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Market access and agricultural land use: Does distance matter? Insights from Colombia[1]

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Abstract

A rich dataset, based on the agricultural census, characterizing Colombian agricultural units is used to examine the relationship between market access and market influence, on one hand, and the intensity of land use for productive purposes as instrumented as the share of usable land with respect to the total area of the production unit, on the other. We find that there is a stable and significant negative relationship between the two, meaning that as market access and market influence improve there is a decline in the share of usable land in average, reflecting a lower extent an intensity of agricultural activity. We additionally explore heterogenous effects arising from different market types and find that this relationship changes with the type of municipality, yielding significant implications for land and rural policy. Overall, the results provide evidence supporting the convenience of place-based policies and the usefulness of the qualified von Thünen model for approaching the analysis of rural land use.

JEL: Q15, R14, R12, Q18

Keywords: Market access, Market influence, Land use, Land policy, von Thünen model, Colombia

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1. Introduction.

Colombian rural and agricultural development has been marked and conditioned by high land inequality and underutilization, low shares of investment, and high levels of violence (Banco Mundial, 2004; PNUD, 2011). Although agriculture's share of national GDP fell from 14% in 1995 to 6% in 2020, it still employs more than 60% of rural workers (OECD, 2022b) and has the potential for providing an important leverage for economic development in general (DNP, 2015). Enhancing agricultural growth in Colombia implies navigating three main transitions, as summarized by the World Bank (Banco Mundial, 2004) and partly echoed by other analyses (DNP, 2015; PNUD, 2011). First, reorienting agricultural production to activities with comparative advantage better suited for the agroecological and human endowments of the country. Second, moving from an agriculturally oriented rural sector to a diversified and multifunctional one. And third, leaving behind civil conflict, war, and exclusion, in favor of a peaceful and inclusive society.

Within a broad arrange of policy fixtures aimed at addressing these challenges, the relationship between the location of agricultural activity and its proximity to markets is of central importance, as it greatly contributes to determine the effectiveness of agricultural and land policy (OECD, 2009). In this research we quantitatively explore this relationship and considering the results obtained, we comment on the issue of policy effectiveness.

Colombia has an explicit national rural policy defined as part of the National Planning Program that is issued at the beginning of each presidential term (the current is under development and the former covered the period 2018-2022). It has, among others, provisions for supporting agricultural competitiveness, specific policies for diversifying the rural economy, mechanisms for promoting climate-smart agriculture, guidelines for agricultural land-use planning, and the elaboration of a national multimodal transport plan.

One of the key challenges for rural policymaking is improving rural connectivity. Rural roads and infrastructure in general are one of the dimensions for achieving integral rural development in Colombia, according to the United Nations Development Program (PNUD, 2011). The Mission for the Transformation of the Colombian Countryside, put in place by the Colombian government in 2014 for developing the guidelines for rural and agricultural policies for the next 20 years, issued a similar proposition (DNP, 2015). Furthermore, the OECD in its latest review of Colombian rural policy, lists as one of its key recommendations the strengthening of transport projects for rural communities as a way to remove a key bottleneck for rural development (OECD, 2022b).

Against this backdrop, there is a notorious lack of knowledge on the way location and market access (understood as a function of physical connectivity) interact with the agricultural use of rural land in Colombia and, hence, on its incidence on the workings of rural policy (agricultural and land policies chiefly). In a sense, the canonical model for analyzing the first connection is provided by von Thünen (O'Kelly & Bryan, 1996; Parr, 2015) whose model yields a core-periphery structure characterized by the well-known concentric rings of land use with the higher-value or perishable goods cultivated nearer the core. Nowadays agricultural production serves multiple markets, location decisions must minimize total costs instead of the cost of serving a particular market, and the space is heterogenous, with different agroecological conditions and access to transport networks. As a result, returns from and the profitability of agriculture, as well as the opportunity cost of keeping land under agricultural use are space dependent (OECD, 2009).

While some of these considerations essentially qualify the von Thünen model, others radically affect its assumptions. This is especially the case near the core, in peri-urban areas, where the opportunity cost of agricultural land use exponentially increases in the face of mounting pressure from urbanization. In this qualified von Thünen model, agricultural activity in peri-urban areas tends to be unprofitable as land rent increases and the likelihood of land conversion toward urban uses discourages agricultural long-term investments in otherwise potentially lucrative activities. Under these circumstances, the agricultural use of land can be either highly intensive, as happens in the vicinity of Colombia´s capital city with cut flower cultivation for export, or rather basic, with low investment and small scale, developed on land that faces a high probability of being urbanized in the short term. Also, land use change to residential recreational uses induces lower-productivity use of agricultural land, leading to decreased intensity of the activity (Towe & Chen, 2022). In either case, contrary to the unqualified von Thünen model, the intensity of land use for agriculture decreases in this area.

Immediately beyond the peri-urban area there is the core agricultural area, where the typical concentric ring pattern of cultivation, determined by the highest location rent, is predicted by the model (Parr, 2015). It is argued that even for modern agriculture the von Thünen model still holds as a general case for this area, although with important variations (OECD, 2009). One of these variations relates to the idea of the extensive margin. As the space is not homogeneous, the productive capacity of farmland varies, carrying with it different land rents and hence differing capabilities for profitably sustaining agricultural activities as output prices change. Lands on the extensive margin in the sense just described (i.e., of inferior quality on any significant dimension) are of two types. Either they are permanently out of the market and therefore are not bought or sold (or are unused) irrespective of output prices, or they lay on the economic margin of two or more competing agricultural uses, being therefore on the extensive margin of the higher-value use, typically changing from high to low intensity use as output prices decrease, production and transport costs increase, or agricultural policies create or fail to create strong enough incentives (Lubowski et al., 2006). Another significant variation comes from the fact that most agricultural regions serve more than one market. Hence, the relevant transport costs are complex, location can be more varied, and the interplay between the intensive and extensive margins is richer. Whether or not demand for agricultural products and technological change lead to an increase in demand for land for agricultural uses depends on the supply elasticity of land, the price elasticity of demand for agricultural goods (a function of the type and size of demand), and the competitiveness of the specific region (Villoria et al., 2014).

Lastly, away from the core, at the far margin area, farmland is marginally profitable and faces the prospect of being withdrawn from agricultural production as transportation costs, poor infrastructure, and other adverse conditions make it poorly suitable for sustaining a competitive foothold. In this area there are transition zones, akin to those present near the core, with the key distinction that agriculture is a low-value economic activity near the core, but a high-value one far from it (OECD, 2009).

From the above it follows that in peri-urban areas it is expected that the agricultural use of land be relatively scant and of low intensity and that both, use and intensity, tend to increase as distance from the core increases. Meanwhile, in the core agricultural area it can be expected a mosaic of agricultural use and intensity mainly dependent upon the changing conditions of land across the space, the transport network, and the size and complexity of the markets that are served. On top of this diversity, a pattern should be observed in which the agricultural use of land and its intensity decrease as one moves far away from the markets. Finally, in the far margin area the agricultural use of land and its intensity should be declining in a heterogeneous way until land is no longer able to generate profits from economic activities.

From another viewpoint, urban activity has enormous gravity on land use and the type of agriculture that locates in peri-urban areas, yielding agricultural and land use policies aimed at preserving farming, largely useless. The extent of this effect, of course, is dependent on the size and complexity of the urban center. In contrast, within the core agricultural area the opportunity cost of land use is low, and it essentially plays a role in inducing switching from one agricultural activity to another according to circumstances. In the far margin area, agricultural activity is marginally profitable and declines in economic returns may lead to withdrawing land from production (OECD, 2009).

Considering this stylized view, our main aim is to quantitatively explore the relationship between location, understood as distance from markets, and the patterns of the agricultural use of land in the case of Colombia. We build indices of market access and influence as instruments to measure the ability of urban economic activity to affect the way land is used for agricultural activities, while controlling for factors that allow for a rich characterization of location from the physical, spatial, and economic dimensions. Using the information provided by the 2014 National Agricultural Census we use regression analysis techniques in which the dependent variable are several alternative definitions of productive land use and measure the effect on them of market access.

The remaining of the paper is structured as follows. Section 2 briefly describes the main literature on the subject, while Section 3 lists the sources of information used, shows how the relevant variables were built, and discusses the methodological approach of the study. Section 4 presents and discusses the basic statistical results that allow characterizing the implications of market access on the intensity of agricultural land use. Section 5 discusses the results generated by the econometric analysis on the relationship between market access, market influence, and agricultural land use. Section 6 presents additional results on the relationship between market access and influence and the pattern of land use to test the stability of our findings. Lastly, section 7 provides a final discussion.

