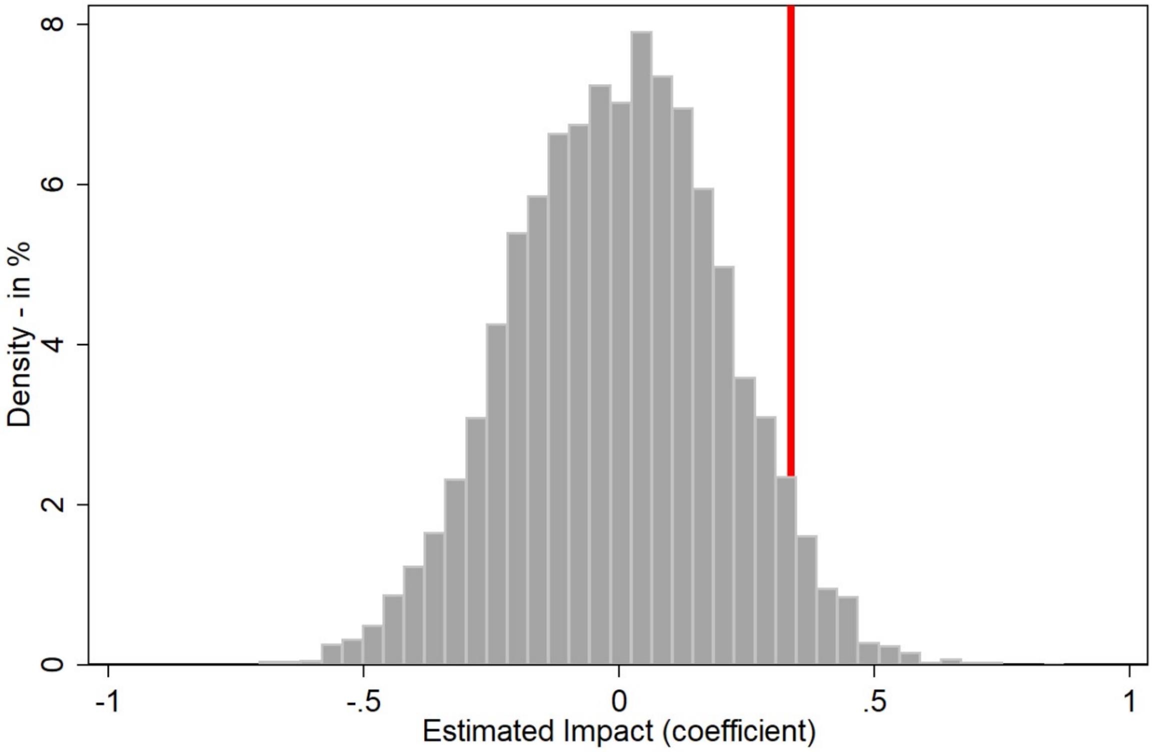


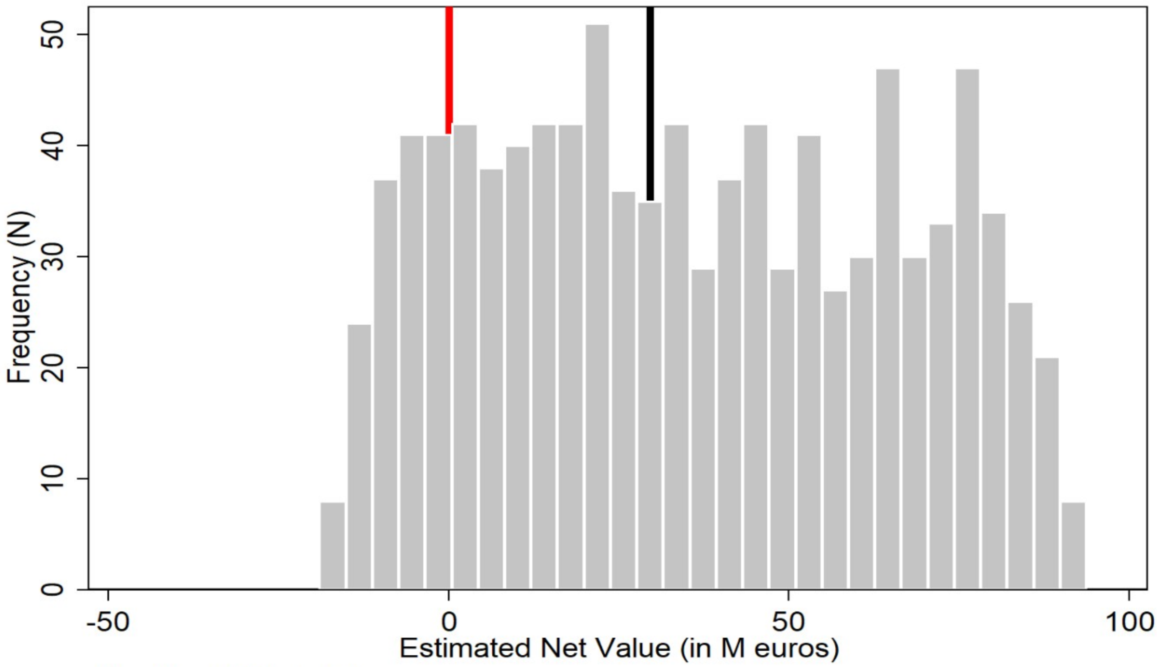
Figure 3: Determination of the pseudo p-value using a permutation test.



Significance test by permutations (pseudo p-value)

Legend: Red → Estimated Value; Grey → Permutations estimated values

Figure 4: Support for positive benefit-cost ratio



Result for 1,000 simulations

Legend: Red line → Δ = 0; Black line → Point esimate

Table 1: Identification of the treatment/control groups by zone.

	Distance to the old pylons			
	< 200 m.		**]300; 700] m.**	
Time	N. obs.	Sale price (in €)	N. obs.	Sale price (in €)
Before March 19 2009	17	172555.9	72	116524.7
After March 19 2009	7	182428.6	29	136224.1
Between 2003 and 2014	24	175435.4	101	122181.0

Note: All prices are in nominal values

Table 2: Descriptive statistics of the sample

	Full sample				Selected sample			
Variables	Mean	s.d	Min	Max	Mean	s.d	Min	Max
Sale price (nominal €)	121759.60	64809.46	22867	390000	132405.80	64044.45	22867	390000
