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The Informational Content of Land Price and its Relevance for Environmental Issues

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ABSTRACT

As the support of human and natural activities, land is a resource of major interest both for environmental and socio-economic issues. Research aimed at improving land management and conservation has long recognized the need to integrate both issues, but a consensual and consistent framework is still lacking. We argue that land price could be one of the possible links here, as a consistent proxy for some of the multiple dimensions of values that people put on land resources. We present the elementary economic theory about land price, namely the present value model, and we review the abundant empirical literature using this classical theory to study the informational content of land price. We then propose a typology of this literature, highlighting its strengths and weaknesses, in order to guide future environmental research which aim at drawing out some socio-economically oriented policy recommendations.

Keywords: economic valuation, natural resource, multidisciplinary, public policies

JEL Codes: Q15, Q24, Q51

1 Introduction

The need to integrate the socio-economic dimension into environmental studies is regularly claimed (Polasky, 2008; Sanchirico and Wilen, 2008; Groffman *et al.*, 2010). One relevant aspect of economic theory is that it can provide insights into the way people value natural resources, which is of high interest in order to reach more sustainable earth stewardship (Chapin *et al.*, 2011; Gammon *et al.*, 2011). Land resources have been the subject of numerous analyses both in economics (Duke and Wu, 2014) and in environmental sciences (Turner *et al.*, 2007). However, we believe that the price of land is an underutilized variable in environmental studies and with this paper we aim to provide some guidelines so that the informational content of land price can be better exploited for such studies.

Since aggregate land supply is fixed, land market outcomes–land price in particular–are almost always studied through their demand side. Some exceptions exist when land supply and demand are specifically considered in relation to the different uses of the resource (Wiltshaw, 1985; Evans, 2008). As such, land supply could be defined but its determinants for a particular use remain totally dependent on the demand for other uses. Thus, in almost all cases, land market outcomes could be fully described by the interactions of competing and exclusive demands for the same limited resource. This makes the present value model (PVM), originating from modern asset pricing theory, the preferred framework for the study of the economics of land price.

The PVM states that the land price equals the present discounted value of the stream of present and future–tangible and intangible–earnings. Hence, land price is an intertemporal, consistent indicator of the underlying multidimensional and embedded values that heterogeneous individuals place on the attributes of land, on its environment, and on the commodities and services that it can provide. The PVM could be compared to the trophic cascade theory in ecology, which places the emphasis on high trophic levels because they proxy the general health of the ecosystems grounded on complex interactions. Consequently, the PVM attributes a high informational content to land price, and this is our focus in this review. This informational content is exploited by numerous empirical studies, covering a wide array of applications that we review in this article.

The PVM puts strong informational content on land price due to four important features of the model. First, it states that land price is determined by the returns that land can provide to its owner. According to the PVM, land price is a consequence, not a cause, of economic value. Second, land price gives a measure of temporal preferences and growth expectations. As with any durable good or investment, a land purchase is made by individuals who take into account the future returns from the resource. Third, under the PVM assumptions, the observed land price corresponds to the optimal land-use path that can be made of the resource. This optimal land-use path is defined as the sequence of land uses that provides the highest private value at each moment of time. Fourth, the land price arises from private values, limited to internalized earnings. As a practical consequence, the interpretation of the informational content and its comparison with the social costs or benefits have to be made carefully.

After a presentation of the elementary economic theory about land price, we review the empirical papers that apply this framework to the study of the informational content of land price for environmental issues. Although we refer to "land prices" in the following, it should be noted that empirical studies use a variety of measures such as transaction prices, owner-reported estimates, and the assessed values of land parcels. With the use of econometric regression models, the effects of the numerous determinants of land prices are estimated and are interpreted as economically consistent indicators. Importantly, the informational content of the land price is not limited to the current characteristics of the parcel transacted. In addition to these intrinsic characteristics (such as soil quality, climatic conditions, water availability), we highlight that the land price contains information on the value of extrinsic characteristics from neighboring parcels (such as landscape patterns, infrastructures, ecosystem services) and about the anticipated future outcomes (such as timber harvest, land degradation, urban developement). This distinction has some strong implications for the values identified from the land price at different spatial and temporal scales. Another major distinction is related to the legal regime prevailing, since in different countries or regions land ownership does not always have the same implications for the stewardship of environmental characteristics. Depending on the legal regime, the land buyer could exclude other potential users from the benefits associated with land (excludability) or capture the benefits from the others (rivalry). We provide a typology of land characteristics across these two dimensions that make sense from both an environmental and an economic point of view. This typology allows us to provide some guidance on the key features of this literature and to identify research strategies that can help environmental researchers.

We present the PVM in section 2, from its most basic form to the classical extensions that can be found in the literature. In section 3, we review the empirical papers that use the PVM to study the informational content of land price. Then we discuss in section 4 some potential applications for environmental sciences, and section 5 concludes.

2 The present value model and its extensions

2.1 The standard capitalization formula

In its standard form, the PVM emerges from a stylized economy with well-defined and well-enforced property rights. Consider a competitive land market characterized by a large number of buyers, with perfect information about market price, perfect capital markets, and zero transaction costs during land exchanges. In this case, the market participants bid for land ownership at the maximum value they are willing to pay for holding the land. Accordingly, the current price of a parcel of land at t is given by:

$$P_t = \max_i \left\{ \mathbb{E}_{it}[R_t] + \mathbb{E}_{it}[P_{t+1}]/(1 + r_{it}) \right\} \tag{1}$$

where R_t is the uncertain return provided by the land parcel at t, generated after the land transaction has taken place. The term r_{it} is a discount rate that is subjective to the i-th buyer and P_{t+1} is the uncertain land price at which the parcel can be sold in the next period. $\mathbb{E}_{it}$ is the expectation operator taken on the future states of the economy, conditioned by the subjective beliefs of i at t. Positive discount rates r_{it} indicate a preference for the present over the future, or the opportunity cost of money invested in land.

Equation 1 is the general formulation of the PVM. This formulation has a long history in economics, from the classical authors (David Ricardo, Karl Marx) to authors who have followed the marginal revolution

(Irving Fisher, Alfred Marshall). The formula is alternatively viewed as originating from a natural law, an equilibrium arising from free entry into the land market or an arbitrage-free condition. In all cases, the model holds prime position in the economics of land price. Equation 1 indicates that the current land price is the sum of expected current returns and the expected land price in the next period actualized by a subjective discount rate. The maximum mathematical operator indicates that the market's land price corresponds to that of the buyer with the highest bid. The reasoning in terms of competing individual bids stems from the demand-oriented paradigm presented above. The returns, while expressed in money, could include both tangible and intangible values.

