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Theoretical Foundation of Agricultural Land Price and Agent-Based Models: A Literature Review

Tarımsal Arazi Fiyatının Teorik Temeli ve Ajan Tabanlı Modeller: Bir Literatür Taraması

Sedat ARSLAN
Sorumlu Yazar / *Corresponding Author*
Akdeniz Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, İktisat Bölümü
sedatarslan07@gmail.com
ORCID: 0000-0003-2415-4584

Peyman UYSAL
Dr. Öğr. Üy., Antalya Bilim Üniversitesi, İktisat, İdari ve Sosyal Bilimler Fakültesi, İktisat Bölümü
peyman.uysal@antalya.edu.tr
ORCID: 0000-0001-6843-601X

Ali KOÇ
Prof. Dr., Akdeniz Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, İktisat Bölümü
alikoc@akdeniz.edu.tr
ORCID: 0000-0001-7225-0349

Ahmet BAYANER
Prof. Dr., Akdeniz Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, İktisat Bölümü
abayaner@akdeniz.edu.tr
ORCID: 0000-0002-7629-6026

Selim ÇAĞATAY
Prof. Dr., Akdeniz Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, İktisat Bölümü
selimcagatay@akdeniz.edu.tr
ORCID: 0000-0002-5471-3474

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Abstract

This paper provides a systematic review of theoretical approaches to agricultural land valuation and land rental market mechanisms in agricultural policy-oriented agent-based models (ABMs). Four valuation methodologies are examined: the Net Present Value Model, the Hedonic Price Model, the Shadow Price Approach, and the Willingness to Pay/Accept framework. A systematic review and harmonized elasticity analysis of 25 hedonic price studies across 17 countries, in which coefficients from heterogeneous hedonic models are converted into comparable elasticity measures using reported sample means, identifies lot size, soil quality, and distance to town as the most frequently significant determinants of farmland values. The computed elasticities indicate that a 1% increase in soil quality produces an average 0.214% increase in farmland price. The comparative analysis of five ABMs reveals that all current models are restricted to land rental operations, with none permitting purchase and sale transactions. The review identifies a gap in the integration of hedonic land characteristics into ABM price formation mechanisms, as most models rely on shadow prices adjusted for transportation costs. The findings highlight the need for incorporating land sales markets and hedonic attributes into future agent-based land market simulations.

Keywords: Farmland price, Hedonic price model, Land price in ABM

Tarımsal Arazi Fiyatının Teorik Temeli ve Ajan Tabanlı Modeller: Bir Literatür Taraması

Öz

Bu makale, tarımsal arazi değerlemesine yönelik teorik yaklaşımların ve tarım politikası odaklı ajan tabanlı modellerde (ABM) kullanılan arazi kiralama piyasası mekanizmalarının sistematik bir derlemesini sunmaktadır. Dört değerleme yöntemi incelenmektedir: Net Bugünkü Değer Modeli, Hedonik Fiyat Modeli, Gölge Fiyat Yaklaşımı ve Ödeme/Kabul İstekliliği çerçevesi. 17 ülkeyi kapsayan 25 hedonik fiyat çalışmasının sistematik derlemesi ve uyumlaştırılmış esneklik analizi — farklı hedonik modellerden elde edilen katsayıların, raporlanan örneklem ortalamaları kullanılarak karşılaştırılabilir esneklik ölçülerine dönüştürülmesiyle — arazi büyüklüğü, toprak kalitesi ve şehre uzaklığın tarımsal arazi değerlerinin en sık anlamlı bulunan belirleyicileri olduğunu ortaya koymaktadır. Hesaplanan esneklikler, toprak kalitesindeki %1'lik artışın tarımsal arazi fiyatında ortalama %0.214'lük bir artışa yol açtığını göstermektedir. Beş ABM'nin karşılaştırmalı analizi, mevcut modellerin tamamının arazi kiralama işlemleriyle sınırlı olduğunu ve hiçbirinin alım-satım işlemlerine olanak tanımadığını ortaya koymaktadır. Derleme, çoğu modelin ulaşım maliyetlerine göre düzeltilmiş gölge fiyatlara dayandığını ve hedonik arazi özelliklerinin ABM fiyat oluşum mekanizmalarına entegrasyonunda bir boşluk bulunduğunu tespit etmektedir. Bulgular, gelecekteki ajan tabanlı arazi piyasası simülasyonlarına arazi satış piyasalarının ve hedonik özelliklerin dahil edilmesi gerekliliğini vurgulamaktadır.

Anahtar Kelimeler: Tarım arazisi fiyatı, Hedonik fiyat modeli, ABM'de Arazi fiyatı

1. INTRODUCTION

Agricultural land constitutes a distinctive production factor in economic analysis. Unlike capital or labour, land is spatially fixed, finite in supply, and non-reproducible. These properties necessitate a specialized analytical treatment that distinguishes land from other factors of production. The classical economic tradition was the first to address these characteristics systematically. Ricardo (1815) introduced the theory of differential rent based on variations in land fertility, while von Thünen (1826) developed a spatial rent model linking land value to distance from the central market. Both contributions established that the economic value of agricultural land is fundamentally shaped by its physical characteristics and geographic location. Despite centuries of theoretical inquiry, however, the question of how to accurately determine agricultural land values and how to computationally represent land market transactions remains a subject of active debate in both agricultural economics and computational social science.

