Revisiting the von Thünen model: Urban Expansion and Reorganization of Agricultural Land Use. Evidence from an Italian Case Study

Introduction

Urban expansion is one of the most pervasive land-use dynamics. Conversion of agricultural and natural land into artificial surfaces has recently accelerated across Europe, driven by population growth, infrastructure development, and changing settlement patterns. Literature has largely documented the direct effects of urban expansion, highlighting how urban growth leads to: i) the irreversible conversion of fertile soils, endangering food security; ii) fragmentation of rural landscapes, limiting environmental quality; and iii) increased pressure on ecosystem services, with long-term implications for biodiversity loss, sustainability and resilience (Kalnay & Cai, 2003; Chace & Walsh, 2006; Seto et al., 2012; d'Amour et al., 2017). Far less attention has been given to the indirect effects of urban expansion, particularly its impacts on non-urban areas that remain agricultural, but are still affected by nearby urban dynamics. In particular, relatively few studies investigate how urbanization affects agricultural intensity, investment decisions, and the spatial reorganization of agricultural activities.

This paper aims to fill this knowledge gap by analyzing how urban expansion influences the composition and intensity of agricultural land use in neighboring rural areas. Drawing on the classical land-rent theory of von Thünen (1826), revisited in a dynamic framework, the study builds on the idea that the spatial location choices of agricultural producers are shaped by transport costs and land rents. In von Thünen's model, central areas, with lower transport costs and stronger competition, command higher land rents, implying that only activities capable of generating sufficient returns can afford to locate closer to the market. Land rent thus acts as the key organizing principle of economic activities in space, with higher-value-added productions occupying more central locations. Within this framework, urban expansion is expected to progressively push agricultural activities outward, increasing land values in proximity to cities, and intensifying competitive pressure at the urban fringe. As a result, agricultural systems near expanding urban areas are likely to restructure rather than simply contract, favoring high-value-added, more intensive productions close to the urban margin, while extensive, lower-value-added activities are displaced toward more peripheral locations.

An empirical analysis is conducted on the Emilia-Romagna region, one of Italy's most productive agricultural areas despite intense urbanization and dense infrastructure. The main objective of the paper is to assess whether urban expansion affects agricultural land-use intensity in areas that remain agricultural, and to identify spatial spillover effects associated with urban growth. By addressing this objective, the paper seeks to bridge theoretical insights from spatial economics with empirical evidence from high-resolution land-use data, thereby stimulating discussion on the future of peri-urban agriculture and integrated territorial planning.

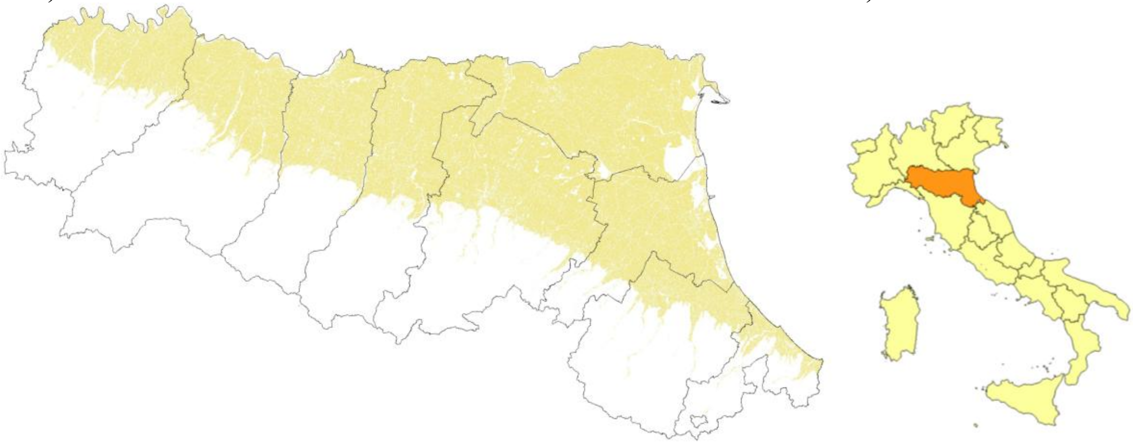
Data and research methodology

The empirical analysis relies on integrating multiple high-resolution spatial datasets within a panel econometric framework. In particular, two datasets are combined. Firstly, urban expansion is measured using official data on soil consumption (i.e., land take) provided by ISPRA (Italian Institute for Environmental Protection and Research). This dataset captures artificial land cover resulting from urbanization, infrastructure, and other non-agricultural uses, distinguishing between permanent soil consumption and reversible soil consumption. Data are available annually and cover the entire Italian territory, ensuring consistency and comparability across space and time (Strollo et al., 2020). Secondly, agricultural land uses are obtained from the iColt dataset (available at: https://sites.google.com/arpae.it/servizio-climatico-icolt). The dataset classifies crops using multi-temporal satellite imagery, providing annual information on agricultural land use for the lowland areas of Emilia-Romagna and allowing crops to be aggregated into macro-categories reflecting different levels of value added. Specifically, for the purpose of this analysis, agricultural land is classified into:

- Low value-added uses, including winter cereals and permanent grasslands;
- Medium value-added uses, including summer arable crops;
- High value-added uses, including vineyards and fruit orchards.