Equation 1 is fairly general but of limited empirical application due to the unobservable nature of intangible earnings, subjective beliefs about the future, and temporal discounting. The formula has been simplified in the empirical literature to provide inference and predictions about land price. The simplest form assumes that agents have the same expectations. This amounts to considering a constant discount rate r such as the market interest rate, and assuming that the earnings generated by the parcel grow at a constant expected rate g. Substituting recursively the terms $\mathbb{E}_{it}[P_{t+s}]$ for $s = 1, 2, \ldots$ in Equation 1, the PVM is then a sum of a geometric series that can be reduced as follows:

$$P_t = \mathbb{E}_t[R_t]/(r - g) \tag{2}$$

Equation 2 shows a proportional relationship between land price and expected current earnings, under the condition that $g < r$ for convergence. This simple relationship puts a high informational content on land price since it presents the land price as depending on time preferences, expected returns from land, and expected growth of these returns.

As such, a first implication of the PVM is the implicit sorting process of buyers i. Landowners, who express their preferences and beliefs with regard to land prices, are not randomly selected in the population. In a competitive land market, the buyer of land is the one who expresses the highest bid. Therefore, an observed land price is the discounted value of the agent with the highest willingness to pay for owning the land. Under mild restrictions on preferences (Kuminoff *et al.*, 2013), the equilibrium price of land with given characteristics identifies exactly this highest-bidder point on buyers' inverse demand. This workhorse of the hedonic theory of Sherwin Rosen, 1974, is already present in Lind, 1973, for the case of land. Applied to farmland by Palmquist, 1989, the hedonic framework is consistent with the PVM (Feichtinger and Salhofer, 2013), and can be included in the new economics of equilibrium sorting (Kuminoff *et al.*, 2013). The hedonic approach presents land as a differentiated product with intrinsic and extrinsic characteristics and decomposes its price into estimates of the contributory value of each characteristic. This point is of major importance given the plethora of articles that refer to the hedonic framework to reveal some of the informational content on land price. While Equation 2 is consistent with a sorting process, we have to mention that the sorting effects apply in the case of heterogeneous agents and are canceled out by the assumption of a constant discount rate and constant expected rate of growth.

2.2 Extension to uncertainty about future returns

The simplest way to control for uncertainty in estimating the present value of an asset is to use risk-adjusted discount rates for risk neutral agents (Cochrane, 2005). Such rates $\widetilde{r}$ are generally calculated as the sum of the classical risk-free discount rate r and a risk premium $\delta > 0$ such that $\widetilde{r} = r + \delta$. The value of the risk premium depends on the risk aversion of the individuals and their perception of the size of the risk. The amount of risk inherent in a land purchase is incorporated in the discount rate and used in the present value calculations. According to the capital asset pricing model, the risk premium also depends on the correlation with the representative asset of the economy (called the beta of the returns from land in Cochrane, 2005).

The risk-adjusted discount rate corrects the discount factor by taking into account the uncertainty of the returns from land. To account for higher uncertainty, a higher discount rate is used, and the inverse is true for lower uncertainty. The net present value is inversely proportional to the risk-adjusted discount rate, since an increase in the adjusted rate will decrease the observed land price:

$$P_t = \mathbb{E}_t[R_t]/(\widetilde{r} - g) \tag{3}$$

Adjusting the discount factor is the simplest way to integrate uncertainty into the PVM, but more complex frameworks exist in the theoretical literature. For example, Just and Miranowski, 1993, considered the price of land for farmers with constant absolute risk aversion. Chavas and Thomas, 1999, linked the PVM to the micro-economic behavior of land buyers and sellers in a framework with dynamic preferences. By contrast, a risk-adjusted discount factor has the advantage of limiting the added complexity of the PVM and allowing some additional elements to be incorporated gradually.

The adjusted discount rate that appears in Equation 3 has to be interpreted in relation to the sorting process presented in Equation 1. The risk premium expressed in the PVM comes from the preferences of the highest bidders. The informational content of land price in terms of time and risk preferences is related to private preferences that might or might not match social preferences. Heal and Millner, 2014, suggested aggregating individual discount rates into a representative rate. Note also that uncertainty in future discount rates implies a decreasing discount factor (Arrow *et al.*, 2014) that can be easily incorporated in the PVM. As we analyze land as a private good, traded in a market between private agents, the informational content of the observed prices is relative to private values and not to social values.

2.3 Extension to uncertainty about property rights

The assumption of well-defined and well-enforced property rights is central to thoroughly interpreting the informational content of land price as a stream of discounted private returns. This assumption is challenging in developing countries typically because of their institutional settings. This assumption can also be questioned in developed countries when landowners do not have total freedom or full entitlement in their use of the land. In fact, numerous property systems are applied to and affect the use and valuation of land resources (Deininger and Feder, 2001; Ostrom and Cole, 2011).

Here we propose an extension by endogenizing property right enforcement with the help of a non-zero annual probability of losing the returns from land (Costello and Kaffine, 2008). Losing the returns from land may arise in the case of the revocation of rights, since some governments may stop enforcing and defending property rights or move out part of the population. This extreme case of uncertain property rights is closer to the situation of developing countries. The public policies limiting land entitlement in developed countries such as zonings or easements are considered in the next subsection about the extension of the PVM to alternative land uses. Here, the constant probability of losing definitively the returns from land is noted h, assumed to be constant in time and across landowners. The expected return from land at $t+s$ is strictly greater than zero if the property right has not been revoked between t and $t+s$. For $s = 1, 2, \ldots$, this probability is equal to $(1-h)^s$ and can be incorporated in the geometric series of the PVM to obtain:

$$P_t = \frac{1+g-h-g\cdot h}{\widetilde{r}-g+h+g\cdot h} \times \mathbb{E}_t[R_t]. \tag{4}$$

With a positive probability of the risk of loss of property rights, the land price is undoubtedly diminished. Equation 4 also shows that the effect of uncertain property rights is more stringent for parcels with high growth rates.

The consequences of integrating uncertainty about property rights into the informational content on land price are not unequivocal. On the one hand, Equation 4 predicts that empirical researchers can analyze through land price the subjective probability assigned by people to the revocation of property rights. This informational content can be interpreted as the degree of confidence in institutions, a value of major interest in developing countries. On the other hand, insecurity of property rights is a disturbing factor complicating the estimation of private values about future returns from land that can be downward biased compared to the classical net present value (Equation 2 or Equation 3). In addition, we have assumed that the stream of returns is exogenous while uncertainty about property rights can produce feedback effects. In effect, insecure property rights can affect how land is managed, which would then affect the land price by changing the stream of returns (Bohn and Deacon, 2000; Hornbeck, 2010). These feedback effects are called “impermanence syndrome” (Berry, 1978) in the presence of a potential land-use change which is the subject of the next subsection.

2.4 Extension to alternative land uses

The PVM presented above is for one single and constant land use, and can be interpreted as the price of land with a use that is constrained to be constant (by zoning, conservation easement, or any biophysical constraint). The standard economic result is that the price of land equals the discounted sum of expected net returns obtained by allocating land to its most profitable allowed use. When land use is freely chosen by rational agents, current land price describes an upper envelope of the net present values from the different potential uses of land.