The significance of agricultural land markets extends beyond the farm level. These markets serve as the primary mechanism through which structural change in farm sectors takes place. Land transfers, whether through sales or rental contracts, determine the scale, efficiency, and demographic composition of farming operations. The dynamics of these markets are influenced by economic conditions, financial performance indicators, policy instruments such as subsidies and taxation, and institutional frameworks governing property rights and land use. A thorough understanding of these dynamics is therefore essential for the design and evaluation of agricultural policies (Pyykkönen, 2006).

The theoretical literature on agricultural land valuation has developed along four principal methodological lines. The first is the Net Present Value (NPV) model, which defines the maximum price a farmer would pay for a given plot as the discounted sum of expected future income streams from that land (Feichtinger & Salhofer, 2011). The second is the Hedonic Price Model (HPM), rooted in consumer theory (Lancaster, 1966; Rosen, 1974), which decomposes observed land prices into the implicit values of individual land characteristics such as soil quality, lot size, climatic conditions, and proximity to urban centres. The third approach is the Shadow Price method, which derives the value of land from its marginal productivity within a mathematical programming framework (Dupraz & Temesgen, 2012). The fourth is the Willingness to Pay/Accept (WTP/WTA) approach, which determines land prices endogenously through the interaction of supply and demand agents in a simulated market environment (Bert et al., 2010).

Among these approaches, the hedonic price model has generated the most extensive empirical literature. A systematic search of studies published between 2000 and 2021 identified 31 studies across 17 countries that aimed to determine the drivers of farmland values. The functional forms employed in these studies are either linear, semi-logarithmic, or double logarithmic. Of the 25 studies included in the harmonized elasticity analysis, lot size, soil quality, and distance to urban centres emerged as the most frequently significant determinants of farmland values. In addition, variables representing climatic conditions, water availability, land use shares, and development potential were found to exert measurable effects on land prices, though the magnitude and direction of these effects varied across geographic and institutional contexts.

In parallel with the empirical valuation literature, agent-based models (ABMs) have emerged as a powerful computational tool for simulating agricultural policy impacts. ABMs offer the capacity to represent individual farm-level decision-making and the interactions between heterogeneous agents within spatially explicit landscapes. A growing body of literature has applied ABMs to agricultural land markets, with several prominent models incorporating dedicated land market modules. These include AgriPoliS (Happe, Kellermann, & Balmann, 2006), RegMAS (Lobianco & Esposti, 2010), MP-MAS (Berger, 2001; Troost & Berger, 2015), SWISSland (Mohring et al., 2016), and LARMA (Bert et al., 2010). Each of these models implements distinct mechanisms for land valuation, bid price determination, and rental price formation. The land rental market processes employed vary considerably across models, from iterative bidding coordinated by an auctioneer agent to neighbourhood-constrained allocation procedures. However, a critical observation is that none of these models permits land purchase and sale transactions. All are restricted to land rental and leasing operations, with land exchange generally achieved through bidding processes subject to specific constraints regarding buyer types, spatial proximity, and shadow price calculations.

The exclusive focus on rental markets within existing ABMs represents a significant limitation. This restriction means that current models are primarily suited for short-period assessments and cannot adequately capture the long-period structural dynamics of agricultural land markets, including investment decisions and farm exit processes that involve the permanent transfer of land assets. Furthermore, the integration of hedonic land characteristics into ABM price determination mechanisms remains limited. While the hedonic price literature has identified a rich set of variables influencing farmland values, most ABMs rely primarily on shadow prices adjusted for transportation costs, with minimal consideration of the broader set of hedonic attributes.

The objective of this paper is to provide a systematic review of the theoretical approaches to agricultural land valuation and the land rental market mechanisms employed in agricultural policy-oriented ABMs. The paper makes four contributions. First, it examines and compares the four principal land valuation methodologies: NPV, HPM, Shadow Price, and WTP/WTA. Second, it presents a harmonized elasticity analysis of 25 empirical hedonic price studies spanning 17 countries to identify the most significant determinants of farmland values and their elasticities. Third, it analyses the land rental market processes in five prominent ABMs, including participation rules, bid price determination, and rental contract procedures. Fourth, it discusses the implications for future modelling efforts and identifies avenues for methodological advancement.

The paper proceeds as follows. Section 2 lays out the theoretical background on the four land valuation methods and details the procedures used for the systematic review and harmonized elasticity analysis. Section 3 presents the findings and discusses their implications. Section 4 draws conclusions and suggests directions for future work.