2. Literature review.

To the best of our knowledge, there is not much that we systematically know about the significance of the location of agricultural activity in Colombia. It is known that accessibility, the distance from roads and towns as an indicator of market access, is a significant predictor of the pattern of deforestation, both at the national and regional levels (Etter et al., 2006). This includes river access as has been documented for the Colombian Amazon for areas with relatively high population density, where cattle ranching and illegal cropping also take place (Armenteras et al., 2006). On the other hand, it is claimed that the increase in distance to urban centers is associated with decreases in the share of farmers trading products in the market, with the effect increasing as geography controls are considered (the effect is the same when investments in land improvements is the dependent variable). Furthermore, the distance to urban centers affects the patterns of crop specialization, with faraway areas less specialized in trading crops (Gáfaro & Pellegrina, 2022).

As we point to contribute to filling this gap, our results indicate that greater market access and influence has a negative effect on the proportion of the surface of farms that is suitable for productive activities and that the same occurs with the proportion of area used for agriculture and livestock, both considered independently or simultaneously. Likewise, they indicate that the proportion of family labor employed in the farm and the output destined for self-consumption increase as market access and influence decrease.

The second set of results is not surprising since family farming and self-consumption are expected to be higher as farms are far away from the market. However, the first set is challenging because greater proximity to the market, in terms of both access and influence, is associated with greater intensity in the productive use of the land, at least in the agricultural core area, because of the logic of the cost of location. Indeed, greater market access should translate into lower costs of transporting products, greater competitiveness, and lower costs of purchasing inputs that foster greater productivity and, presumably, profitability, as has been found in some studies at the international level.

Several factors may have an impact on this result, including considerations about the type of productive activity and the technology used; spatial variation in land rent (Ricardian rents); competition between alternative uses of land out of agriculture, as happens in peri-urban areas and in the far margin area. The exploration of which of these, or other, factors may be influencing the inverse relationship between the intensity of agricultural land use and market access is outside the purpose of this paper, but the finding itself is significant for policy making.

Agricultural policy in Colombia essentially lacks an explicit spatial reference, with the exception of the issuing of an "agricultural frontier" aimed at limiting the intrusion of agriculture in lands that otherwise should be preserved, and that is expected to act as a filter for having access to most policy instruments (Ministerio de Agricultura y Desarrollo Rural, 2018), having therefore an effect that concentrates on the far margin.

From the broader perspective of rural policy, as mentioned, there have been some recent and still incipient developments that provide a basis for building a place-based approach to rural development, that, by definition, has an explicit reference to territories and location. A fuller development of this approach, needed for untapping regional development, could benefit from a better understanding of the way distance to markets and the agricultural use of land interact. If rural roads building and maintenance is predicated as an urgent rural policy measure, our findings imply that as market access improves as its consequence, the intensity of the agricultural use of land will be driven away from the markets partly denying the expected welfare gains from policy interventions.

In the international front, on the other hand, the empirical literature has developed numerous works that seek to measure how market access affects the decisions of economic agents in different contexts. In the case of farmers, this aspect takes on relevance since market access implies transaction costs that impact the benefits derived from economic activities and their cost structure, as it relates to other types of infrastructure (Hugo, Squalli, & Wilson, 2006). It also impacts access to other inputs such as labor, capital, technology, including information transfer, and credit, with effects on poverty and economic development (Gani & Adeoti, 2011).

In coping with this multidimensionality of the effects of distance, Verburg et al. (2011) adopt a broad view of the concept of market access and introduce a market influence indicator, which is determined not only based on distance but also on the relative importance of the market accessed. Hence, distance to the market considers both physical space and travel time, which imply infrastructure availability, and the size of the market that is accessed, weighted by its gross domestic product. Using worldwide data and three different indicators of market influence, they find that market influence is related to population density, modifications of natural land cover, the intensity of cultivation, and other environmental patterns.

Using similar indicators, although primarily considering distance as a measure of accessibility, the effect of market access on the intensification of agricultural activity, land uses, and the prices of goods have been studied by several authors. Binswanger-Mkhize and Savastano (Binswanger-Mkhize & Savastano, 2017) use data for six African countries (Ethiopia, Malawi, Niger, Nigeria, Uganda, and Tanzania) from the Living Standards Measurement Study–Integrated Surveys on Agriculture to estimate the causal effect of market access on the intensification of agricultural activity. The authors argue there is an interactive effect of market access and population growth, which intensifies agricultural activity, mainly in areas with agroecological potential. Market access has a more significant impact on intensification in regions where the land is more suitable for agricultural production. Villoria and Liu (Villoria & Liu, 2018),using the indices proposed by Verburg et al. (Verburg et al., 2011), to study land supply elasticities in the Americas, finds that the variation in these elasticities is completely explained by market access and suitability for agriculture.

Market access is also found to be related to the intensity and orientation of agriculture, be it expressed in terms of land management practices, use of irrigation, and fertilizer use (Kiprono & Matsumoto, 2018; Lambin et al., 2001), land prices, and access to inputs (Keys & McConnell, 2005), productivity (Aggarwal et al., 2022; Buckmaster et al., 2014; Neumann et al., 2010), output prices (Minten, 1999; Minten & Kyle, 1999), technology adoption (Chamberlin & Jayne, 2013; Staal et al., 2002; Van Leerzem & Ur -, 2015), and food security (Ahmed et al., 2017).

Authors such as Castella et al. (2002), Verburg et al. (2004), Castella et al. (2005), Braimoh & Onishi (2007), Schmitt & Kramer (2009), Castella & Phaipasith (2021), Schielein et al. (2021), Chan (2022) among others, have focused their analysis on the impact that market access can have on land use and cropping patterns. Specifically, Castella et al. (2002) find a direct geographical relationship between the road network, the distribution of natural resources, and land use systems in the Bac Kan province, Vietnam. Subsequently, in their 2005 study, they note that the distribution of rice paddies among households which usually takes place in upland areas played a key role in land use changes, characterized by an increase in cultivated areas and in deforestation levels in those areas Castella et al. (2005).

For the American context, Chan (2022) focuses on the expansion of the U.S. railroad at the end of the 19th century to show that agricultural production increases in counties with greater market access but not necessarily in crops in which there is a comparative advantage, instead this expansion comes from a growth in rural population which leads to an increase in the resources allocated to production. Also, Donaldson and Hornbeck (Donaldson & Hornbeck, 2016) find that the expansion of the railroad network towards the end of the 19th century in the U.S., by improving market access, had a very significant impact on land values. However, the impact of this type of policy intervention is not always significant on agriculture as shown by the case of Nicaragua where, after the construction of highways in 2007, that made it possible to connect previously remote areas, no major level of response was observed in agricultural markets, finding instead that there was no relationship between the intensity of land use and the distance to the highway and also encountering different patterns of spatial variation in prices (depending on the crop) and minor changes in the percentage of households allocating products to specific markets Schmitt & Kramer (2009).

Other studies have analyzed the consequences of road development and transportation costs on land use patterns (Alphan (2018), Morando (2021), Nelson et al. (2004)) but, overall, the effects found are diverse and dependent on multiple factors, such as the access measure adopted (Schielein et al., 2021), the industry analyzed (Schmitt & Kramer, 2009), the initial access in place, and the pre-existing conditions of the households involved (Castella & Phaipasith, 2021). In particular, Hettig et al. (2015) conducted a review of 70 studies on the subject, finding an inverse U-shaped relationship between market access and agricultural expansion, by which improved access leads first to agricultural expansion but in a second stage households start to invest in non-agricultural activities.

Other market access effects that are usually explored are those on the adoption of technology, mainly for agricultural production. On this topic Aggarwal et al. (2022) make an important contribution in their study for Tanzania, in which they find that the doubling of transportation costs to the main regional market is associated with an increase in the price of fertilizers and, in turn, a reduction in the adoption of this technology by 14 percentage points. In addition, they show that remoteness is also negatively correlated with the use of improved seeds and, due to the aforementioned, lower yields are generated in rural areas, where these increases in transportation costs reduce crop production by almost 25%. Subsequently, in their study conducted in 2020, also in Tanzania, they develop a spatial model of fertilizer adoption with which they produce evidence that those villages with lower access or higher transport costs face prices between 40% and 55% less favorable than those with better access, and consequently face a decrease in the adoption of inputs and in the sale of their products (Aggarwal et al., 2022).

Linked to the above mentioned, there is a group of studies that focuses specifically on productivity or efficiency outcomes, mainly for agricultural products. An example of this is the analysis for Ethiopia by Katungi & Horna (2011) using a survey of common bean producers in 2008, showing that market access has both intensification and specialization effects on grain yields and that, additionally, access to credit, extension, and household wealth have a similar effect. On the same track, Liang (1981) finds, for prewar China, a positive relationship between accessibility to the nearest regional market, which induces a more efficient use of resources in production, and income generated from agricultural production.