The extended PVM formula without uncertainty and conversion costs used to compute land price in the presence of L potential land uses, is as follows:

$$P_t = \sum_{s=1}^{\infty} \sum_{\ell=1}^{L} \mathbb{1}_{\ell t+s} \times \mathbb{E}_t[R_{t+s}]/(1+r)^s. \tag{5}$$

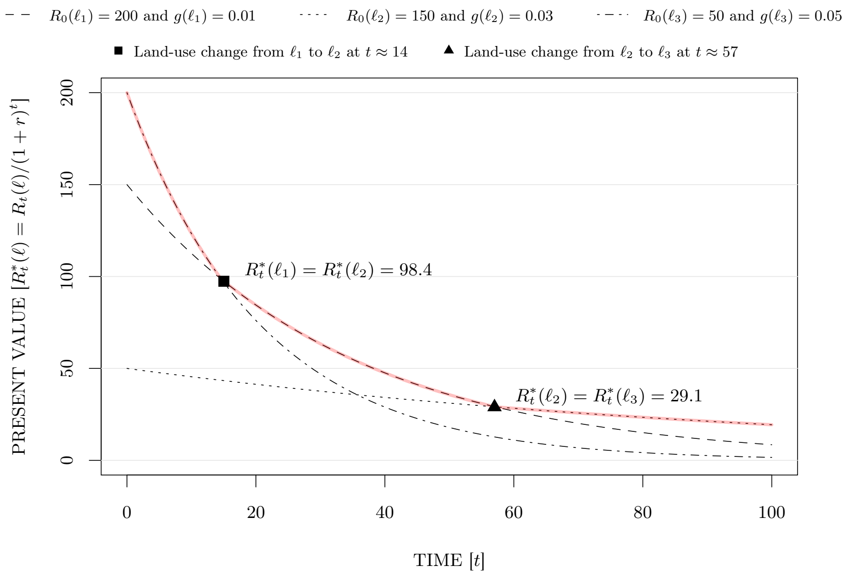
We note $\mathbb{1}_{\ell t+s}$ the indicator function which equals 1 if the land use ℓ provides the highest expected return at $t+s$ and 0 otherwise. Figure 1 and Equation 5 show that the current price of land does not depend exclusively on the returns from the current land use. Land price contains information about the credibility of a future land use change and the future associated value. Figure 1 below presents a graphical illustration for the case of a given land plot with three potential land uses.

Some important simplifications can be made in restricting the number of potential land uses to $L = 2$. For example, the typical case studied in the literature is the choice between agricultural and urban land uses. The extension of the PVM to an alternative land use typically introduces a new parameter, namely the number of periods T waiting for a land use change, corresponding here to the development of agricultural land. Indexing the values corresponding to agricultural and urban uses by a and u, respectively, and restricting Equation 5 to two land uses, we obtain:

$$T = \frac{\log(\mathbb{E}_t[R_t^a]/\mathbb{E}_t[R_t^u])}{\log[(1+g_u)/(1+g_a)]} \tag{6}$$

The development occurs at $t+T$ if the land is currently in agricultural land use a ($\mathbb{E}_t[R_t^a] > \mathbb{E}_t[R_t^u]$) under the assumption that returns from urban use u grow more rapidly ($g_u > g_a$). With continuous time,

Figure 1: **Accounting for alternative land uses in the present value model.** Consider a landowner with a risk-adjusted discount rate $\widetilde{r} = 6\%$, choosing between three potential land uses, ℓ_1, ℓ_2 and ℓ_3. With ℓ_1, $R_0(\ell_1) = 200$ monetary units are earned at $t = 0$ and the annual growth rate is $g(\ell_1) = 1\%$. The respective curves for ℓ_2 and ℓ_3 are $R_0(\ell_2) = 150$ and $R_0(\ell_3) = 50$, and $g(\ell_2) = 3\%$ and $g(\ell_3) = 5\%$. The three black curves represent the present value of each land use. The upper envelope (in brown) is the present value of the best land-use path, used to compute the price of land according to the PVM. The optimal timing of land conversion is $t \approx 14$ from ℓ_1 to ℓ_2 and $t \approx 57$ from ℓ_2 to ℓ_3.



Shoup, 1970, found that conversion to a use with higher returns (urban use) should take place when the rate of change of the development value of the land is equal to the sum of the interest rate, minus the rate of return in current use (agriculture) earned by delaying the date of redevelopment one more period. In the case of two land uses without conversion costs, a constant discount factor and constant growth rates, the PVM applied to land price is as follows:

$$P_t = \mathbb{E}_t[R_t^a]/(r - g_a) + \tau \times \mathbb{E}_t[R_t^u] \quad (7)$$
$$\text{with } \tau = \sum_{s=0}^{\infty} \frac{(1+g_u)^s - (1+g_a)^s}{(1+\widetilde{r})^s}$$

with $\tau > 0$ as $g_u > g_a$. Equation 7 shows that the possibility of an alternative land use increases the current price of land relatively to the constrained situation. This increase in price is an increasing function of the expected returns from the alternative land use and of the associated growth rate, and a decreasing function of the growth rate of the current use. Equation 7 could also be used to evaluate the effects of limiting land entitlement in developed countries through zonings or easements. The effect on land price of such constraints about land use change is simply τ times the expected value of the prohibited land use.

Still using a framework without uncertainty, Capozza and Helsley, 1989, showed more particularly that farmland price also depends on the costs of conversion, the value of accessibility, and the expected future growth increase. Such an analysis provides additional information content in land price at the urban fringe, and can also be used for other land use trade-offs: conservation versus development, conservation versus agriculture, forest versus agriculture, etc. The simple introduction of uncertainty about future returns in a model with two land uses and two periods can be traced back to Titman, 1985. The author showed that uncertainty causes the current land price to increase at least for the case where investors are risk neutral, but fails to take into account the irreversible effect of land development.

2.5 Extension to option value

The numerous forms of irreversibility that certain land use choices imply have an impact on land price. Developing agricultural land, clearing a forest or cropping a natural area produce some forms of irreversibilities that constrain future choices. Coupled with the assumption that time generates learning (delaying a choice allows a more informed choice to be made), the presence of irreversibility adds an option value to the current price of land. One of the pioneer analyses about the existence of an option value dealt with environmental preservation related to land (Arrow and Fisher, 1974). To the best of our knowledge, the first analysis about the option value of urban development that impacts farmland price is Clarke and Reed, 1988. A recent review can be found in Womack, 2015.

The most comprehensive framework showing the presence of an option value in the price of farmland is Capozza and Helsley, 1990. The authors showed that uncertain returns from urban development (random drifts from an increasing trend) coupled with a learning about the uncertainty produce a positive option premium that enters additively in the PVM of farmland price:

$$P_t = \mathbb{E}_t[R_t^a]/(r - g_a) + \tau \times \mathbb{E}_t[R_t^u] + OP_t \quad (8)$$

with OP_t the option premium and the term τ as defined in Equation 7.

For endogenous city boundaries, the option premium typically increases with the variance of returns. This option premium grows smaller as the distance from the boundary of the urban area increases and as the time of development moves further into the future. Failure to account for the option premium may cause the land price evaluation from the PVM to underestimate the true cost of a land use change and to over-predict land use change both at the extensive and the intensive margin (for the size and for the intensity of development, respectively).