2. MATERIAL AND METHOD

2.1. Theoretical Background of Land Price and Valuation

Agricultural land is the primary input for farming and the most valuable asset on a farm's balance sheet. Its spatial fixity sets it apart from other factors of production. The non-commodity services that land provides cannot easily be expressed in monetary terms. Beyond its role in production, land carries ecological, cultural, informative, educational, recreational, and social functions (Pyykkönen, 2006).

Classical economic theory, built on the assumption of a fixed land supply, holds that land values differ according to fertility (Ricardo, 1815) and proximity to the market (von Thünen, 1826). Yet land-use decisions for any given plot are also shaped by additional forces, including socioeconomic conditions such as output prices and policy instruments such as taxation and subsidies (Chakir & Lungarska, 2017).

Classical economists further assumed that no other input could replace land in the production process, which strengthened the case for treating land separately in economic analysis. Over time both the fixity and non-substitutability assumptions have been relaxed, yet land remains an extremely scarce factor whose substitution elasticity is low. Neo-classical theory places land alongside labour and capital as equivalent production factors, but the distinctive properties of land are broadly acknowledged. Miranowski and Cochran (1993) pointed out that because land is tied to a fixed location, it is inseparable from the geo-climatic setting that determines soil quality and productive capacity. This means that the supply of land suitable for any particular type of farming is inherently limited. In essence, land is immobile, non-reproducible, and permanent (Pyykkönen, 2006).

2.1.1. Net present value model

Under the NPV framework, the highest price a farmer is prepared to offer for a given plot at time t equals the discounted sum of all expected future earnings from that land (Feichtinger & Salhofer, 2011). This approach is regarded as theoretically robust and remains the most frequently referenced model in the farmland pricing literature. In practice, farm value is obtained by discounting projected net cash flows—covering both investment and operating components—at an appropriate rate that reflects the required return on capital (Jeanneaux, Desjeux, Enjolras, & Latruffe, 2017). The NPV model does not, however, account for every driver of land prices. Competing demand from non-agricultural uses, notably urban development pressure, can push prices above the level justified by farming income alone. Market structure also matters: where only a handful of landowners are willing to sell, their bargaining power may distort prices (Feichtinger & Salhofer, 2011). A key limitation of the NPV model is that it captures only the demand side of price formation, essentially measuring buyers' willingness to pay (Feichtinger & Salhofer, 2011).

2.1.2. Hedonic price model

The hedonic pricing approach draws on consumer theory (Lancaster, 1966; Rosen, 1974) and rests on the premise that an observed land price can be decomposed into contributions from individual land attributes (Feichtinger & Salhofer, 2011). Typical explanatory variables include proximity to markets or major infrastructure, parcel size, crop yield as a proxy for soil quality, irrigation and climatic conditions, indicators of urban development pressure, local population density, and site-specific amenities. For estimating land values and rents, hedonic models have been applied extensively using both time-series and cross-sectional survey data. In the Czech context, Slaboch, Čechura, Malý, and Mach (2022) showed that official land prices are largely driven by the evaluated soil ecological unit (ESEU) price. The ESEU score captures the productive potential of a plot through a set of soil-quality indicators—climatic region, main soil unit, slope, exposure, profile depth, and skeleton content. The authors noted that ongoing climate change has caused the reference values underlying these indicators (e.g., long-run average temperature or precipitation for a climatic region) to diverge from current conditions. Using a hedonic specification, they estimated shadow prices that quantify the magnitude and direction of each soil and climate variable's effect on ESEU values.

The HPM may be viewed as a natural extension of the NPV approach and has found broad application in environmental economics, natural resource economics, and real estate valuation. First formalised by Rosen (1974), the model analyses the prices of differentiated goods by tracing them back to their constituent attributes. Its central purpose is to uncover the implicit price that the market assigns to each characteristic of a heterogeneous product.

2.1.3. Shadow price approach

The conceptual link between land rent and farm-level returns traces back to two classical contributions: Ricardo's (1815) theory of differential rent grounded in fertility differences and von Thünen's (1826) spatial rent model driven by transport costs to the central market. Under these classical frameworks, farmland value equals net revenue after deducting production costs—a magnitude commonly called the imputed residual return or the imputed value of farmland. Neo-classical economists took a different route by embedding land within their capital theory to derive the net return to farmland and the corresponding rental price. The resulting measure is the Marginal Value of Land (MVL), more widely known as the shadow price of farmland (Feichtinger & Salhofer, 2011). Operationally, the shadow price reflects land's marginal productivity and is typically estimated through mathematical programming models or production-function approaches such as quadratic profit functions (Feichtinger & Salhofer, 2011; Chakir & Lungarska, 2017). Shadow prices are commonly employed as a substitute when observed market rents are unavailable. A further justification is that market prices do not necessarily capture the true economic value of the resources involved. This can occur for a variety of reasons; in small, monopolised markets, for instance, dominant actors may set prices independently of competitive alternatives (Curry, 1987).