Sale price (log)	11.55	0.599	10.04	12.87	11.66	0.561	10.04	12.87
Distance to closest pylon (new) (m.)	1721.81	348.489	1040.73	2195.28	1679.07	352.413	1040.73	2195.28
Distance to closest pylon (old) (m.)	381.80	151.179	38.47	695.70	373.85	152.988	38.47	695.70
Lot size (m^2)	869.04	990.918	35.00	7864.00	886.76	963.962	35.00	7864.00
Lot size (m^2) - log	6.21	1.146	3.56	8.97	6.26	1.141	3.56	8.97
Number of rooms	3.92	1.934	0	6	3.99	1.899	0	6
Number of bathrooms	0.96	0.513	0	2	0.99	0.516	0	2
Number of parking spaces	0.88	0.519	0	2	0.90	0.536	0	2
Sale year	2006	3.904	2000	2014	2007	3.322	2003	2014
Number of floors	1.70	0.883	0	3	1.68	0.921	0	3
Townhouse	0.34	0.474	0	1	0.34	0.474	0	1
Detached single-family houses	0.52	0.501	0	1	0.54	0.501	0	1
Distance to St-Etienne (km)	16.55	2.130	12.36	19.93	16.33	2.256	12.36	19.49

Note: Full sample size is 152 transactions; Selected sample size is 125 transactions