The study area covers the Emilia-Romagna Region (which is located in Northern Italy), with a specific focus on lowland areas where both urban expansion and agricultural activity are most intense. In particular, the area covered by iColt is shown in Figure 1.

Figure 1. Area of the Emilia-Romagna Region covered by iColt dataset (a), and Emilia-Romagna in Italy (b)



To harmonize spatial units and enable fine-grained analysis, the study adopts a regular grid approach, dividing the Emilia-Romagna Region into 1 km × 1 km cells. Each grid cell constitutes one observational unit. Only cells covered by both ISPRA and iColt datasets are retained. Thus, the final sample comprises 12,443 grid cells observed at 2015 and 2022.
The econometric strategy is based on panel models in first differences (Hausman and Taylor, 1980; Augustyniak et al., 1985), allowing the analysis to focus on changes over time while controlling for time-invariant unobserved heterogeneity at the spatial unit level. This approach is particularly suitable in a land-use context, where many structural characteristics (e.g., soil quality, historical land patterns) are fixed in the short to medium run.
Given the inherently spatial nature of urban expansion and agricultural dynamics, the analysis explicitly incorporates spatial econometric elements. Spatial spillovers are modeled using a contiguity-based spatial weight matrix, adopting a "queen" criterion, where the cells sharing either a border or a vertex are considered neighbors (Cliff & Ord, 1981; Anselin, 1988). Both first-order and second-order neighbors are included (Anselin and Smirnov, 1996), allowing the identification of indirect effects transmitted through nearby areas.
Separate models are estimated for each category of agricultural value-added uses (low, medium, and high value-added), according to formula (1).

$$\Delta Y_{it} = \alpha + \beta \Delta X_{it} + \theta \Delta (W X_{it}) + \Delta \varepsilon_{it} \qquad (1)$$

Where:

- Y = agricultural areas that remain agricultural in both 2015 and 2022;
- X = urban areas;
- W = spatial weight matrix, standardized by row, "queen" contiguity-based.

Robust standard errors clustered at the spatial unit level are used to account for heteroskedasticity and spatial dependence.

Discussion of results

Table 1 presents the descriptive statistics of the variables included in the analysis. Between 2015 and 2022, low-value-added agricultural uses (i.e., the most prevalent ones in the lowlands of Emilia-Romagna) increased by 8.1%. Vineyards and orchards also expanded, by 6%. In contrast, medium-value-added uses - comprising summer arable crops - declined by 10.6%.

Table 1. Descriptive statistics: areas and % variation

	Total area (kmq)		% var. (2015-2022)
	2015	2022	
urban areas	1472.3	1509.9	2.6%
non-urban areas that remain agricultural in both years	6992.9	6992.9	0.0%
Low value-added uses (winter cereals and permanent grasslands)	*3357.8*	*3629.8*	8.1%
Medium value-added uses (summer arable crops)	*2954.6*	*2641.5*	-10.6%
High value-added uses (vineyards and fruit orchards)	*680.6*	*721.6*	6.0%

Table 2 shows the main results of the models. Empirically, the results are consistent with the theoretical predictions of the von Thünen (1826) model. In the non-urban areas that remain agricultural, the effect is heterogeneous across different types of agricultural use. Specifically, proximity to urbanized areas (*urban area_lag_queen*) is associated with a decline in low-value-added agricultural uses, while a positive effect on medium-value-added activities is observed. Lastly, a relative expansion of high-value-added crops, such as vineyards and orchards, is observed but only when considering urban expansion in second-order neighbors.