In the AROPAj agent-based model, Chakir and Lungarska (2017) adopted the shadow price of land as a proxy for rental value, deriving it from a mathematical programming framework. Empirical evidence from a dual production function estimated with French FADN data revealed a persistent gap between shadow prices and observed market prices for both land and labour. Over the period studied, the average shadow value of farmland reached approximately 550 €/ha/year—roughly five times the average market rental price of 112 €/ha/year (Feichtinger & Salhofer, 2011). This divergence is commonly attributed to institutional constraints and hedonic factors. Development potential, for example, is typically absent from official land price statistics, so implicit prices derived from hedonic models tend to exceed recorded market values. In France specifically, public bodies regulate the agricultural land market and impose upper limits on both land prices and rents (Feichtinger & Salhofer, 2011). Arslan (2011) noted that market prices may be a poor guide to farmers' land allocation decisions when the prices that actually govern behaviour are shadow prices departing from market levels. This is particularly relevant for producers who place considerable non-market value on their crops; if market prices do not reflect the value farmers truly assign to their output, models built on market data risk generating inaccurate predictions and underestimating farmers' responsiveness to price signals. Jeanneaux et al. (2017) raised a further objection, pointing out that shadow-price and market-value methods for appraising farm assets overlook the sociological dimension of intangible assets.

The following subsections outline how four of the five ABMs—MP-MAS, AgriPoliS, RegMAS, and SWISSland—organise their land rental market:

MP-MAS: In the original implementation, every surveyed plot constitutes a single parcel and enters the rental market independently. Supply and demand decisions rest on shadow prices: each agent computes a plot-specific shadow price based on soil type and benchmarks it against the average shadow price across all agents. An agent will list a plot for rent when its shadow price, adjusted by a mark-up parameter and net of transport costs from the farmstead, falls below the overall average. Conversely, agents whose shadow prices exceed the average seek to rent plots offered at auction. The market module then ranks all bids and selects the highest bidder. A rental contract is concluded if the winning bid surpasses the owner's minimum acceptable rent, with the actual payment fixed at the midpoint of the bid and the owner's reserve price. Following each transaction, both parties recalculate their shadow prices and reassess whether to supply or bid for further plots (Berger, 2001; Troost & Berger, 2016).

AgriPoliS: Land available for rent is allocated each period through an iterative auction mechanism (McAfee & McMillan, 1987). The auctioneer invites farm agents to bid on individual plots within the region, and each agent preferentially targets free plots that are near its farmstead and adjacent to parcels it already operates. The maximum bid a farm agent can place depends on transport costs to the plot and the number of neighbouring plots under the same management. As in MP-MAS, the shadow price is therefore adjusted for distance and spatial contiguity, and the resulting figure is compared with an average shadow price computed over eight additional plots. This averaging is necessary because the shadow price obtained from the optimisation model can shift abruptly when more than one plot is evaluated simultaneously—a non-trivial computational concern. In practice, the model calculates both the shadow price for a single extra plot and the mean shadow price for eight extra plots, and the bid is based on whichever is higher. A symmetric logic governs plot abandonment: a farm will release a rented plot when the shadow price no longer covers plot costs, defined as rent plus transport costs. After each release the shadow price is recalculated, and the process continues until the shadow price at least equals plot costs. Owned land cannot be rented out to other agents unless the owner exits farming entirely. Because bids are rooted in shadow prices, the rent actually paid for a plot does not correspond directly to the auction bid, which can produce substantial rent variation across farms—a feature that departs from observed market behaviour. To address this, most new contracts incorporate a regional benchmark, and the final rent is set as the square root of the weighted geometric average of the auction bid and the prevailing regional rent (Happe et al., 2006).

Contract duration is another key design element in land rental market modules. AgriPoliS assumes that a farm agent may end a lease at the close of the planning period when the rented plot yields a negative gross margin, and will renew the contract when the return is positive (Happe et al., 2006). Land therefore re-enters the market either through contract termination or because a farm agent exits agriculture. In MP-MAS, leases are set at one year by default but can be lengthened to suit the research question. This flexibility was exercised when the model was adapted for climate-change adaptation simulations in Germany, where longer contract periods were permitted (Troost & Berger, 2016).

RegMAS: The land rental market in RegMAS operates through fixed-term contracts whose length is drawn randomly from a predetermined interval. Direct leasing between two farm agents is not permitted; instead, all transactions pass through intermediary land pools that collect plots recently surrendered by existing farms alongside previously unlisted parcels. Agents compete for available plots in a bidding round, and the highest bidder secures the parcel. Each agent's bid is derived from the shadow price of the plot in question, discounted by a fraction that accounts for fixed and variable transaction costs and overheads. The shadow price itself is calculated by solving two mixed-integer programming (MIP) optimisation problems—one including the plot and one excluding it—and taking the profit differential between the two solutions (Lobianco & Esposti, 2010).