An option value arises not only in the extreme case of urban irreversibilities, it can also emerge from sunk costs that are spent at the beginning of a project and cannot be recovered if the project is abandoned for a different one. Schatzki, 2003, showed that, because the cost of planting forests cannot be recovered if the land is converted to cropland after a few years, land use choice and land price are impacted by an option value. The presence of an option value also impacts on the timing of land development, delaying the conversion moment to the appropriate date.

2.6 Empirical validation of the present value model

Similarly to all models derived from classical economic assumptions, the empirical relevance of the PVM needs extensive validation in the real world where none of these assumptions holds perfectly. The aim of numerous studies in the 1980s and 1990s was to formally test the PVM empirically, using time series models and aggregate data on land prices. The most representative papers are Campbell and Shiller, 1987, Falk, 1991 and Nickerson *et al.*, 2012, as well Nickerson and Zhang, 2014, which offers an extensive overview of this literature. Empirical support for the PVM is mixed. Unsatisfactory results are principally due to the data aggregation that is necessary for sufficient temporal depth, and to poor econometric assumptions, such as independent data distribution (Falk, 1991; Clark *et al.*, 1993; Tegene and Kuchler, 1993).

Nevertheless, more recent papers (Gutierrez *et al.*, 2007; Erickson *et al.*, 2008) have found more convincingly that the PVM cannot be rejected for historical data from the United States (US). They show that some classical PVM assumptions can be relaxed at the cost of added complexity.

While most literature about land price a few decades ago does not use the micro-economic informational content of land price (e.g., Melichar 1979; Feldstein 1980; Shalit and Schmitz 1982; Phipps 1984; Alston 1986; Burt 1986; Baker *et al.* 1991), this is not the case for more recent studies. One major reason is the increasing availability of individual parcel-level data which has produced a shift in the research on land price, focusing on cross-sectional (spatial and static) variations rather than time variations. This is also true for papers that use panel data, as the informational content of land price is principally elicited from cross-sectional variations of land price, while the temporal dimension is exclusively used to control for constant unobserved heterogeneity. These more recent studies focus more directly on the informational content of land price in order to quantify, based on the PVM, the value of the human and natural environments as well as the effect of public policies. In these studies, the land price is not studied *per se* but for the information that it contains. We explain this in more details in the next section.

3 Review of the informational content of the PVM for environmental issues

An informative example of the interest in using the informational content of land price through the PVM can be found in Weersink *et al.*, 1999. The authors used the PVM to analyze the impact of two sources of agricultural returns, namely farm production and government subsidies, on land price. Allowing the discount rate to vary between these two sources of returns, the authors extracted from land price variations the belief about the stability of both returns, a case that is similar to our Equation 4. The authors found that, in Ontario between 1947 and 1993, government payments were discounted less heavily than market-based returns, implying that the former were considered to be more certain than the latter. Still regarding agricultural subsidies, Goodwin *et al.*, 2003, also used land price to elicit farmers' beliefs regarding the stability over time of payments. The above two papers show the value of the PVM in revealing information about buyers. As mentioned in the previous section, the PVM can also be helpful in revealing information about the natural value of land. We review here studies making use of the informational content of PVM with an environmental focus. For this, we separate environmental characteristics of the land into intrinsic and extrinsic characteristics.

We define the intrinsic environment as the set of physical characteristics that are directly related to a given land parcel, such as soil attributes, associated climate, and water availability. By contrast, the extrinsic characteristics refer to the characteristics from surrounding land parcels that are only indirectly bought during land transactions (landscape patterns, infrastructures, or ecosystem services). The immobility of land resources implies that the price of land has also an informational content about the value of extrinsic characteristics. This distinction is important as the ownership and stewardship of these two sets of characteristics depend strongly on the legal regime prevailing. An intrinsic characteristic such as groundwater availability could impact land prices in different ways depending on the legal definition of water property. We review in the rest of this section the papers using the informational content of PVM to study the value of the intrinsic and extrinsic environment. Then we turn to papers that study the value of anticipated changes in the environment and the value of public policy related to land.

3.1 The value of intrinsic environment

Among the first applications of the hedonic principle to land price, Miranowski and Hammes, 1984, used farmland price to estimate the unitary values of soil characteristics for agricultural production in the US. The values are elicited from a linear model regressing farmland price on soil depth and pH, taking account of possible interactions with erosion potential. Other things being equal, the value of an additional inch of topsoil was estimated at between US $12 and $31 (in 1978) as a determinant of land productivity and, consequently, of agricultural returns. This paper was followed by many others that used similar methodologies and that also showed the importance of biophysical determinants in land prices (Ervin and Mill, 1985; Xu *et al.*, 1993; Elad *et al.*, 1994; Boisvert *et al.*, 1997; Maddison, 2000). Peterson, 1986, used the same idea of the capitalization of the biophysical attributes of land (natural fertility, water holding capacity, among others) and provided for the US the value of such biophysical attributes as revealed by land prices. Related to this, Gardner and Barrows, 1985, investigated whether the value of soil conservation investment is capitalized into land prices, by including in a hedonic function classes of soil created according to the productivity and erosion, and the value of improvements made to the land. The authors found that such capitalization–rewarding the land seller for his/her past care of the soil–did not occur in Southern Wisconsin. These results indicate a potential substitution between natural and man-made soil fertility, of major interest to environmental quality and sustainability. Despite substantial technological innovation and rising land values from 1945 to 2002, Hornbeck, 2012, found that counties' environmental characteristics continued to influence land prices. The intrinsic environment has not become less costly, as technological innovation has not reduced the importance of natural advantages or disadvantages.

According to our definition, climate variables are also intrinsic characteristics, and their hedonic values for agricultural production can be elicited from land prices (Uematsu *et al.*, 2013). Widespread use of the informational content of land price in terms of climate variables is related to the evaluation of climate change's effects on the agricultural sector. The seminal paper of Mendelsohn *et al.*, 1994, used the capitalized value of climate in the land price for about 3,000 counties in the US. The authors estimated a hedonic model based on current climatic conditions, and used it to project the value of land according to future climate scenarios. Then, the net economic effect of climate change on agriculture was computed as the difference between the land values obtained. This approach has been paramount in the agricultural economics literature because it accounts for land-use adaptations by farmers (see Equation 5), contrary to the traditional agronomic studies (Carleton and Hsiang, 2016). Mendelsohn et al.'s empirical application found a potential positive effect of global warming. Numerous studies followed, with some being critical of the methodology used, such as Cline, 1996, Quiggin and Horowitz, 1999 and Schlenker *et al.*, 2006, among others (Carleton and Hsiang, 2016). The main criticisms are that the approach is not suitable for estimating dynamic adjustment costs and that irrigation technology is not incorporated in the analysis. Cline, 2007, investigating the issue for the whole world, found both negative and positive effects, depending on the region of the globe considered. Since the land-use adaptations are kept implicit in these hedonic approaches, some authors have integrated the land-use choices in this framework (Timmins, 2006; Seo and Mendelsohn, 2008; Ay *et al.*, 2014).