Table 2. Results of the models

	Low value-added uses (winter cereals and permanent grasslands)			Medium value-added uses (summer arable crops)			High value-added uses (vineyards and fruit orchards)		
	m1	m2	m3	m1	m2	m3	m1	m2	m3
Costant	24701.6***	27157.3***	27134.2***	-27754.0***	-29668.0***	-29669.0***	3052.6***	2510.4***	2534.8***
	(1522.3)	(1707.5)	(1706.6)	(1506.7)	(1692.8)	(1691.1)	(450.4)	(495.0)	(505.0)
Urban area	-0.105	-0.109	-0.097	0.103	0.106	0.105	0.002	0.003	-0.008
	(0.082)	(0.082)	(0.078)	(0.081)	(0.081)	(0.078)	(0.023)	(0.023)	(0.022)
Urban area_lag_queen_1_order	-0.824***	-0.467*		0.744***	0.468*		0.080	-0.001	
	(0.195)	(0.210)		(0.190)	(0.204)		(0.060)	(0.064)	
Urban area_lag_queen_2_order		-1.145***			0.889**			0.256**	
		(0.286)			(0.285)			(0.079)	
Urban area_lag_queen_1&2_order			-1.624***			1.365***			0.259**
			(0.288)			(0.284)			(0.082)
Balanced panel									
n	12430	12422	12430	12430	12422	12430	12430	12422	12430
T	2	2	2	2	2	2	2	2	2
Adj. R-Squared	0.001	0.002	0.002	0.001	0.002	0.002	0.000	0.000	0.000
F-statistic	8.253***	9.694***	14.508***	7.067***	7.307***	10.960***	0.657	2.593°	3.24*

Signif. codes: ***: < 0.001; **: < 0.01; *: < 0.05; °: < 0.1

Thus, spatial spillover effects are at play. Urban expansion in one cell is likely to influence neighboring cells not only through direct land competition but also via changes in land prices, infrastructure accessibility, labor markets, and demand conditions. These spillovers may generate non-linear and spatially differentiated patterns, reinforcing agricultural intensification in some areas while accelerating marginalization in others. Overall, the empirical results show that urban expansion acts as a reorganizing force, reshaping the spatial structure of agriculture rather than simply reducing its extent.

Main conclusions and pathways for future research

The findings of the paper confirm that urban expansion should be understood not only as a driver of agricultural land loss but also as a force of spatial and economic reorganization within agricultural systems. Peri-urban agriculture is not uniformly threatened by urban growth; rather, it adapts through processes of intensification, specialization, and reorientation toward higher value-added activities. These results have important policy implications. They highlight the need for integrated urban-rural planning strategies, recognizing the economic and functional interdependencies between cities and surrounding agricultural areas. Policies aimed at containing soil consumption should be complemented by measures supporting agricultural restructuring, such as incentives for high-value and multifunctional agriculture, short supply chains, and environmentally sustainable practices.

The study also acknowledges some limitations, including the aggregation of crops into broad categories, the lack of information on farming practices and value-chain integration, and the focus on a single region and a limited time span. These limitations open avenues for future research, such as extending the analysis to other regions, incorporating farm-level data, or explicitly modeling land prices and investment decisions.

The paper's potential to stimulate discussion at the conference lies in its interdisciplinary relevance. It speaks to debates in agricultural economics, urban studies, spatial planning, and environmental policy, and invites reflection on how classical spatial theories can be revisited using modern data and methods.

References

Anselin, L. (1988). *Spatial econometrics: Methods and models*. Dordrecht, Netherlands: Kluwer Academic Publishers.

Anselin, L.; Smirnov, O. (1996). Efficient algorithms for constructing proper higher order spatial lag operators. *Journal of Regional Science*, 36(1), 67–89. Doi: 10.1111/j.1467-9787.1996.tb01101.x

Chace, J.F.; Walsh, J.J. (2006). Urban effects on native avifauna: A review. *Landscape and Urban Planning*, 74, 46–69. Doi: 10.1016/j.landurbplan.2004.08.007

Cliff, A.D.; Ord, J.K. (1981). *Spatial processes: Models & applications*. London, UK: Pion.

d'Amour, F. C.B.; Reitsma, F.; Baiocchi, G; Barthel, S.; Güneralp, B.; Erb, K.-H.; Haberl, H.; Creutzig, F.; Seto, K.C. (2017). Future urban land expansion and implications for global croplands. *PNAS*, 114(34), 8939-8944. Doi: 10.1073/pnas.1606036114.

Hausman, J.A.; Taylor, W. E. (1981). Panel data and unobservable individual effects. *Econometrica*, 49(6), 1377–1398.

Kalnay, E. Cai, M. (2003). Impact of urbanization and land-use change on climate. *Nature*, 423, 528–531. Doi: 10.1038/nature01675

Liker, J.K.; Augustyniak, S.; Duncan, G. J. (1985). Panel data and models of change: A comparison of first difference and conventional two-wave models. *Social Science Research*, 14(1), 80–101.

Seto, K.C.; Güneralp, B.; Hutyra, L.R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *PNAS*, 109(40), 16083–16088. Doi: 10.1073/pnas.1211658109

Strollo, A.; Smiraglia, D.; Bruno, R.; Assennato, F.; Congedo, L.; De Fioravante, P.; Giuliani, C.; Marinosci, I; Riitano, N.; Munafò, M. (2020). Land consumption in Italy, *Journal of Maps*, 16(1), 113-123. Doi: 10.1080/17445647.2020.1758808

von Thünen, J. H. (1826). *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie*. Hamburg.