Despite the evidence provided, this correlation is not always positive but, like the impact on land use, depends on other factors considered in the analysis. In Ethiopia, for example, the expansion of rural roads and extension services (consulting, subsidized seeds, fertilizers, and credits) had a positive impact on agricultural productivity, but only in those places where there was a joint expansion of these two factors. In contrast, in those places where access to a road is gained without extension services, households tend to reduce the effort invested in agricultural labor and the most qualified people are recruited for other areas, thus decreasing productivity in the sector (Gebresilasse, 2023). Analogously, Kamara (2004) finds that productivity increases with improved market access, but these gains differentially benefit large and small farmers.

The literature also points to the emergence of trade-offs for land use. Chomitz and Gray (Chomitz & Gray, 1996) analyze how market access in Belize promotes economic development, but at the same time, increases deforestation because of the reduction in migration costs and access to land tenure. At a global level, Geist and coauthors examine the proximate and underlying causes of land use and land cover change, identifying market access as one the main drivers of these changes (Geist et al., 2008). In examining land use and land cover changes, several studies point to the importance of market access as one of their determinants, as in the upper Yangtse River in China (Yin et al., 2010), south-eastern Albania (Müller & Sikor, 2006), the Netherlands (Verburg et al., 2016), or the Amazonian region (Schielein & Börner, 2018), to name a few.

3. Data, variables definition, and methods.

The primary source of information used is the National Agricultural Census (CNA, for its Spanish acronym) 2014. The observation unit of the CNA is the Agricultural Production Unit (UPA, for its Spanish acronym), which is defined as the unit of organization of agricultural production under a single management and can be formed by part of a property or a complete property, (DANE, 2016). The CNA collects information on the productive and socioeconomic characteristics of 2,913,163 UPA. Among the characteristics it is included data on the UPA's land use, data from which it is possible to identify the area usable for productive purposes, and its use according to its productive destination, e.g., agricultural use (individual crops), livestock use, pastures, infrastructure, housing, and other uses.

For our ends, we consider the following definitions to analyze the different levels of land use, all of which we have instrumented using information from the CNA:

Table 1. Variables definition.

Variable	Definition
Usable land	UPA' s total area - Other land uses and other land cover - Land dedicated to buildings or non-agricultural infrastructure - Natural forests
Rest land	Short term fallow land (up to a year) + Long term fallow land (from one to three years) + Shrub land (more than three years and shrub cover)
Share of usable land	Usable land / Total area
Share of land in use	(Land in agricultural use + Agricultural infrastructure) / Usable land
Share of land in crops use	(Land in agricultural use – Land of natural pasture – Land of planted pasture) / Usable land
Share of land in pasture use	(Land of natural pastures + Land of planted pastures) / Usable land

Table 2. Land use indicesTable 2 presents the averages obtained for the land use indices listed above and their standard deviations. It is estimated that at the national level the usable area of the UPA is 82%; the area in use is only 68% of the usable area (or 56% of the total area); 32% of the usable area is destined to crop activities and 34% to pasture, a use potentially related to livestock activities. We correlate this information with various data sources at a high level of spatial disaggregation to examine how these characteristics relate to the distance and access of the UPA to the market. The granularity of the data allows capturing the physical and climatic conditions of the UPA and along a set of municipal variables makes it possible to control for the context in which the productive activities take place.

Table 2. Land use indices.

Variable	Average (%)	Std Dev
Usable land index	0.820	0.315
Land in use index	0.680	0.396
Land in crops use index	0.325	0.433
Land in pasture use index	0.344	0.425

Source: CNA 2014, authors' calculations.

To identify the impact of access on land uses, in addition to the information from the CNA, it is necessary to construct access and distance measures for each productive unit. For this, it is crucial to carry out a validation process of the information available on georeferencing. This process yielded as a result that 2,335,063 UPA distributed throughout the Colombian territory have valid data and were suitable for the analysis. To start, we adopt Verburg et al's definition, according to which the relevant markets are the set of municipalities with a population of 50,000 inhabitants or more (Verburg et al., 2011), as this is about the midpoint for the category of intermediate municipalities in Colombia.[2] With this, two indices are constructed. First, an access index that depends on the distance to the nearest market with a population of at least 50,000 inhabitants. Second, a market influence index that, in addition to distance, incorporates population density and per capita income as variables that determine the potential demand in these markets or its economic importance. These variables are expected to capture the effect of agglomeration and purchasing power on land use decisions.

After grouping the municipalities that belong to the same metropolitan area, which can be treated as a single location for identifying the relevant market, we identified 107 markets with more than 50,000 inhabitants. Taking these markets as a reference, we calculate the geodesic distance of each UPA to the markets' centroids and identify the one that corresponds to the smallest distance. Table 3 presents the results obtained and describes how land uses vary depending on different distance intervals from the relevant market. It is observed that the percentage of the usable area increases with distance, as does the percentage in crop use. In contrast, the uses in pastures and infrastructure decrease. Although in part an artifact of the distance ranges we use, it is observed too that the number of UPA located at more than 80 kilometers from its closest market decreases drastically.

[2] See section 4 for details on the characterization of municipalities.

Table 3. Land use for different distance to market ranges.

Land percentage	Distance to market ranges			
	< 20 km	20-40 km	40-80 km	> 80 km
Usable land	67.36%	66.57%	70.12%	74.38%
Land in crops use	30.01%	32.52%	33.13%	43.53%
Land in pasture use	35.44%	33.00%	36.49%	30.22%
Agricultural infrastructure	1.24%	0.69%	0.34%	0.32%
Number of UPAs	644,976	771,395	699,947	113,407

Source: CAN 2014, authors' calculations.

To control for other variables that can determine land use, we integrate complementary information that allows for a better physical, spatial, and economic characterization of the UPA. For this, we use information from WorldClim.org, a database built by Fick and Hijmans (Fick & Hijmans, 2017), that contains information on elevation (meters above sea level), solar radiation (*kJ* per square meter and per day), the mean temperature, diurnal range of temperature variation, annual precipitation (liters per square meter), and precipitation seasonality (coefficient of variation) at a high level of spatial disaggregation. Considering the georeferencing of the UPA, information on the variables mentioned above is extracted from rasters with resolution levels of 1 km2. These rasters are constructed as the average of each variable for the period 1970-2000.

Additionally, we consider descriptive variables of soil quality characteristics for agricultural production taken from IIASA-FAO's agro-ecological zones (IIASA & FAO, 2012). In this case, the available data are rasters of approximately 30 km2 with information related to the workability of the soil, the availability and retention of nutrients, and rooting properties. Each variable is categorized into seven restriction levels: 1. No restrictions, 2. Moderate restrictions, 3. Severe restrictions, 4. Very restricted, 5. No soil, 6. Gelisol, 7. Body of water.

Finally, we consider variables at the municipal level obtained from different statistical operations carried out by the National Administrative Department of Statistics of Colombia (DANE, for its Spanish acronym). In particular, we include the municipal importance index built upon the municipality's participation in the departmental (state) economic activity and the value added generated by the municipality, both variables corresponding to 2014. Additionally, we add the multidimensional poverty index, the rate of economic dependency, and the informality rate, which are based on the 2018 National Population and Housing Census. Lastly, to control for the importance of agriculture in the region, the proportion of the value added of the primary sector at the municipal level is considered, according to regional statistics.

Table 4 shows the averages for the set of variables described above and explores the possible relationship of these characteristics with distance. For market characteristics, a negative association between population density and distance is observed, but this pattern does not hold for what concerns value added. For the UPA, the proportion of these with extensions of less than 1 ha decreases with distance, suggesting a decreasing fragmentation pattern. Also, there seems to be a negative relationship between elevation and distance to markets, which looks consistent with the fact that many of the cities in Colombia have been developed on the Andean mountain's ranges and consequently, much of the economic activity occurs in municipalities with a high average elevation. This relationship is also observed with other climatic variables such as solar radiation, temperature range, and the coefficient of precipitation variation. In contrast, it is observed that the UPA located closer to the markets are in places with lower average temperatures and lower precipitation levels.

Table 4. Characteristics of the UPA and municipalities for different distance to market ranges.