Purchasing land is also a mean to obtain access to underground resources such as water or oil. Underground water availability is crucial for the agricultural use of land. According to the PVM, since this availability strongly modifies the expected returns, the value of water is included in the informational content of land prices. Empirical evidence can, for example, be found in Miranowski and Hammes, 1984, Faux and Perry, 1999 and Buck *et al.*, 2014. In irrigated regions the presence of groundwater usable for irrigation according to the legal regime increases land prices. Such appraisals provide an estimation of the subjective value that farmers place on water and can help policy-makers better target their policy measures related to water use. Thus, by reverting the PVM formula, observed land prices can be used to infer the value of water availability (Koundouri and Pashardes, 2003). Land price has also an informational content about underground resources not directly related to the agricultural use. Recent papers have called for attention to be paid to the presence of shale gas development opportunities which might affect the findings obtained from hedonic regressions on land prices, due to dis-amenities caused by such natural opportunities (Weber and Hitaj, 2015).

3.2 The value of extrinsic environment

A particular parcel of land benefits from the attributes of neighboring parcels through amenity effects such as open space, typical landscapes or environmental conservation (Boyd *et al.*, 2016). The potential buyer of a land plot does not own the extrinsic environment of the plot, but these extrinsic characteristics are capitalized in the land price since they impact the expected returns made from the use of land. Bastian *et al.*, 2002, reported that the presence of scenic amenities (such as diversity of view) and the existence of trout and elk habitats are positively related to farmland prices in Wyoming. In Southern Michigan, Ma and Swinton, 2011, estimated the values of ecosystem services from the price of farmland, showing that such services are capitalized through variables related to ecological areas such as lakes, rivers, wetlands, forests and conservation land. In addition, Borchers *et al.*, 2014, showed, for the US as a whole, that land prices are determined by the recreational and natural amenities provided by farmland, such as tree cover and hunting license. Uematsu *et al.*, 2013, analyzed the value of a set of natural amenities and found that its impact is more pronounced at higher price range of farmland.

Among the extrinsic attributes capitalized in land prices, institutions and human improvements are also investigated though the PVM applied to land prices. Egan and Watts, 1998, focused on the costs to ranchers resulting from the lack of secure property rights to the public forage resource. The authors found that the regulatory and property rights regimes prohibit other groups from entering the public forage market and decrease ranchers' wealth through the decline in the value of forage. Henderson and Moore, 2006, studied the effect of hunting lease rates on farmland values in Texas and found that a hunting lease allows counties with higher wildlife recreation income streams to have higher land values. Hornbeck, 2010, used the introduction of barbed wire in the US to study the effect of property enforcement on land price. The author found an increase in land prices arising from farmers' increased ability to protect their land from encroachment, highlighting the importance of property rights for agricultural development. Libecap and Lueck, 2011, studied another side of property rights, through the demarcation of land and the role of coordinating property institutions. The centralized rectangular system provides high and persistent increases in land prices. Woestenburg *et al.*, 2014, introduced some institutional aspects, such as property rights, transactional arrangements and governance context, as explanatory variables in the PVM of land price. For the Netherlands, such variables significantly improve the power of the model, which means that they are significantly capitalized in the land price.

The range of extrinsic characteristics that can be inferred from the land price through the PVM is wide, and also contains numerous land improvements made in proximity to land plots. Pines and Weiss, 1976, proposed a theoretical framework showing the extent to which the benefit of a project is reflected in the changes in land prices. To the best of our knowledge, this was the first paper that linked the informational content of land price to public decisions. Following this framework, Pardew *et al.*, 1986, estimated the increase in land price that follows road construction, Colwell, 1990, studied the effects of power lines, Folland and Hough, 1991, the effects of nuclear sites, Knaap *et al.*, 2001, the effects of rail plans and Henderson and Gloy, 2009 the effects of ethanol plants on land prices. All these papers found statistically significant effects of land improvements on the prices of land parcels not directly concerned with these improvements, with positive or negative signs depending on the desirability of land improvements.

3.3 The value of anticipated changes in the environment

We have shown that the PVM is an intertemporal indicator of the value that individuals put on land resources (Equation 1). This temporal dimension implies that land prices may capture landowners' expectations regarding changes in the environment of a parcel. Even if they are not actually observable and not included as such in the environmental characteristics of land plots, some elements of the future returns of a given land parcel are currently capitalized in its price. Land price contains some information about potential land-use conversions and the probability of a change in the environmental characteristics of a site (Equation 7). Palmquist and Danielson, 1989, found a negative effect of erosion risk, as Boisvert *et al.*, 1997, for environmental contamination and Horsch and Lewis, 2009, for aquatic invasive species.

Land-use conversions have been particularly studied in the land price literature. Urban development is typically an attribute that is not currently observable, but that is incorporated into land price (Adams *et al.*, 1968; Clonts, 1970; Hushak, 1975). If rents from development exceed agricultural rents in the future, the higher rents from future development will be capitalized into the current price of farmland. Various proxies for expectations of land use changes are used in the literature: Chicoine, 1981, used the distance of parcels to roads and metropolitan areas, Shi *et al.*, 1997, relied on a gravity model with distances and population densities as inputs, Plantinga and Miller, 2001, considered distance to metropolitan areas, and changes in populations, Cavailhès and Wavresky, 2003, used the distance from the central business district for both agricultural and developed lands, Guiling *et al.*, 2009, employed population and income, and Delbecq *et al.*, 2014, used an endogenous smooth transition between urban fringe and rural areas. All these studies found that potential future land development increases the current farmland price.

For agricultural activities, the proximity to urban areas is both an opportunity and a threat (Livanis *et al.*, 2006). It is an opportunity in the sense that local markets (for both inputs and outputs) are closer, and this enables farmers to survive as high-quality local producers of goods that are costly to move. But it is also a threat due to the induced competition for the use of land resources, the speculation of landowners about land-use changes and the difficulty of managing the negative externalities that farmers generate and that affect the population (odors, machinery noise and pollution, etc.). Using land prices as the capitalized net values (equal to opportunities minus threats) of urban proximity allowed Livanis *et al.*, 2006, to classify, according to their importance, the various influences of urban areas on agriculture. Urban impacts on farmland prices are high and the global effect on agricultural returns is found to be positive. The existing literature suggests that proximity to cities appears as more of an opportunity than a threat to agriculture and increases land prices. Nevertheless, in absolute terms, Salois *et al.*, 2012, found that changes in farmland values are more strongly associated with changes in the distribution of agricultural returns than urban proximity. However, this result is not true for every region of the US and for the whole period studied.

In the presence of irreversibilities, the value of anticipated environmental changes adds an option value to land price, which is elicited empirically through the additive term presented in Equation 8. Shilling *et al.*, 1990, used the theory of option pricing to evaluate the value of land option contracts between a landowner and a developer without irreversibility. The authors tested the theoretical prediction of an option premium close to zero, and did not reject this result empirically. Some recent studies aimed at providing an empirical quantification of the option premium of the irreversible urban development. For the US as a whole, Plantinga *et al.*, 2002, evaluated the share of farmland prices that the option value represents relative to agricultural returns. The authors found a distribution of option-value shares with a high heterogeneity–between 0% and 80% with a median of about

10%–but did not study precisely the spatial variations of the shares at the metropolitan scale. Taking the city of Seattle as a local application, Cunningham, 2006, estimated option values due to potential development of farmland and investigated the timing of development. The author found evidence of both implications of the PVM model: a greater uncertainty of urban rents both increases the price of farmland and delays the moment of land-use change.