Table 3: Estimation results and robustness check

Variables	Base Model		DID model		Robustness (1)†		Robustness (2)‡	
	Coefficient	sign.	Coefficient	sign.	Coefficient	sign.	Coefficient	sign.
Lot size (m^2) - log	0.2844	***	0.2835	***	0.2754	***	0.2294	***
Number of rooms (ref: 2 or less)								
3	-0.3285		-0.3327		-0.2829		-0.0884	
4	-0.2669		-0.2564		-0.2104		-0.0327	
5	-0.0711		-0.0675		-0.0326		0.1381	
> 6	-0.1726		-0.1239		-0.0969		0.0791	
Number of bathrooms (ref: 0)								
1	0.0269		-0.0038		-0.0607		-0.1028	
2	0.2517		0.2285		0.2006		0.0890	
Number of parking spaces (ref: 0)								
1	0.0990		0.1200		0.0684		0.1469	
2	0.1773		0.1717		0.1303		0.2062	
Sale year (ref: 2003)								
2004	0.3642	*	0.3532	*	0.3460	*	0.1894	
2005	0.4003	**	0.4019	**	0.4343	**	0.3299	**
2006	0.5663	**	0.5739	**	0.5801	*	0.4257	*
2007	0.4517	***	0.4511	***	0.4404	***	0.3684	**
2008	0.3302		0.3307		0.3278		0.3053	*
2009	0.5090	*	0.3175		0.3221		0.3492	
2010	0.3159		0.3352		0.1078		0.3340	
2011	0.8141	***	0.6941	***	0.6666	***	0.5376	***
2012	0.7532	***	0.7357	***	0.7309	***	0.6194	***
2013	0.3966	*	0.3313	*	0.3093	*	0.2163	
2014	0.7351	***	0.6850	***	0.6629	***	0.4885	***
Number of floors (ref: 0)								
1	0.0584		0.0087		0.0303		-0.1069	
2	-0.0345		-0.0807		-0.0497		-0.1664	
3	-0.0002		-0.0218		-0.0277		-0.1026	
Townhouse	0.1932		0.2255		0.1490		0.1601	
Detached single-family house	0.3691	*	0.3824	**	0.3356	*	0.3480	**
Distance to St-Etienne (km)	-0.0583	***	-0.0571	***	-0.0536	**	-0.0458	***
Within 200 m of old pylons			0.0460		0.0308		0.0965	
Within 200 m after announcement			0.3360	*	0.3323	*	0.3315	*
Constant	10.1559	***	10.1480	***	10.2444	***	10.3784	***
N	125		125		118		162	
F-Stat	13.93	***	14.43	***	13.56	***	11.17	***
R^2	0.6479		0.6655		0.6536		0.6293	
RMSE	0.37471		0.3690		0.3713		0.3543	
Moran's *I* Index	-0.0126		-0.0157		-0.0172		-0.0126	

Legend: *** p < 0.001; ** p < 0.01; * p < 0.05

† Analysis is made using transactions within 300–600 m of the old pylon as the control area

‡ Analysis is made using transactions within 300–800 m of the old pylon as the control area

Table 4: Estimations results of sensitivity tests

Variables		Robustness (1)†		Robustness (2)‡		Robustness (3)Ŧ	
		Coefficient	sign.	Coefficient	sign.	Coefficient	sign.
Lot size (m^2) - log		0.2980	***	0.2913	***	0.2417	***
Number of rooms (ref: 2 or less)							
	3	-0.3580		-0.3026		-0.1364	
	4	-0.2617		-0.2042		-0.0897	
	5	-0.1372		-0.0864		0.0481	
	> 6	-0.1649		-0.1300		0.0161	
Number of bathrooms (ref: 0)							
	1	0.0003		-0.0607		-0.1368	
	2	0.2781		0.2529		0.1073	
Number of parking spaces (ref: 0)							
	1	0.1131		0.0720		0.1696	
	2	0.1485		0.1164		0.1938	
Sale year (ref: 2000)		Included		Included		Included	
Number of floors (ref: 0)							
	1	0.0135		0.0268		-0.0850	
	2	-0.0394		-0.0216		-0.1274	
	3	0.0456		0.0335		-0.0565	
Townhouse		0.1645		0.0923		0.1154	
Detached single-family house		0.3265	**	0.2814	*	0.2954	**
Distance to St-Etienne (km)		-0.0585	***	-0.0551	***	-0.0444	***
Within 200 m of old pylons		0.0161		0.0031		0.0622	
Within 200 m after announcement		0.3715	*	0.3618	*	0.3776	**
Constant		10.1122	***	10.1633	***	10.2362	***
N		152		144		198	
F-Stat		15.03	***	13.31	***	14.64	***
R^2		0.7038		0.6998		0.6705	
RMSE		0.36585		0.3674		0.3539	
Moran's *I* Index		-0.0152		-0.0164		-0.0119	