SWISSland: Leasing decisions in this model are guided by the incremental income a farm agent expects from acquiring an additional plot. Because other inputs—particularly labour—impose capacity constraints, the marginal benefit of each extra parcel diminishes as a farm expands. When an agent decides to exit farming based on the income criteria described above, its plots are offered first to the five geographically nearest agents. Allocation and pricing follow a plot-by-plot bidding procedure. The initial asking price is set equal to the base-year regional average lease rate for arable land and grassland, taken from FADN data. Each candidate agent is then optimised with the new plot included, and the parcel is awarded to the agent that achieves the largest income gain, provided this gain covers the maximum lease price. If no nearby agent can absorb the plot at the asking price, the search area is widened to include more distant agents. Should the asking price remain too high even for these agents, it is progressively reduced and the bidding round is repeated. Where the lease price is positive yet no agent can profit from the plot, the parcel is classified as fallow. However, the model stipulates that a plot will be transferred to a neighbouring agent at zero rent rather than being left idle, as long as that agent derives any benefit from farming it.

2.1.4. Willingness to pay/accept approach

The LARMA model, designed for the Argentine Pampas, provides a practical application of the Willingness to Pay/Accept framework (Bert et al., 2010). Its authors describe it as a hybrid model: it draws on neo-classical economic principles yet overcomes some of their limitations by embedding the price mechanism within an agent-based structure. The land rental price (LRP) is determined endogenously, assuming market equilibrium in which rental land supplied equals land demanded. Two components drive the LRP: (a) the willingness-to-accept price (WTAP) of landowners who consider renting out their land because they lack sufficient capital or are dissatisfied with recent economic performance, benchmarked against a Minimum Progress Rate (MPR); and (b) the willingness-to-pay price (WTPP) of potential tenants, derived from their expected gross margin and available working capital (WC). Owners set their WTAP on the basis of the profit they estimate they could earn by farming the land themselves. Tenants set their WTPP according to the gross margin they expect from the next production cycle. The model tracks an economic Progress Rate (PR)—the relative growth in a farmer's WC over recent cropping cycles—and compares it with the MPR assigned to that farmer at initialisation. A farmer whose PR meets or exceeds the MPR continues to farm. When PR falls below MPR, the farmer considers renting out the land even if sufficient WC to operate remains, and therefore forms a WTAP. The farm is actually rented out only when the prevailing LRP exceeds the owner's WTAP. WTAP formation assumes that the owner estimates the profit achievable from efficient operation of the farm. Because agricultural income is uncertain, the model converts a range of possible incomes into an expected utility measure expressed as a certainty equivalent (CE), adjusted for the owner's degree of risk aversion. WTAP is then set equal to the CE. An initial simulation under simplified price conditions showed no major differences in regional land tenure patterns between the endogenous LARMA price and an exogenous fixed LRP. The simulated rental price paths closely tracked the observed dynamics, following the trajectory of crop yields and profits over time (Bert et al., 2010).

2.2. Methodology

The methodology has two components. The first is a systematic review and harmonized elasticity analysis of empirical hedonic price studies on agricultural land valuation. The second is a comparative examination of the land rental market modules built into five agricultural policy-oriented agent-based models (ABMs). Neither component involves primary data collection; both rely entirely on published sources. The procedures for literature search, study selection, elasticity computation, and ABM comparison are described below.

The hedonic price component of the review covered empirical studies published between 2000 and 2021 that sought to identify the determinants of farmland values or prices. A search was carried out on Google Scholar using two keyword strings: "factors determining agricultural land prices" and "factors determining farmland purchase and sale prices". The target material comprised peer-reviewed articles, working papers, and technical reports whose main analytical tool was the hedonic price model. To be included, a study had to estimate an econometric model in which agricultural land value or price served as the dependent variable and a set of land characteristics as independent variables. Studies with no direct relevance to agricultural land valuation, or with only a marginal link to the topic, were excluded. Studies focusing exclusively on urban or non-agricultural land markets were likewise removed. Only English-language publications were considered.

The search returned 31 studies satisfying the inclusion criteria, spread across 17 countries and offering wide geographic coverage of farmland valuation research. Ten of the studies originate from the European Union—including Germany, Finland, Poland, and the Czech Republic—seven from the United States, and two from Brazil. The remainder represent single-country analyses for Türkiye, Nigeria, Tanzania, and Ukraine. Of the 31 studies, 25 reported sufficient information for inclusion in the harmonized elasticity analysis. Table 1 lists each of these 25 studies together with the author(s), country, data source, econometric model type, and statistically significant variables.

The explanatory variables encountered in the reviewed studies fall into two broad categories. The first covers non-monetary land attributes: soil quality, lot size, climatic variables (temperature and precipitation), the shares of forest, grassland, building, and horticultural land in total area, availability of a water source, distance to the nearest district centre or municipality as a measure of urban proximity, and the development potential of the location. The second category covers monetary factors linked to farmers' production decisions, including crop type, livestock operations, yield, and net farm income. A number of studies also introduced buyer type as an additional variable, differentiating among agricultural, non-agricultural, and cooperative purchasers.