Variable		Distance to market ranges			
		< 20km	20-40 km	40-80 km	> 80 km
Market characteristics	Population density (ln)	5.92	5.69	5.58	4.33
	Value added (pp thousands, ln)	2.41	2.37	2.49	2.41
UPA Physical characteristics	Share of UPA < 1 ha	0.47	0.37	0.34	0.26
	Elevation	1,634.93	1,530.11	1,513.89	829.81
	Solar radiation	1,6782.28	1,6624.14	1,6529.90	1,5956.92
	Mean temperature	19.18	19.69	19.83	23.06
	Diurnal range temperature	9.77	9.74	9.71	9.05
	Annual precipitation	1,736.39	1,852.18	2,095.37	3,041.84
	Precipitation seasonality	43.95	43.31	45.52	42.04
Soil properties	Workability	1.92	1.97	2.04	1.59
	Availability of nutrients	2.15	2.34	2.49	2.78
	Retention of nutrients	1.79	1.81	1.93	2.14
	Rooting properties	1.80	1.94	2.03	1.59
Municipality characteristics	Importance index	4.23	5.40	5.87	5.79
	Value added (thousands, ln)	12.87	11.99	11.59	11.58
	Multidimensional poverty index	31.58	39.91	45.52	59.06
	Rate of dependency	35.76	39.65	43.72	49.99
	Informality rate	84.99	88.34	90.20	91.49
	Primary sector's share in VA	0.23	0.32	0.31	0.30

Source: Authors' calculations.

Soil characteristics are a crucial factor for agricultural productivity and therefore constitute a significant parameter to determine land use. It is observed that for the UPA located at up to 80 kilometers from the reference market, soil workability, availability of nutrients and rooting properties deteriorate with distance, while for UPA in faraway areas (more than 80 kilometers) they improve for soil workability and rooting properties, but not for retention of nutrients. Meanwhile, availability of nutrients deteriorates with distance. Regarding municipal characteristics, it is observed that poverty, dependency, and informality increase with distance, while importance and economic activity decrease (a lower importance index implies greater economic relevance of the municipality). As for the share of the primary sector in the local economy there is a divide between the UPA located the closest to their reference market and the rest of them, as the share jumps from 23% to around 31%.

As mentioned above, the market influence index includes the population density and the income level of the reference market. While an agglomeration effect arises because of the relationship between distance and population density (the lower the distance, the greater the population density), there seems to be no predetermined pattern between distance and income. On the other hand, the size of the UPA also appears to have a strong correlation with distance, as illustrated by the behavior of the share of UPA with areas under one hectare that, as mentioned above, decreases with distance.

To quantify the extent to which both market access and influence determine land use, we estimate regression models for the latter in which, additionally to controlling for the factors mentioned above, we include different functions of the distance to the reference market that represent either an index of access or the index of market influence. This corresponds to a specification such as the following:

$$y_{ij} = \alpha + \beta f\left(dist, Z_{ij}\right) + \delta' X_{ij} + \theta' W_j + \varepsilon_{ij}$$

where y_{ij} is a specific land use index of the UPA i located in the municipality j. $f(\cdot)$ is a known function of distance, representing an index of market access or influence, which depends on other auxiliary variables Z_{ij}, e.g., population density. Therefore, the parameter of interest is β. X_{ij} and W_j are the control variables mentioned above at the UPA and municipality levels.

Considering the indices proposed by Verburg et al (Verburg et al., 2011), the access index is defined as a normalized measurement given by:

$$AI_{ik} = \frac{Access_{ik}}{\sum_{i=1}^{n} Access_{ik}}$$

where k denotes the reference market, set at the urban location with the least physical distance to the UPA *i*. Concomitantly, the measure of access is built through the function:

$$Access_{ik} = \exp\left(-\frac{d_{ik}^2}{\vartheta}\right)$$

where d_{ik} is the distance between the UPA and the reference market and $\vartheta = 2d_*^2$, with $d_* = 80\ km$. The parameter ϑ determines an inflection point in the access curve from which accessibility decreases rapidly. The 80 km threshold approximately corresponds to the distance value for the 95th percentile of UPA in the data and is reasonable given the Colombian geography. However, we do sensitivity analysis of the results to changes in it.

The market influence index combines the normalized measure of access with population density and income level to consider the importance of the market. Therefore:

$$MII_{ik} = AI_{ik} \times Dens_k \times VApc_k$$

where $Dens_k$ represents the population density of the reference market, and $VApc_k$ is a measure of per-capita wealth, or in this case, the level of value added per capita. These variables are taken in logarithms. In this way, market access along with the demand potential of the market are weighted. The index makes it possible to capture the heterogeneity between markets of similar size but with different economic conditions, which can have a differential effect on land use decisions.

4. Characterizing market access in Colombia.

Considering the previous definitions, the access index and the market influence index are estimated, both mediated by the access function that by construction takes values in the interval between 0 and 1. Table 5 shows the average value for the different types of land use by level of market influence measured in quartiles. The patterns observed are alike those obtained in relation to distance, i.e., as the market influence decreases, the usable area and the area used for crops decrease, while the area used for pasture increases. However, in the case of land used for holding infrastructure, the pattern shows oscillations with no clear trend but low use levels.

Table 5. Land use by quartiles of the market influence index.

Land percentage	Q1	Q2	Q3	Q4
Usable land	71.15%	71.23%	64.82%	66.04%
Land in crops use	40.57%	38.20%	29.15%	22.26%
Land in pasture use	29.14%	32.18%	34.68%	42.65%
Agricultural infrastructure	0.85%	0.59%	0.68%	0.76%
Number of UPAs	557,432	557,431	557,436	557,426

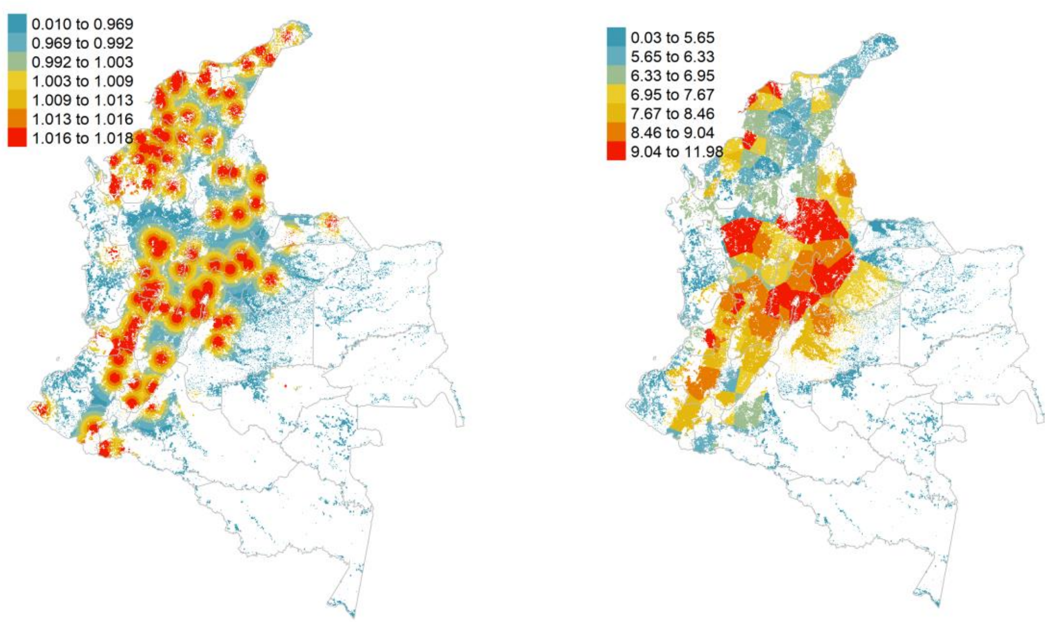
Source: Authors' calculations.

The spatial component of market access is crucial as in Colombia there is significant heterogeneity at the regional level. Figure 1, which displays the results obtained for the market access and market influence indices, shows a high centrality around the Andean zone and the Caribbean region, while the Southeastern (Orinoco and Amazonian regions) and Pacific regions present an evident lack of market access. It is worth noting that when comparing the access index and the market influence index there is an important difference between them as the economic importance of the markets located in there is lower.

Figure 1. Access to reference markets.

a. Access index

b. Market influence index



Source: Authors' calculations.

Relevant insights emerge when looking at the specific differences in land use, with clear spatial patterns that show that in general the Andean zones have lower levels of land usability, while in the Pacific and in the East of the country there is a higher percentage of usable land (as shown in Figure 2). This contrasts with the agricultural use, mainly for crops. A more intensive use of the usable area for crops is observed in the Andes and the Pacific, suggesting a certain level of specialization in agricultural activities since a higher use in pastures is found in eastern Colombia.