Legend: *** p < 0.001; ** p < 0.01; * p < 0.05
Include transactions from 2000 to 2014
† Analysis is made using transactions within 300–700 m of the old pylon as the control area;
‡ Analysis is made using transactions within 300–600 m of the old pylon as the control area;
Ŧ Analysis is made using transactions within 300–800 m of the old pylon as the control area;

Table 5: Scenarios for benefit-cost analysis

CBA component	Negative	Mean	Positive
Benefits (K€)			
Impact/house	*3.66*	*68.91*	*158,33*
# of house	*650*	*650*	*650*
Estimation	2379	44793	102913
Costs (K€)			
Cost/km	*2800*	*1900*	*1000*
# of km	*8*	*8*	*8*
Estimation	22400	15200	8000
Difference (M€)	**-20.02**	**29.59**	**94.91**
# of houses needed‡	**6119**	**221**	**51**
Note: ‡ to have a difference of 0			

Appendix

Stata code for simulating the (partial) net benefit analysis

```
clear all
set seed 01181979		/*Retrieving the same simulation results*/
global reps = 1000  /*Number of simulations*/

/*General parameters*/
set obs 1
global scale = 1000
global NHouse = 650
global Nkm = 8
/*Benefits*/
global bmin = 3660/$scale
global bmax = 158327/$scale
global bgap = $bmax - $bmin
global bmean = $bgap/2
/*Costs*/
global cmin = 1*$scale
global cmax = 2.8*$scale
global cgap = $cmax - $cmin
global cmean = $cgap/2

/*Creating variables to be filled*/
quietly generate nsimul = .
quietly generate eb = .
quietly generate ec = .
quietly generate cost = .
quietly generate benefit = .
quietly generate netvalue = .

/*Making the calculations*/
local nobs = 1
quietly {
forvalues i = 1/$reps {
replace nsimul = _n if _n==`nobs'

/*Calculating the benefits & costs*/
**Costs
replace ec = uniform() if _n==`nobs'
replace cost = (($cmin + (ec*$cgap))*$Nkm)/$scale if _n==`nobs'
**Benefits
replace eb = uniform() if _n==`nobs'
replace benefit = (($bmin + (eb*$bgap))*$NHouse)/$scale if _n==`nobs'
**Net Benefit
replace netvalue = benefit - cost

local nobs = `i'+1
set obs `nobs'
}
}

keep nsimul cost benefit netvalue
#delimit ;
histogram netvalue,
	frequency fcolor(gs12) lcolor(white)
	xline(0, lwidth(thick) lpattern(solid) lcolor(red))
```

```
        xline(29.6, lwidth(thick) lpattern(solid) lcolor(black))
        xtitle(Estimated Net Value (in M euros))
        ytitle(Frequency (N))
        scheme(s1color) legend(off)
        note("{it:Result for 1,000 simulations}")
        caption("Legend: Red line {&rarr} {&Delta} = 0; Black line {&rarr} Point esimate", size(*0.8));
#delimit cr
graph export "AnalyseRentabilite.png", as(png) replace

summarize netvalue if netvalue <0
scalar sign = r(N)/_N
scalar list sign
```