Three functional forms appear across the reviewed econometric models: linear, semi-logarithmic, and double logarithmic. Of the 31 studies, 8 used a linear specification, 15 a semi-logarithmic specification, and 8 a double logarithmic specification. The choice matters because the functional form determines how the estimated coefficients should be read. In a double logarithmic model the coefficient is itself the elasticity of the dependent variable with respect to the regressor at every observation. Coefficients from semi-logarithmic and linear models, by contrast, measure marginal effects that differ across the sample and need to be transformed into elasticities before studies can be compared on a common basis.

Where a study used a semi-logarithmic or linear specification, its coefficients had to be converted into elasticities. The conversion follows the procedure set out in Gujarati and Porter (2009), which uses the arithmetic means of the dependent and independent variables to carry out the transformation. The three functional forms encountered in the reviewed studies and their corresponding elasticity expressions evaluated at the sample means are given by:

$$\varepsilon=\beta\cdot(\bar{X}/\bar{P}) \text{ for the linear form } P=\alpha+\beta X \qquad (1)$$

$$\varepsilon=\beta\cdot\bar{X} \text{ for the semi-log form } \ln P=\alpha+\beta X \qquad (2)$$

$$\varepsilon = \beta \text{ for the log-log form } \ln P = \alpha + \beta \ln X \qquad (3)$$

where ε is the price elasticity of farmland with respect to the hedonic characteristic X, β is the estimated regression coefficient, and $\bar{P}$ and $\bar{X}$ denote the sample means of farmland price and the hedonic characteristic, respectively, as reported in each study. Equation (3) shows that for the double-logarithmic specification, the estimated coefficient is itself the elasticity at every observation, so no transformation is required.

The derivations underlying these expressions are straightforward applications of the elasticity definition $\varepsilon = (\partial P/\partial X)\cdot(X/P)$. For the linear form, the partial derivative is $\partial P/\partial X = \beta$, yielding Equation (1) when evaluated at the sample means. For the semi-logarithmic form, differentiation gives $\partial P/\partial X = \beta P$, so that $\varepsilon = \beta X$, which at the sample mean of X reduces to Equation (2). For the double-logarithmic form, $\partial(\ln P)/\partial(\ln X) = \beta$ by definition, confirming that the coefficient is itself the elasticity at every observation, as stated in Equation (3).

The harmonized elasticity analysis first records how often each hedonic characteristic reaches statistical significance across the sample of studies. It then uses the computed elasticities to compare the size and sign of each characteristic's effect on farmland values. When the elasticities for a particular variable carried opposite signs in different studies, positive and negative values were split and reported separately. This was the case for distance-related variables: theory predicts a negative link between distance to town and land value, but not every study confirmed that expectation.

The second methodological component is a comparative analysis of the land rental market modules in five well-known agricultural policy-oriented ABMs: AgriPoliS (Happe et al., 2006), RegMAS (Lobianco & Esposti, 2010), MP-MAS (Berger, 2001; Troost & Berger, 2015), SWISSland (Mohring et al., 2016), and LARMA (Bert et al., 2010). The focus was on how each model's land market module operates in practice. Comparison was structured along four dimensions: the valuation method applied to land, the rules that determine which agents may participate in the rental market, the mechanism through which bid prices are formed, and the procedures governing lease initiation and termination.

The analysis of each ABM relied on the original publications and accompanying technical documentation that describe the model's architecture. The aim was to pinpoint what these models share and where they diverge in representing land rental transactions. Special attention was paid to three aspects: how shadow prices feed into bid formulation, what spatial restrictions apply to market participation, and how lease duration is handled. The analysis further assessed whether each model accounts for hedonic land characteristics in its price formation process. The resulting comparison is used to map the current state of land market representation in agricultural ABMs and to flag areas that call for methodological improvement.

This comparative framework is essential because the way an ABM represents its land market directly shapes the model's capacity to simulate realistic policy outcomes. If a model restricts land transactions to rental-only operations, it cannot capture how investment subsidies, inheritance patterns, or credit policies affect farm-level land acquisition decisions. Similarly, if a model relies solely on shadow prices without accounting for hedonic characteristics such as soil quality or proximity to markets, it may underestimate the spatial heterogeneity of land values and produce misleading policy recommendations. By systematically comparing these design choices across five prominent ABMs, this study provides a diagnostic map of current modelling capabilities and their limitations.

3. FINDINGS

The literature review identified studies that apply the hedonic price model to determine the attributes driving agricultural land values. Following the variable classification set out in the methodology, the attributes captured by these models can be grouped into non-monetary land characteristics—such as soil quality, parcel size, climatic conditions, land-use composition, water availability, urban proximity, and development potential—and monetary factors tied to production decisions, including crop choice, livestock activity, yield, and net farm income. Several studies also accounted for buyer type, distinguishing agricultural, non-agricultural, and cooperative purchasers. The results below synthesise the findings from this body of literature and the computed elasticities.