5. Results.

We run the specification presented above for the share of usable land as the dependent variable, against both the market access and the market influence indexes (alternatively). The results are presented in the first three columns of Table 6 for the market access index and in the last three for the market influence index. In each case, the first column shows the results for a specification including only population and value added of the reference market as controls, while in the second the physical characteristics of the UPA are added as controls, and in the third soil characteristics and municipal characteristics are added too.

As shown, both market access and market influence display a negative relationship with the share of usable land whose magnitude changes moderately as more controls are included. The implication is that as market access or market influence increases, the share of usable land decreases (more so in the case of market access), so, on average, the extent of land use is lower near cities or towns. As in the second and third columns we control for the size of the UPA (and it yields a significant and negative coefficient), the amount of usable land depends on land suitability given that, for instance, the presence of barren land limits it from a physical stance or the presence of natural forests may limit it from a regulatory perspective. It also depends on investment as the soil can be built with appropriate interventions (at a cost) or as more land is cleared for production when there are no stringent physical or regulatory constraints. In this sense the result indicates that the intensity and the extent of land use for productive ends decreases the nearer the UPA is located to the reference market.

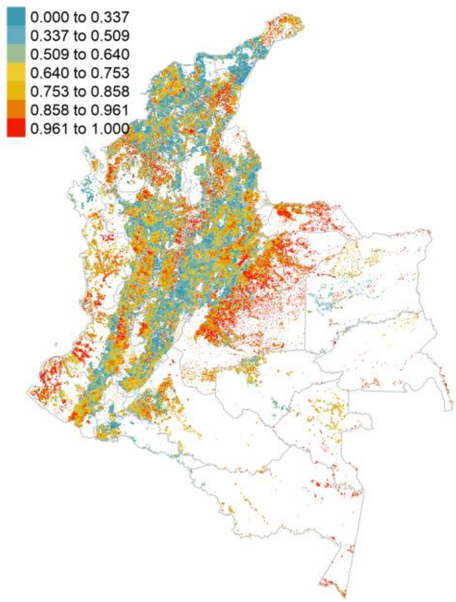
Given the share of usable land, we now explore the situation with respect to its main uses (i.e., how is it allocated to crops, livestock, both, and infrastructure), searching for potential differences among them. Table 7 reports, for each type of use, the results when the full set of controls is used, and market access is the measure for the reference market.[3] As follows from there, the share of crop, pasture, and mixed uses decreases with the proximity to the market, the effect being of a larger magnitude in the cases of mixed uses and pastures. In contrast, but with a small magnitude, the effect of market proximity on land use for infrastructure is positive, a result that may relate to the relative economic return that this type of investment has in the proximity to markets. Therefore, with respect to the general pattern there are no significant differences in the behavior of productive land use other than that the decline in the share of crop use is significantly lower than for pasture. The results when market influence is used instead of market access are similar in sign and, again, of a lower magnitude. However, in the case of infrastructure the relevant coefficient is negative

[3] Choosing this specification as the base for presenting the results is arbitrary as, for expository purposes, there are no practical differences arising from using any of the two variables.

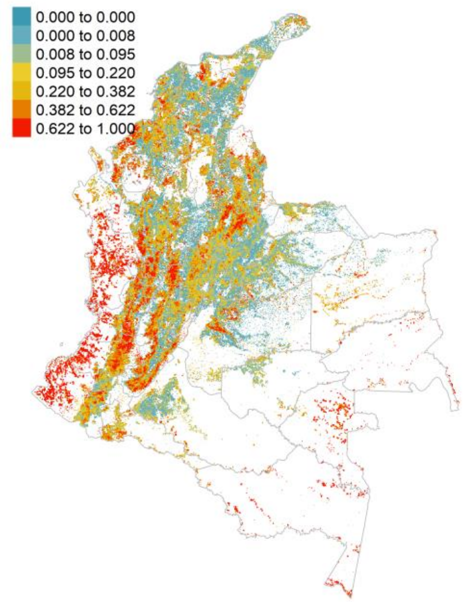
instead of positive, generating ambiguity on the direction of the relationship (see Appendix Table A. 1).

Figure 2. Land uses.

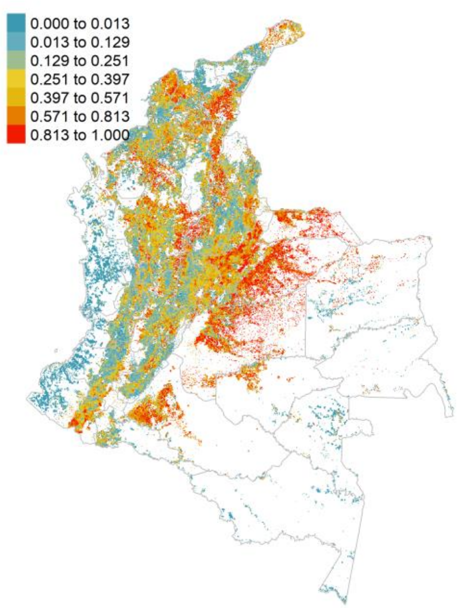
a. Usable land



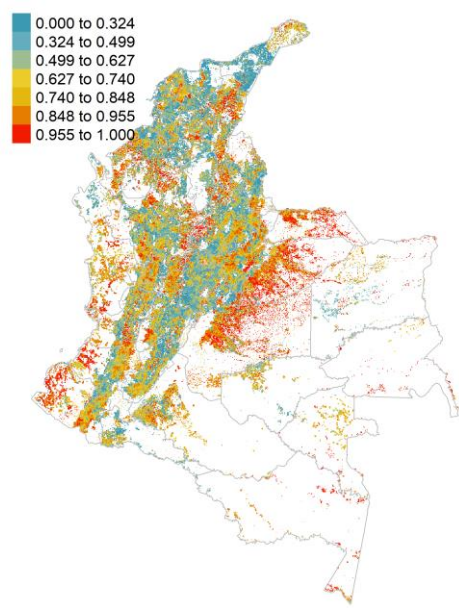
b. Crop use



c. Pasture use and others



d. Mixed use



Source: Authors' calculations.

Table 6. Regression results for the share of usable land.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Market access	-0.0674***	-0.0460***	-0.0464***			
	(0.002)	(0.002)	(0.002)			
Market influence				-0.0146***	-0.0173***	-0.0176***
				(0.000)	(0.000)	(0.000)
Market population	-0.0203***	-0.0271***	-0.0254***			
(logs)	(0.000)	(0.000)	(0.000)			
Market value added	0.0005	-0.0048***	-0.0078***			
(logs)	(0.001)	(0.001)	(0.001)			
Constant	0.8637***	2.6126***	1.3026***	0.8020***	2.6978***	1.3663***
	(0.002)	(0.042)	(0.051)	(0.001)	(0.042)	(0.050)
Physical controls	No	Yes	Yes	No	Yes	Yes
Soil controls	No	No	Yes	No	No	Yes
Municipality controls	No	No	Yes	No	No	Yes
Observations	2,229,725	2,229,725	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.006	0.022	0.024	0.006	0.021	0.024

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations.

Table 7. Regression results for the share of crop, pasture, mixed, and infrastructure uses.

	(1)	(2)	(3)	(4)
VARIABLES	Crop use	Pasture use	Mixed use	Infrastructure
Market access	-0.0094***	-0.0378***	-0.0472***	0.0004
	(0.002)	(0.002)	(0.002)	(0.000)
Market population	-0.0010***	-0.0242***	-0.0252***	-0.0003***
(logs)	(0.000)	(0.000)	(0.000)	(0.000)
Market value added	-0.0435***	0.0394***	-0.0041***	-0.0025***
(logs)	(0.001)	(0.001)	(0.001)	(0.000)
Constant	-1.2147***	2.2402***	1.0255***	0.1707***
	(0.053)	(0.052)	(0.051)	(0.007)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.110	0.118	0.029	0.027

All regressions include physical, soil and municipality controls.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations.

As a test of these results in a somewhat different direction, we use two additional variables related to the organization of production as dependent variables. On the one hand we use two measures of whether the UPA engages in self-consumption, either if it is for production purposes (like keeping some output for use as seeds, for example) or for direct consumption. On the other hand, we use a measure of family labor usage to reflect the extent to which the UPA is characterized as a family farm. Specifically, we proxy for family farming through the ratio of the number of family workers working at the UPA to the total number of workers (permanent and temporary). The regressions for these two variables show a negative relationship in both cases either when market access or market influence are used. Interestingly, the magnitude of the coefficients is considerably higher than for usable land, suggesting steeper declines for self-consumption and family farming as the UPA locate closer to the markets. This result is expected as a greater proximity to the market implies a potentially higher engagement in economic networks, as transaction costs decrease, be them related to the marketing of output, the purchase of final consumption items (lowering the need for self-consumption), or entry into labor markets of greater scope and deepness. (See Appendix Table A. 2)

So far, we find an average relationship between market access and market influence with the pattern of rural land use that indicates that the extent and intensity of productive land use decreases as the farms locate nearest to markets, the effect being greater for pasture and mixed (crops and pastures) uses. This is consistent with the conceptual framework discussed above, as it concerns the expected behavior in peri-urban areas, but not for the core agricultural area nor necessarily for the faraway areas. Hence, now we explore this issue by considering the type of municipality the reference market is. For this we use a typology of municipalities that was specifically constructed to reflect the rurality of the municipalities in the context of the Colombian system of cities to better characterize its gradation.