3.4 The value of public policies

Policy regulations that may affect the land market can take several forms, such as cash support, constraints on quantity (quotas), and restrictions relating to the use of land. Historically, agricultural policies in developed countries aimed mainly at supporting farm income and as such were captured within the returns generated by land. The existence of differentiated capitalization rates can give information about the economic distortions generated by these policies (Floyd, 1965). The capitalization, or the incidence (Roberts *et al.*, 2003; Kirwan, 2009), of subsidies in land price is a standard empirical finding (Barnard *et al.*, 1997; Lence and Mishra, 2003; Latruffe and Le Mouël, 2009; Michalek *et al.*, 2014), but it is more difficult to understand what this result implies theoretically. Latruffe and Le Mouël, 2009, provided a graphical demonstration of the effect of output price support and land subsidy on farmland price, as well as a review of empirical findings on the effect of several types of agricultural support though they differentiated between capitalization rates and redistributive outcomes.

By contrast to cash support, quotas have generally relied on hedonic pricing approaches where quotas are used to explain land prices. Capitalized values of flue-cured tobacco allotments were estimated for the period between 1934 and 1962 by Seagraves, 1969, using the PVM (Equation 2). Moreover, Taylor and Brester, 2005, studied the case of sugar quotas in the US that keep domestic sugar prices high. Le Goffe and Salanié, 2005, investigated the influence of livestock manure limits in France. Another existing approach is the inverse farmland demand model applied by Vukina and Wossink, 2000, to investigate the same issue for the Netherlands.

The paper by Lind, 1973, is a cornerstone work about the recognition that benefit measurement for (fixed or produced) public goods could be deducted from the variations in private land value. Interestingly, this paper, uniquely concerned with the value of land, was published before the seminal paper by Rosen, 1974, which explicitly introduced the hedonic framework that relates to all types of differentiated goods. This suggests that the informational content of marginal prices (namely the hedonic principle) first arose for the case of land, without naming it as such. Within a stochastic framework about the future of urban policies and land use restrictions (in particular limiting urbanization) Geniaux *et al.*, 2011, and Vyn, 2012, used farmland prices to reveal the beliefs of participants in the land market about future urban policies (the potential future supply of development rights in the case of the former study, the impossibility of developing farmland in greenbelts in the latter). The fine spatial resolution of farmland sales allowed the former authors to map these effects. They showed that some municipalities present low capitalization rates of urban influences on land prices, revealing a credible policy for the limitation of urban development, and some municipalities show the opposite.

More generally, land-use regulations prohibit certain uses on specific sites and can take the form of constraining land-use choices through zoning, tax abatements or exemptions, or preservation programs. In the presence of land-use regulations, the parcel may have a lower value since it is not in its best use. For example, Nickerson and Lynch, 2001 and Lynch *et al.*, 2007, provided evidence of reduced land values of preserved parcels in Maryland. A similar result was found in the close proximity of Toronto by Deaton and Vyn, 2015. This recent evidence contrasts with that from Henneberry and Barrows, 1990, who found both negative and positive effects of agricultural zoning on farmland prices. The effects of land-use regulations on farmland price may be threefold (Jaeger, 2006) and therefore result in a net effect that may be positive or negative. First, restriction effects are neutral or negative, in that the regulations may prevent the parcel to being put to its best use and therefore would decrease its price. Second, scarcity effects are positive, but they do not apply to the parcel regulated. It is the price of unregulated parcels that is increased through scarcity effects, since parcels where a specific use is still permitted become scarcer and may be more in demand. Finally, the price of a regulated parcel may be increased due to amenity effects. The regulations aim at promoting the supply of amenity in the parcel, and, when they succeed, increase its value. For example, tourism attracted by open space may generate extra-farming revenues for farmers. Jaeger, 2006, provided a literature review of studies analyzing the influence of land-use regulations on land price. No general conclusion can be drawn since, as underlined in the studies, it is not possible to anticipate a priori the direction of the net effect of land-use regulations and the issue has to be investigated empirically. One recent example is Turner *et al.*, 2014, who showed for US data how the effects of regulation can be decomposed into restriction, external, and scarcity effects. In the case of the European Union (EU) Nitrate Directive, farmers may be constrained in the number of livestock and therefore in their production level. By contrast, amenity effects, which increase the supply of ecological benefits, may generate additional returns to land. In addition, as noted by Nickerson and Lynch, 2001, land prices may not be affected by land-use restrictions if market participants expect that such restrictions will not be binding.

The PVM could also help reveal by how much landowners could be compensated for actions made to protect the environment. For example, suitable habitats for biodiversity constitute a global public good that allows some endangered species to be maintained. Providing such natural areas that are threatened by conversion to intensive agricultural production, implies some opportunity costs for landowners, that are at the interplay between the necessity to provide natural habitat at least cost and the necessity to sufficiently compensate landowners. In the case of wetland easement in the US, Shultz and Taff, 2004, regressed farmland sale prices on land's physical and institutional characteristics. Even though the authors did not find a significant effect of easement on prices, they provided evidence that each additional acre of permanent wetland under easement decreases average prices by 79 %, which can give an indication of compensation fees. For the case of perpetual conservation easements that permanently remove the option to convert existing habitat to more intensive agricultural production, Lawley and Towe, 2014, inferred the marginal opportunity cost of such constraints. Here again, the capitalization formula is reversed to answer the question of the adequate compensation of landowners by conservation agencies. However, as suggested by Grout *et al.*, 2014, if agents anticipate that a compensation scheme or waiver for a land-use restriction policy will be implemented in the future, then the negative restriction effect that decreases land returns may be offset by the positive increase in land revenues even prior to the implementation of the regulation.

4 Implication for environmental issues

4.1 A typology of current and potential applications

In order to guide future research relying on the use of the informational content of land price through the PVM, we provide a typology of applications in Table 1. We cross the distinction of intrinsic, extrinsic, and anticipated environmental land attributes, with a commonly used economic classification about the private or public nature of the attributes, initially presented by Samuelson, 1954, to categorize economic goods. The resulting typology of the applications of the PVM allows them to be related to the informational content of land price in terms of the degree of capitalization. This idea of a qualitative grouping in terms of capitalization degree is also present in Starrett, 1981, regarding public spending. Table 1 shows a gradient of informational content from top row to bottom row, from full informational content for private attributes to no informational content for pure public attributes. The full value can be obtained from environmental characteristics whose consumption is excludable, as is the case for private and local public characteristics. As for the attributes that are non excludable but rival in consumption (namely the public attributes), they are only partly capitalized in land price. This is a typical case of the tragedy of the commons (Hardin, 1968) that arises from free rider behavior. Attributes that are neither excludable nor rival are not capitalized in land prices and in this case the land price has no informational content.