The systematic search yielded 31 studies across 17 countries—10 from the European Union, 7 from the United States, 2 from Brazil, and individual studies from Türkiye, Nigeria, Tanzania, and Ukraine. As noted in the methodology, 25 of these provided the descriptive statistics required for elasticity computation. Table 1 presents the full details of the reviewed hedonic farmland price estimates. Table 2 reports the minimum, maximum, and mean elasticity values for 16 hedonic land characteristics derived from the 25 studies included in the harmonized elasticity analysis.

Lot size emerges as the most frequently significant hedonic attribute, appearing in 15 of the 25 studies. Soil quality and distance to town follow, each reaching significance in 13 studies. The computed elasticities show that a 1% rise in soil quality corresponds to an average 0.214% increase in farmland price. For the distance-to-town variable, however, the raw positive average is misleading: it is driven by two studies with exceptionally large coefficients. When positive and negative elasticities are separated, the negative mean of -0.605 is consistent with theoretical expectations. The number of farms variable also shows mixed effects. Studies from Germany and Finland yield positive elasticities (mean 0.144), which the authors interpret as evidence that higher farm density reflects local demand pressure. By contrast, studies from Czechia and Illinois yield negative elasticities (mean -0.142); these results have been attributed to bargaining-power asymmetries among buyer types and to environmental disamenities associated with intensive livestock operations. Overall, elasticity estimates indicate that yield, soil quality, temperature, precipitation, horticultural and building and cropland shares, lot size, on-site water availability, and development potential exert upward pressure on farmland values. Distance from urban centres and higher shares of forest and grassland, by contrast, are associated with lower land values.

Table 1. Hedonic price literature on farmland value/price estimation

Author(s)	Country	Data Source	Model	Significant Variables
Takac et al. (2020)	Slovakia	Official data	Log-log	Distance to town
Merry et al. (2008)	Brazil	Survey	Log-log	Fraction of cropland, distance to town, share of forest land
Ma (2010)	USA (Michigan)	Official data	Log-lin	Soil quality, distance to town, share of forest land, share of building land, lot size
Reydon et al. (2014)	Brazil	Official data	Log-log	Soil quality, share of building land, electricity
Kocur-Bera (2016)	Poland	Official data	Log-lin	Soil quality, distance to municipality, share of forest land
Patton & McErlean (2003)	Ireland	Official/Survey	Log-log	Soil quality, distance to municipality, lot size, potential site
Hüttel et al. (2016)	Germany	Official data	Linear	Soil quality, shares of grassland/forest/building land, lot size, number of farms
Sills & Caviglia-Harris (2009)	Brazil	Official/Survey	Log-lin	Soil quality, lot size, distance to town, share of horticultural land
Curtiss et al. (2013)	Czechia	Official data	Log-lin	Distance to town, lot size, number of farms
Ritter et al. (2020)	Germany	Official data	Log-lin	Soil quality, share of grassland, lot size
Huang et al. (2006)	USA (Illinois)	Official data	Log-log	Soil quality, distance to municipality/town, lot size, number of farms
Ma & Swinton (2012)	USA (Michigan)	Official data	Log-lin	Soil quality, distance to town, shares of forest/grassland/building land, lot size
Feichtinger & Salhofer (2013)	Germany	Official data	Linear	Soil quality, distance to town, potential site
Borchers et al. (2014)	USA	Official data	Log-log	Share of forest land, lot size, potential site
Wineman & Jayne (2018)	Tanzania	Official data	Log-lin	Soil quality, temperature/precipitation, distance to town, share of horticultural land, water source
Sklenicka et al. (2013)	Czechia	Official/Survey	Linear	Distance to town, lot size, municipality population
Pyykkönen (2005)	Finland	Official data	Semi-log	Temperature/precipitation, lot size, water source, number of farms
Andriy (2016)	Ukraine	Official data	Log-lin	Soil quality, lot size, water source on lot
Vasquez et al. (2002)	USA (Idaho)	Official data	Linear	Soil quality, lot size
Monaco et al. (2019)	Italy (Milan)	Official data	Log-lin	Temperature/precipitation, water source on lot
Bastian et al. (2002)	USA (Wyoming)	Official data	Log-lin	Soil quality, distance to town
Mallios et al. (2009)	Greece	Official data	Log-lin	Distance to municipality/town, lot size
Ehirim et al. (2017)	Nigeria	Survey	Log-log	Soil quality, lot size, water source on lot
Stinn (2012)	USA (Iowa)	Official data	Log-log	Lot size
Vural & Fidan (2009)	Türkiye (Bursa)	Survey	Linear	Lot size

In short, the harmonized elasticity analysis confirms that physical land attributes—especially lot size, soil quality, and urban proximity—are the dominant price drivers across the reviewed studies. This finding has direct implications for the ABM literature examined below, where most land market modules ignore these hedonic characteristics in their price formation mechanisms.