The typology establishes four categories of municipalities. Cities and agglomerations, which comprise municipalities with commuting patterns with other municipalities involving at least 10% of the work force, more than 100,000 inhabitants in the urban core, and municipalities with less than 100,000 that are of strategic importance in terms of services delivery. Intermediate municipalities, with populations between 25,000 and 100,000 people in the urban core, that are of regional importance, or municipalities with lower population levels but with high density (more than 10 inhabitants per square kilometer). Rural municipalities, with populations lower than 25,000 inhabitants in the urban core and intermediate population densities (between 10 and 100 inhabitants per square kilometer). Lastly, dispersed rural municipalities, comprising municipalities and conglomerates not incorporated as such, with the lowest population and density levels in the system (DNP, 2014).

With this information we include dummy variables for the type of municipality and an interaction between market access or influence and the type of municipality. Only three categories of municipalities are considered as our cut off for selecting the reference market is 50,000 inhabitants (for the whole municipality, i.e., including the population in the urban core and in rural areas), a criterium that excludes several intermediate, rural and dispersed rural municipalities, but preserves all that belong to the cities and agglomerations category. In this way, there are 64 reference markets corresponding to agglomerations, 37 intermediate cities and 6 rural municipalities. The results from these regressions are reported in Table 8 for the case of market access as the measure for the reference market.

Table 8. Regression results for the shares of usable land, crop, pasture, and mixed uses with municipality type interactions.

VARIABLES	(1) Usable land	(2) Crop use	(3) Pasture use	(4) Mixed use
Market access*city	-0.1067***	-0.0483***	-0.0580***	-0.1062***
	(0.003)	(0.003)	(0.003)	(0.003)
Market access*intermediate	0.0840***	0.2292***	-0.1431***	0.0861***
	(0.004)	(0.004)	(0.004)	(0.004)
Market access*rural	0.0963***	-0.2390***	0.3134***	0.0744***
	(0.004)	(0.005)	(0.004)	(0.004)
Intermediate munic.	-0.2330***	-0.3405***	0.1074***	-0.2331***
	(0.004)	(0.005)	(0.004)	(0.004)
Rural munic.	-0.1901***	-0.0699***	-0.1088***	-0.1787***
	(0.004)	(0.004)	(0.004)	(0.004)
Constant	0.6632***	-2.3838***	2.7901***	0.4063***
	(0.052)	(0.055)	(0.054)	(0.053)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.027	0.118	0.124	0.031

All regressions include physical, soil and municipality controls.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations.

As expected, the results qualify the ones discussed above in several ways. As it respects the share of usable land, its average is larger in the proximity to cities, lowers significantly in the case of intermediate municipalities, and lowers a bit less in the case of rural municipalities. On the other hand, as one compares between municipality types (looking at the coefficients for the interaction terms), as market access increases in the vicinity of cities the amount of usable land decreases significantly, while in the case of UPA in the vicinity of intermediate municipalities it increases. The same happens for increased market access for the UPA in the vicinity of rural municipalities where the effect is marginally higher than for the UPA in the vicinity of intermediate municipalities. The results obtained when market influence is used instead of market access, largely validate the ones just discussed. They are presented in Table A. 3 in the appendix.

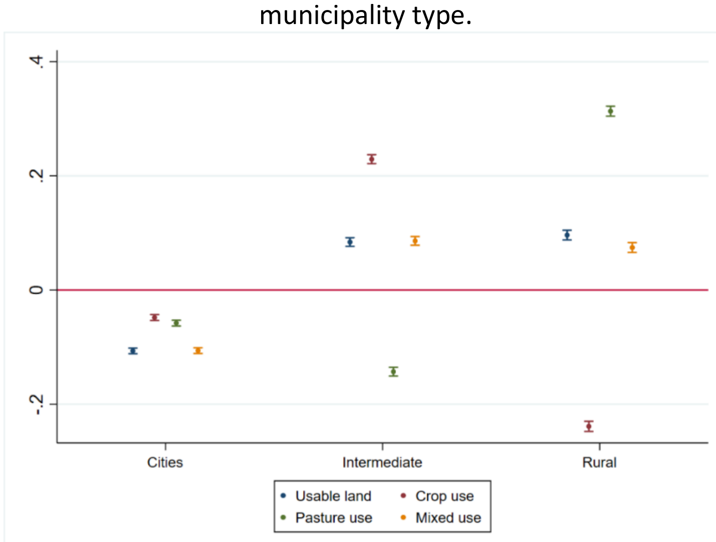
As such, the narrative coming out from these results indicates that, in average, the extent and intensity of the agricultural use of land is higher for the UPA closer to cities and decreases for the UPA located closer to intermediate and rural municipalities, implying that the economic activity stemming from the UPA correlates with the size and complexity of the surrounding economy. This validates to a great extent the conceptual framework provided by the qualified von Thünen model. Within peri-urban areas (vicinity of cities), as opposed to what happens in other areas, better access leads to less agricultural activity as there is greater competition for land use with non-agricultural activities. Within the core agricultural area (vicinity of intermediate municipalities), as opposed to other areas, better access leads to greater agricultural activity, and within faraway areas (vicinity of rural municipalities), as opposed to other areas, there is also an increase in agricultural activity as access improves.

With respect to the land shares used for crop, pasture or mixed use, the outcome is as follows. For crop use, its average share significantly lowers for the UPA in the vicinity of intermediate municipalities, as compared to UPA in the vicinity of cities, and does the same but to a lesser degree in the vicinity of rural municipalities. Additionally, improvements in market access for the UPA in the vicinity of cities lead to a decrease in the share of land used for crops, while they lead to a significant increase in this share for the UPA in the vicinity of intermediate municipalities, and to significant decreases for the UPA in the vicinity of rural municipalities. Therefore, the main differences between the share of land devoted to crops and the share of usable land are that the magnitude of the coefficients vary and that, contrary to what happens for usable land, in the case of the UPA in the vicinity of rural municipalities, the share of land used for crops decreases significantly as market access improves.

The behavior found for the share of land in pastures presents three particularities. First, the average share for the UPA in the vicinity of intermediate municipalities is significantly higher than for those in the vicinity of cities. Second, the average share for the UPA in the vicinity of rural municipalities is significantly lower than for those in the vicinity of cities. And third, improvements in market access lead to decreases in the share of pastures for the UPA in the vicinity of intermediate municipalities and to increases for the UPA in the vicinity of rural municipalities. Lastly, in the case of the share of land devoted to mixed use the observed pattern is like that found for the share of usable land, both in direction of the relationships and in their magnitude.

Consequently, as market access improves, within municipal categories the share of land in crops decreases in cities, increases in intermediate municipalities, and decreases in rural municipalities. For pasture use, the share decreases for cities and intermediate municipalities while it increases for rural municipalities. And, for mixed use the average increases with rurality. This pattern can be seen in Figure 3, where there are shown the values of the regression coefficients and their confidence intervals for the interaction term between market access and market type, as we move from cities to intermediate to rural municipalities.

Figure 3. Coefficient values for the share of usable land, crop, pasture, and mixed uses by municipality type.



Source: authors' calculations.

6. Robustness of the results.

There are two variables whose definition may impinge upon the above results. One is the distance threshold of 80 kilometers for computing the market access and market influence measures, the other is the population threshold of 50,000 inhabitants for selecting the set of markets. Correspondingly, we run a set of regressions using both market access and market influence as the measure for the reference market while varying the distance threshold to assess its impact on the coefficient for them. The results of the coefficients on market access and market influence are shown in Table 9 for the cases of the shares of usable land, crops, and pasture as independent variables. As follows from there, the coefficients for usable land exhibit the same signs as the distance threshold is increased from 20 to 150 kilometers showing the stability of the negative relationship between distance and the share of usable land. In the case of the share of land in crops, it is found that as distance increases the sign of the coefficient switches from positive to negative indicating that at small distances this share grows but that as distance increases it shrinks. In contrast, results for the share of land devoted to pasture show the opposite behavior when market access is the measure of the market (moving from negative when distances are small to positive when they grow larger), but, when market influence is the measure of the market it shows negative coefficients irrespective of the distance.