The typology displayed in Table 1 is stylized and has to be adapted to local situations. The economic classification depends on the legal regime prevailing, namely on the definition of property rights and entitlements as presented in subsection 2.3. A change in the settings of property rights can change the economic characteristics of some land attributes, for example shifting from public attributes to local public attributes. This is the case for collective pastures studied by Hornbeck, 2010. The potential of a parcel for recreation is typically an intrinsic private characteristic with full informational content. However, it could also be a public characteristic with only partial informational content such as in the case of hunting in the absence of traded licenses. The

Table 1: **Typology of land attributes and their capitalization degrees.**

Economic Characteristics	**Environmental characteristics** Intrinsic	Extrinsic	Anticipated
Private	*Soil quality, Shale gas*	*Infrastructures, Land improvements*	*Timber harvest*
Local public	*Climate, Exposition*	*Landscape, Living environment*	*Urban proximity*
Public	*Collective forage, Water availability*	*Ecosystem services, Natural amenities*	*Land development*
Pure Public	*Airspace*	*Current biodiversity*	*Future biodiversity*

: Full informational content ; : partial informational content ; : no informational content.
Notes: The economic classification of characteristics is based on the excludability and rivalry in consumption (Samuelson, 1954). A pure public attribute is non excludable and non rival, a public attribute is non excludable but rival, a local public attribute is excludable but non rival, and a private attribute is excludable and rival. The environmental classification is presented in the main text, section 3.

stylized situations presented here come from our literature review and would have to be adapted to specific situations. The presence of uncertainty and irreversibilities can also create an option value as we saw in subsection 2.5. The option value has both a private and a social side and cannot be unequivocally presented as a shortcoming of the informational content of the PVM. In all cases, applications should account for the institutional context of the area under consideration.

Using the PVM to elicit the informational content of land price is a revealed preference method, in that the individual values that potential landowners place on land characteristics are not directly observed but are revealed (Mendelsohn and Olmstead, 2009). Using the PVM is thus one of the possible methods for valuing the environment when attributes are not explicitly traded, through its link with the hedonic methods presented above. Due to the fixity of land supply, this framework is closely related to the PVM in terms of estimating the willingness-to-pay for the perpetual use of the resource. However, even if the classical PVM assumptions are met (see subsection 4.3 below for the cases where these assumptions are not verified), some values are not capitalized in land prices. It is indeed widely recognized that the existence value (of biodiversity for example) can typically not be estimated by approaches based on revealed preferences. This is also true for pure public and intrinsic land characteristics such as airspace.

4.2 Current and potential uses in environmental studies

While references to the PVM are quite rare, the informational content of land price is not totally absent from current environmental studies. Following the seminal paper of Ando *et al.*, 1998, land price was used to: evaluate the cost-effectiveness of conservation programs (Strange *et al.*, 2006); study the spatial correlation between economic and environmental values (Naidoo and Ricketts, 2006; Naidoo *et al.*, 2006); improve biodiversity management (Mattison and Norris, 2005; Reyers *et al.*, 2013); improve species distribution modeling (Ay *et al.*, 2017); and maximize the returns of conservation investments (Withey *et al.*, 2012; Kovacs *et al.*, 2013). Coupled with classical decision theory, such papers studied the trade-offs between economic cost and the environmental benefits of conservation (Cabeza and Moilanen, 2001; Bode *et al.*, 2008). In line with the views defended in our review, Murdoch *et al.*, 2007, argued that conservationist biologists should include and record the costs of conservation actions. Land prices were also concretely used to compute the acquisition costs of conservation policies (Carwardine *et al.*, 2010; Davies *et al.*, 2010; Fisher *et al.*, 2011; Armsworth, 2014), as environmental organizations had to buy the resources they want to conserve under a budget constraint.

This literature is truly valuable for environmental science, and constitutes some important steps to integrate jointly the human and natural sides of well-being (Daily *et al.*, 2009; Bateman *et al.*, 2013). We nevertheless believe that these applications do not exploit the full informational content of the PVM. We outline here two main areas with potential regarding the use of land price in future environmental researches. First, to complete the concrete acquisition cost of conservation areas, multivariate regression analysis of the land price can provide an estimate of the counterfactual value according to a particular land use, and hence compute the opportunity cost (Naidoo and Adamowicz, 2006; Adams *et al.*, 2010). Moreover, the papers reviewed above about the effect of land use anticipation imply that farmland parcels with an unexplained high land price are very likely subject to potential future urban development. Thus, a high land price can be a sign of a high threat for some natural or semi-natural areas. Such information can be valuable for stakeholders aiming at preserving or improving environmental quality. Second, the price of land implicitly contains the values of diverse environmental characteristics. Thus, the economic importance of variables derived from environmental research, in terms of private or social value, can be obtained from hedonic analysis. For example, in terms of private value, it can be shown that soil depth is more important than pH for agricultural producers (Miranowski and Hammes, 1984). In addition, by distinguishing the private and social values of environmental variables, land price can reveal when private decisions are incompatible with social goals. The difference between actual land price and land price integrating the full social value of (intrinsic and extrinsic) environmental characteristics is an indication of the extent of the market failure in setting the optimal use of land resources. In this case, there is a need for public intervention to ensure an environmental quality that is consistent with social aspirations (Newburn *et al.*, 2005; Armsworth *et al.*, 2006; Newburn *et al.*, 2006; Engel, 2016).

In line with the recent increase in the use of the concept of ecosystem services in environmental studies (Fisher *et al.*, 2008; Daily *et al.*, 2009; Bateman *et al.*, 2013; Boyd *et al.*, 2016), we see in the informational content of land price attributed by the PVM an important avenue for future research. Surpassing the basic uses of the PVM in terms of measuring the acquisition cost of land or measuring the value of natural amenities, the informational content of the land price in terms of time preferences, uncertainty, definition of property rights, land use change or option value could be profitably mobilized for major environmental questions. Land management and land-use choices are now widely recognized as major determinants of the provision of ecosystem services and are placed at the center of policy trade-offs (Goldstein *et al.*, 2012). Refining the interpretations of the informational content of land price according to the elements discussed here would allow for better targeted policies for the provision of ecosystem services.