Comparing the five agricultural policy-oriented ABMs reveals one overarching constraint: every model is limited to land rental transactions and none supports outright purchase and sale. Because land sales are absent, these models can only represent short-run adjustments; long-term structural processes such as permanent ownership transfers and asset accumulation lie beyond their scope. Beyond this shared constraint, the models differ markedly in how they organise rental markets. AgriPoliS and MP-MAS both use iterative bidding driven by shadow prices, RegMAS channels all transactions through intermediary land pools combined with paired MIP optimisation, SWISSland allocates plots according to the income gain they generate for neighbouring agents, and LARMA sets rental prices endogenously by matching landowners' willingness to accept against tenants' willingness to pay.

Table 2. Elasticities of hedonic characteristics computed from reviewed studies

Hedonic Characteristics of Land	Number of Studies including the Variable	Min	Max	Mean
Yield	3/25	0.036	1.083	0.553
Soil quality	13/25	0.019	0.725	0.214
Temperature and precipitation	3/25	0.089	1.465	0.596
Share of cropland	1/25	0.066	0.066	0.066
Distance to municipality (+)	3/25	0.200	0.579	0.389
Distance to municipality (-)	2/25	-0.519	-0.039	-0.244
Distance to town (+)	5/25	0.123	3.060	1.569
Distance to town (-)	8/25	-3.685	-0.020	-0.605
Share of grassland	3/25	-0.024	-0.004	-0.009
Share of horticultural land	2/25	0.156	0.196	0.176
Share of forest land	4/25	-0.647	-0.160	-0.258
Share of building land	3/25	0.063	0.455	0.194
Lot size	15/25	0.0002	0.742	0.047
Water source on lot	4/25	0.007	0.370	0.157
Development potential	2/25	0.115	0.459	0.287
Number of farms (+)	2/25	0.131	0.156	0.144
Number of farms (-)	2/25	-0.177	-0.106	-0.142

Note: Cross-study comparability of the reported elasticities should be interpreted with caution. Variables such as soil quality and development potential may be measured very differently across countries and studies. Underlying indices, scoring systems, and operationalisations of these characteristics are not directly equivalent across studies, so a one-percent change in such an index in one study may not be substantively comparable to a one-percent change in another. The reported means should therefore be read as approximate summaries of the direction and order of magnitude of the effects rather than as precise comparable estimates.

A clear gap emerges in the way ABMs handle land heterogeneity. Current models base their price formation almost entirely on shadow prices corrected for transport costs and pay little attention to the wider range of hedonic attributes that the empirical literature has shown to matter. Building these attributes into the bid-price mechanism would bring simulated land market outcomes closer to observed reality.

Several limitations should be noted. Only English-language publications were included, and six studies had to be excluded from the elasticity analysis because they did not report the necessary descriptive statistics. Geographic coverage is also uneven: EU and US studies dominate the sample, and Türkiye is represented by just one study. These constraints notwithstanding, the review offers a structured account of how agricultural land is valued in the empirical literature and how those valuation methods are implemented computationally in agent-based models.

4. CONCLUSION AND RECOMMENDATIONS

This paper has provided a systematic review of the theoretical approaches to agricultural land valuation and the land rental market mechanisms employed in agricultural policy-oriented agent-based models. Four principal valuation methodologies were examined: the Net Present Value Model, the Hedonic Price Model, the Shadow Price Approach, and the Willingness to Pay/Accept framework. A harmonized elasticity analysis of 25 empirical hedonic price studies spanning 17 countries identified lot size, soil quality, and distance to town as the most frequently significant determinants of farmland values. The computed elasticities revealed that a 1% increase in soil quality produces an average 0.214% increase in farmland price, while the distance to town variable, when positive and negative elasticities are separated as reported in Table 2, yields a negative mean elasticity of -0.605, consistent with the theoretical expectation that proximity to urban centres increases farmland values.

The comparative analysis of five prominent ABMs demonstrated that all current models are restricted to land rental operations, with none permitting land purchase and sale transactions. Despite this shared limitation, the models differ substantially in their land rental market processes, including the methods used for bid price determination, spatial participation constraints, and rental contract procedures. The review also identified a notable gap in the integration of hedonic land characteristics into ABM price formation mechanisms, with most models relying primarily on shadow prices adjusted for transportation costs.

Based on these findings, several directions for future research can be identified. First, future ABMs should consider incorporating land sales markets alongside rental markets to better capture the long-period structural dynamics of agricultural land markets. Second, the integration of hedonic land characteristics into bid price determination within ABMs could improve the realism of simulated market outcomes. Third, the geographic coverage of the hedonic price literature should be expanded, particularly for developing countries and underrepresented regions such as Türkiye, where only a single study was identified. Fourth, the development of hybrid models that combine the strengths of different valuation approaches, as demonstrated by LARMA, represents a promising avenue for advancing land market simulation in agricultural policy analysis.

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