Table 9. Regression results for market access as the threshold distance varies.

	Market access			Market influence		
Distance (Kms)	Usable land	Crop use	Pasture use	Usable land	Crop use	Pasture use
20	-0.0008**	0.0072***	-0.0095***	-0.0011***	0.0004***	-0.0017***
30	-0.0114***	0.0094***	-0.0224***	-0.0035***	0.0002***	-0.0038***
40	-0.0213***	0.0116***	-0.0346***	-0.0063***	-0.0002**	-0.0062***
50	-0.0306***	0.0119***	-0.0440***	-0.0095***	-0.0010***	-0.0085***
60	-0.0383***	0.0088***	-0.0485***	-0.0127***	-0.0021***	-0.0105***
70	-0.0438***	0.0018	-0.0466***	-0.0155***	-0.0034***	-0.0119***
80	-0.0464***	-0.0094***	-0.0378***	-0.0176***	-0.0046***	-0.0127***
90	-0.0466***	-0.0240***	-0.0231***	-0.0191***	-0.0057***	-0.0130***
100	-0.0449***	-0.0410***	-0.0043	-0.0202***	-0.0066***	-0.0130***
110	-0.0422***	-0.0593***	0.0169***	-0.0208***	-0.0073***	-0.0129***
120	-0.0392***	-0.0781***	0.0389***	-0.0212***	-0.0079***	-0.0127***
130	-0.0363***	-0.0968***	0.0605***	-0.0215***	-0.0084***	-0.0125***
140	-0.0339***	-0.1149***	0.0812***	-0.0217***	-0.0087***	-0.0123***
150	-0.0321***	-0.1323***	0.1005***	-0.0218***	-0.0090***	-0.0122***

Source: authors' calculations.

These results could be rationalized in several ways. For instance by arguing that in places closer to the urban core the remaining agricultural activity must be profitable enough to compete with non-agricultural uses and is therefore less sensitive to changes in market access, as happens to cut flower cultivation for export in the vicinity of Colombia´s capital city or by arguing that the presence of a large subset of cities and agglomerations in our set of markets induces the showing of an always negative coefficient for pasture use when market influence is the market measure. However, our interest here is not to provide such a rationalization, but to note that they introduce a note of caution for our results for these two variables by suggesting the potential existence of a distance threshold for the decay of the market measure that leads to regime switching for the share of land in crops.

Therefore, as far as usable land (and mixed use, although not shown here) is concerned, we reaffirm the existence of a stable inverse relationship with market access and market influence, as discussed above, while in the cases of crops and pasture there seems to be different dynamics. Changes in the distance threshold suggest that the relationship between market access and the share of land used for crops changes from negative to positive, while in the case of the share of land in pasture it remains negative. As such, the behavior of these two variables may be dependent on how far away from urban centers their pull begins to fade.

For the second robustness analysis, related to the size of the reference market, markets from 25,000 inhabitants are considered, corresponding to 278 markets. With respect to the benchmark estimation, they are composed of a higher percentage of markets in intermediate municipalities (113 markets). This is an important fact since, as was found in the heterogeneous analyses, UPA in the vicinity of markets in intermediate municipalities would increase crop use in the face of increased market access. Estimates using benchmark markets set at 25,000 inhabitants show greater magnitudes in the reduction of usable area, pasture, and mixed use. Unlike the initial estimates, in this case better market access translates in higher cropland use. These results are consistent with our benchmark results and with the fact that the proximity of intermediate markets maintains an intensive effect on core agriculture (Table A. 4 in the appendix). A similar exercise with a population cut of 100,000 inhabitants validates the negative relationship between market access and the share of usable land and mixed use, while generates a positive coefficient for the share of land in crops and a negative one for the share of land in pasture. In this case, there are a total of 52 markets, of which 48 correspond to cities and agglomerations. Additionally, 93.2% of the UPA have this type of market as the closest. This implies that in this specification, the effect of proximity to large markets prevails, reinforcing the general result discussed above.

7. Final discussion.

Using a rich dataset characterizing Colombian agricultural units, we examine the relationship between market access and market influence and the intensity of land use for productive purposes as instrumented as the share of usable land with respect to the total area of the production unit. We find that there is a stable and significant negative relationship between the two, meaning that as market access and market influence improve there is a decline in the share of usable land in average, reflecting a lower extent an intensity of agricultural activity. Furthermore, we explore the heterogenous effects that the typology of the market of reference has on these results and find that this relationship changes with the type of municipality. Production units located in the vicinity of cities and agglomerations, show a decline in the share of usable land as market access increases, while production units located in the vicinity of intermediate and rural municipalities show increases when the measure of the market is market access, while it decreases in all cases when the measure is market influence (the reason for the difference in behavior is explored with the robustness checks).

In view of the results arising from using market access as the measure of the market and as the average share of usable land is larger in production units located in the vicinity of cities and agglomerations, these relationships point in the direction of a relative closing in the gap for the extent and intensity of agricultural activity for production units located in the vicinity of the three municipality types, improving activity levels for production units related to the more rural markets. These results vindicate the policy push toward the betterment of the network of rural roads mentioned above. However, when the measure of the market is market influence improvements in market influence (greater proximity to more dense and valued markets) would amplify the existing gap between units located in the vicinity of cities and agglomerations and the ones located in the vicinity of the other two municipality types. As discussed, the market influence index is a composite of market access, population density and the income level of the reference market. The data shows an agglomeration effect arising because of the relationship between distance and population density (the lower the distance, the greater the population density), but there is no predetermined pattern between distance and income, so it is likely that the difference in the results is mainly due to population density. Therefore, in this case the policy drive toward better rural roads should consider other factors, to which we refer below.

The results also point to a series of warnings in terms of the processes that may take place because of the desired improvement in market access or market influence through a better and more widespread network of rural roads. For instance, the results suggest the potential for a weakening of family agriculture as we find an inverse relationship between the share of family labor used in the production unit and both market access and market influence and of the preservation of traditional knowledge as declines in self-consumption (possibly partly related to the upkeeping of traditional seeds, for instance) are also linked to better market access and market influence. These potential shortcomings may be managed through additional policy interventions as is already happening in the case of the preservation of peasant agriculture by means of the establishment of peasant reserve zones in the country (Ministerio de Agricultura y Desarrollo Rural, n.d.).

Other caveats may be better addressed through focalization and research aimed at an improved understanding of the dynamics of land use change that increases in market access and market influence may induce. With respect to the first, the implications of spatial heterogeneity are important. The share of usable land decreases with market access and market influence improvements for production units in the vicinity of cities and agglomerations. However, among them, more than 57% of production units are located in rural municipalities and more than 26% in intermediate municipalities. As such, for 65% of the total production units located in rural municipalities and 57% of those located in intermediate municipalities, better market access or market influence would likely translate in lower agricultural activity (other factors equal). If the policy objective is to enhance agricultural activity and simultaneously improve living conditions in rural areas, indiscriminate improvements in market access for production units in the area of influence of cities and agglomerations may not be the better way through.

Conversely, improvements in market access for production units in the vicinity of rural municipalities lead to increases in the share of usable land. In this case, almost 86% of production units are located in rural municipalities which is positive for both, the purpose of increasing agricultural activity and that of improving living conditions. Nonetheless, production units located in rural municipalities and related to rural municipalities as their market of reference show the highest level for the share of usable land (0.782), and therefore the expected increase in the use of land may be detrimental from other viewpoints. For instance, there may be greater pressure for forest clearing and a lowering of the supply of environmental services and conservation in general. When the measure of the market is market influence, the above does not hold as the effect of greater market influence is always a decrease in the share of usable land.

Regarding the need for a better understanding of the dynamics of land use change as market access improves, perhaps the best example is the behavior that our results capture in terms of changes in the share of land devoted to crops. First, it seems to switch direction depending on the way the pull of the markets fade. If it fades rapidly, at distances less of around 80 kilometers the share of land used for crops increases with better market access, but if it fades at larger distances it decreases (probably at an increasing rate). In view of this, it is relevant for land use policymaking to understand and better determine these dynamics as their implications are manifold.

To illustrate, production units located in rural municipalities show the lowest share of land devoted to crops and the higher share of land devoted to pasture. If better market access means higher shares of land for crops and lower shares for pasture, these production units would diverge from the current land use pattern, while if the opposite is true, they would reinforce it. As the prevalent technology for (bovine) livestock activities is highly intensive in land use, has low productivity, and the activity is largely located in lands not suitable for its development (UPRA, 2021), a reinforcement of this land use pattern could have deleterious effects for land conservation, emissions of greenhouse gases, and forest conservation, for instance.