4.3 Limits to the use of the informational content of land price

Land market activity may be influenced by several factors that can hide or be included in the informational content of land price. Thus they would need to be accounted for in order for the land price to fully reveal information about environmental characteristics. We discuss here four factors: land institutional and transaction regulations that produce transaction costs; personal relationships; information asymmetries; and bargaining power. Transaction regulations aim at regulating either the type of participant in the market, or the type or quantity of land exchanged on the market. Land ownership may be prohibited for specific entities, there may exist restrictions regarding the size of the plot exchanged, or the government may impose some price regulations. Swinnen *et al.*, 2016, provided an analysis of this diversity in Europe. For example, in Greece, foreigners need special authorization to purchase land in the border area. Restrictions regarding the size of the plot exchanged exist in Lithuania where the maximum size is 500 hectares. In France, some public entities have a pre-emption right to the parcel exchanged, in that they purchase the parcel at a lower price than the one proposed, and can re-sell it later at a lower price or at the same price but to another buyer of their choice. Transaction regulations also relate to the transaction costs that sellers and buyers have to bear. These include registration costs, notary fees, and tax on the capital gains from selling the land. Institutional regulations that may affect the land market include pre-emptive rights for specific buyers, taxes on land ownership (real estate tax), and inheritance rules. Regarding pre-emptive rights, the state often has the right to pre-empt farmland with a view to urban development or land preservation. Also, private entities may have priority in the purchase of the farmland parcel, such as neighboring farmers, current tenant farmers, or current co-owners. All these regulations and restrictions may generate transaction costs. Some authors propose a formal treatment of the presence of such costs in the PVM at the cost of an increased complexity of the model (Lence and Miller, 1999; De Fontnouvelle and Lence, 2002), but in general this is not accounted for although it may blur the capitalization effects of various land attributes.

Another factor that may influence land price, and which is not reflected in the PVM, is the personal relationship that may exist between a buyer and a seller. This relates to social capital, which includes social norms, rules and obligations (Coleman, 1988). Social capital is known to be particularly important for natural resources management as it favors cooperation, increases trust in collective actions and eventually decreases transaction costs (Pretty, 2003). In markets where goods are exchanged, close relationships between sellers and buyers may reduce the price of the transaction. The influence of social capital may be even stronger for farmland markets due to the geographical fixity of this asset, as underlined by Kostov, 2010. Numerous potential buyers are neighbors, as they for example wish to enlarge their land area in order to increase agricultural or environmental productivity. Another feature of farmland is that it is not only considered as a productive asset, but also as a family asset, and therefore a large part of land transactions occurs within the family. This can give rise to preferential treatment of relatives by sellers, including a discount in the sale price. Tsoodle *et al.*, 2006, for example, showed with the hedonic approach that in Kansas farmland exchanged between related parties had a lower sale price per acre (on average 43% lower than that of other land). Perry and Robison, 2001, for the case of farmland in Oregon, revealed that the price was reduced most greatly when the transaction involved a parent and a child. However, the authors also highlighted that some of the parcel's characteristics may be correlated to social capital, as, for example, neighbors mainly purchased high quality land, while strangers mainly purchased low quality land.

A third point to be discussed is the potential existence of information asymmetries between sellers and buyers (Dunford *et al.*, 1985; Barnard and Butcher, 1989). Land prices may not truly reflect the value of the various attributes if the assumption of full information does not hold. In practice, sellers generally have more information on the good exchanged than buyers. For properties, this may be the case for hidden flaws but also environmental dis-amenities (e.g. landfills, flood risk, airport). The bid of a buyer may therefore not purely reflect his/her preference for the characteristics of the property. As stressed by Pope, 2008, an uninformed buyer will overpay for the dis-amenity. The author showed with a hedonic regression that the disclosure of information on flood hazard decreased by 4% the price of properties in a flood zone of North Carolina. The availability of information by one party may also increase their bargaining power over the other party. In some countries (e.g., the US) sellers are required to provide full disclosure or they are penalized, and this creates incentives to limit information asymmetries. However, such disclosure laws are not in place worldwide. In addition, even if they do exist, sellers may unintentionally keep some specific information hidden because they do not consider it important, whereas it may be so to the buyer.

Bargaining occurs for traded goods that are highly heterogeneous in that they have few substitutes and are therefore traded in thin markets. In hedonic analyses on the price of a good, bargaining is generally assumed to be absent, or to have no influence on the price of the good. For this reason, sellers' and buyers' characteristics are not included in the models. However, land transactions may be affected by both parties' bargaining power and skills. For example, a landowner of a parcel with very specific environmental characteristics may have greater bargaining power than the environmental management agency willing to purchase this parcel for natural management purposes. Taylor and Smith, 2000, found that an estimated measure of the market power of firms managing beach rental properties significantly impacts on the hedonic value of beach access. Bargaining power may bias the price of land if bargaining relates to characteristics that are not included in the model used. In hedonic regressions bargaining may be accounted for through the inclusion of sellers' and buyers' characteristics. For the case of housing transactions in the US, Harding *et al.*, 2003, showed with this approach that bargaining power differed depending on the types of agents (e.g. men versus women) or on the season.

5 Conclusion

It is frequently stated that there is a need to improve communication between environmental science and society. In this paper we have shown that the price of land has a high informational content that can be used by researchers to evaluate the economic and social importance of their results. While environmental scientists have devoted much effort to collecting data on species' distributions and natural environments, they have put less effort into collecting and/or using economic data. We encourage them to do this, so that the hedonic values of the environmental characteristics of land parcels can be derived. With increasing access to land price data around the world, we believe that environmental scientists could become autonomous in studying land price: they could develop their own original analysis which is specific to the problem at hand, and have more flexibility in their research.

The literature about the determinants of land price is wide. A large body of the literature relies on the PVM for the basis of empirical estimation of the determinants. The basic formulation of the PVM–the capitalization formula–is frequently used as, in general, it provides consistent results. Some authors have extended the formula by including one or more determinants other than the returns from land. They have usually restricted their methodological improvement to one or two additional determinants, as these were the focus of their interest. Attempts to develop a unified formula accounting for all determinants have rarely been made so far, not only due to the complexity of the exercise but also due to the absence of need.

We have provided here a survey of the informational content of land prices, that is to say what land prices may reveal in the framework of the PVM. Urban influence, non market goods and climate change are topics where the PVM used with applied data may reveal farmers' or landowners' beliefs or subjective values. We have also discussed the topic of public regulations, and how they might affect the land price. As for land institutional and transaction regulations, these are numerous and various, and have not really been considered in the present value framework except for transaction costs and capital gains taxation. In addition, we have discussed how other factors may blur the environmental information contained in the land price, namely personal relationships, information asymmetries and bargaining power.

We wish to end with additional caveats that need to be kept in mind. The PVM has held prime position in land economics, and is both consensual and consistent. However, this approach fails to reconcile the farm scale with the parcel scale when farmland is concerned. Since the PVM is applied to parcels for which data are available, the spatial interactions within a farm are not accounted for, although farm operators consider these interactions when taking decisions on, for instance, enrolling in an easement program. Another issue that is difficult to account for is that of speculation, where land is not held for its productive or environmental use. In this case, the price of land is influenced by expectations that it will increase, independently of the typical values of interest. In addition to the expectations about the future, a recent paper (Gergaud *et al.*, 2017) showed that vineyard prices are anchored on past vineyard classifications. This result questions the possibility of land price containing obsolete information, no longer relevant for actual policies. Finally, from a practical point of view, the main shortcoming of land price data is that they are still sparse, both in space and time, and therefore may convey only partial and heterogeneous information. In developed countries this data is becoming more detailed (in terms of attributes that could affect the land price) and more readily available, and therefore studies that use regional (e.g., county) average data are less numerous. However, this is still not the case in developing countries where land markets are underdeveloped and data are still scarce. Hence, efforts should be made to collect such data around the globe at frequent periods.

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