Similar observations can be made when the measure of the market is market influence with the difference that the switching in the sign of the coefficient occurs at a different threshold distance (around 40 kilometers for the share of crops). In any case, for our standard result (with a population threshold of 50,000 inhabitants and a threshold distance of 80 kilometers) the effects arising when using market access or market influence as the measure of the market are the same as in both cases the share of crops decreases and that of pasture increases for units located in the vicinity of rural municipalities.

In all, our results back the importance of developing a place-based approach to land policy and rural development in Colombia, at least in what refers to rural connectivity, in a way that allows for blending the stylized facts coming out from our results with the nuances that arise from the specific conditions determined by location as illustrated above. They also provide backing for the validity of the qualified von Thünen model as a useful guide for analyzing the location patterns of agricultural activity.

References

Aggarwal, S., Giera, B., Jeong, D., Robinson, J., & Spearot, A. (2022). Market Access, Trade Costs, and Technology Adoption: Evidence from Northern Tanzania: Evidence from Northern Tanzania. *The Review of Economics and Statistics*, 1–45. http://www.nber.org/papers/w25253

Ahmed, U. I., Ying, L., Bashir, M. K., Abid, M., & Zulfiqar, F. (2017). Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PLOS ONE*, *12*(10), e0185466. https://doi.org/10.1371/JOURNAL.PONE.0185466

Alphan, H. (2018). Analysis of road development and associated agricultural land use change. Environmental Monitoring and Assessment, 190(1). https://doi.org/10.1007/s10661-017-6379-3

Armenteras, D., Rudas, G., Rodriguez, N., Sua, S., & Romero, M. (2006). Patterns and causes of deforestation in the Colombian Amazon. *Ecological Indicators*, *6*(2), 353–368. https://doi.org/10.1016/j.ecolind.2005.03.014

Banco Mundial. (2004). *Colombia : Land policy in transition* (Issue 27942). http://documents.worldbank.org/curated/en/2004/10/5401837/colombia-land-policy-transition%5Cnhttp://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2004/11/23/000090341_20041123153005/Rendered/PDF/307340ENGLISH0en0breve0550CO0Land0Policy.p

Braimoh, A. K., & Onishi, T. (2007). Spatial determinants of urban land use change in Lagos, Nigeria. Land Use Policy, 24(2), 502–515. https://doi.org/10.1016/j.landusepol.2006.09.001

Binswanger-Mkhize, H. P., & Savastano, S. (2017). Agricultural intensification: The status in six African countries. *Food Policy*, *67*, 26–40. https://doi.org/10.1016/j.foodpol.2016.09.021

Buckmaster, A., Alwang, J., Peterson, E., & Rivera, M. (2014). Going the Distance: How Does Market Access Affect Demand for IPM Packages? *Journal of Integrated Pest Management*, *5*(1), 1–7. https://doi.org/10.1603/ipm13013

Castella, J. C., Manh, P. H., Kam, S. P., Villano, L., & Tronche, N. R. (2005). Analysis of village accessibility and its impact on land use dynamics in a mountainous province of northern Vietnam. *Applied Geography*, *25*(4), 308–326. https://doi.org/10.1016/j.apgeog.2005.07.003

Castella, J. C., & Phaipasith, S. (2021). Rural roads are paving the way for land-use intensification in the uplands of Laos. *Land*, *10*(3). https://doi.org/10.3390/land10030330

Castella, J.-C., Tronche, N. R., Nguyen, V., Castella, J. C., & Tronche, N. R. (2002). *Landscape changes in Cho Don District during the doi moi era (1990-2000) and their implications for sustainable natural resource management in Viet Nam's mountainous provinces*.

Chamberlin, J., & Jayne, T. S. (2013). Unpacking the Meaning of "Market Access": Evidence from Rural Kenya. *World Development*, *41*(1), 245–264. https://doi.org/10.1016/j.worlddev.2012.06.004

Chan, J. (2022). Farming output, concentration, and market access: Evidence from the 19th-century American railroad expansion. Journal of Development Economics, 157. https://doi.org/10.1016/j.jdeveco.2022.102878

Chomitz, K. M., & Gray, D. A. (1996). Roads, land use, and deforestation: a spatial model applied to Belize. *World Bank Economic Review*, *10*(3), 487–512. https://doi.org/10.1093/wber/10.3.487

DANE. (2016). *Metodología General Tercer Censo Nacional Agropecuario*.

DNP. (2014). Definición de categorías de ruralidad (Informe temático para la Misión para la Transformación del Campo).

DNP. (2015). *El campo colombiano: un camino hacia el bienestar y la paz. Misión para la Transformación del Campo*. Departamento Nacional de Planeación. https://colaboracion.dnp.gov.co/CDT/Agriculturapecuarioforestal y pesca/El CAMPO COLOMBIANO UN CAMINIO HACIA EL BIENESTAR Y LA PAZ MTC.pdf

Donaldson, D., & Hornbeck, R. (2016). Railroads and American Economic Growth: A “Market Access” Approach. The Quarterly Journal of Economics, 131(2), 799–858. https://doi.org/10.1093/QJE/QJW002

Econometría Consultores. (2014). Dinámicas de uso de tierras para la Agricultura y el Comportamiento de los Precios del Suelo Rural: Resultados, conclusiones y recomendaciones de política. In *Mision Para la Transformacion del Campo* (p. 93). Colombian National Planning Department.

Etter, A., McAlpine, C., Phinn, S., Pullar, D., & Possingham, H. (2006). Unplanned land clearing of Colombian rainforests: Spreading like disease? *Landscape and Urban Planning*, *77*(3), 240–254. https://doi.org/10.1016/j.landurbplan.2005.03.002

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/JOC.5086

Gáfaro, M., & Pellegrina, H. S. (2022). Trade, farmers’ heterogeneity, and agricultural productivity: Evidence from Colombia. *Journal of International Economics*, *137*, 103598.

Gani, B. S., & Adeoti, A. I. (2011). *Analysis of Market Participation and Rural Poverty among Farmers in Northern Part of Taraba State, Nigeria*.

Gebresilasse, M. (2023). Rural roads, agricultural extension, and productivity. *Journal of Development Economics*, 103048.

Geist, H., McConnell, W., Lambin, E. F., Moran, E., Alves, D., & Rudel, T. (2008). Causes and Trajectories of Land-Use/Cover Change. In *Land-Use and Land-Cover Change*. https://doi.org/10.1007/3-540-32202-7_3

Hettig, E., Lay, J., & Sipangule, K. (2015). Drivers of households’ land-use decisions-A critical review of micro-level studies in tropical regions. http://resolver.sub.uni-goettingen.de/purl/?webdoc-3959

Hugo, S., Squalli, J., & Wilson, K. (2006). *What Explains Market Access?*

IIASA, & FAO. (2012). *Global Agro-ecological Zones (GAEZ v3.0)* (p. 196). FAO.

Kamara, A. B. (2004). The impact of market access on input use and agricultural productivity: evidence from machakos district, Kenya (Vol. 43, Issue 2).

Katungi, Enid, Daniela Horna, S. Gebeyehu, and L. Sperling. "Market access, intensification and productivity of common bean in Ethiopia: A microeconomic analysis." *African Journal of Agricultural Research* 6, no. 2 (2011): 476-487.

Keys, E., & McConnell, W. J. (2005). Global change and the intensification of agriculture in the tropics. *Global Environmental Change*, *15*(4), 320–337. https://doi.org/10.1016/J.GLOENVCHA.2005.04.004

Kiprono, P., & Matsumoto, T. (2018). Roads and farming: the effect of infrastructure improvement on agricultural intensification in South-Western Kenya. *Agrekon*, *57*(3-4), 198-220.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., … Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269. https://doi.org/10.1016/S0959-3780(01)00007-3

Liang, E. P. (1981). Market accessibility and agricultural development in prewar China. *Economic Development and Cultural Change*, *30*(1), 77-105.

Lubowski, R. N., Bucholtz, S., Claassen, R., Roberts, M. J., Cooper, J. C., Gueorguieva, A., & Johansson, R. (2006). *Environmental Effects of Agricultural Land-Use Change United States Department of Agriculture The Role of Economics and Policy*. www.ers.usda.gov

Ministerio de Agricultura y Desarrollo Rural. (2018). *Identificación general de la frontera agrícola en Colombia. Escala 1:100.00*. https://www.minagricultura.gov.co/Normatividad/Projects_Documents/IDENTIFICACION GENERAL DE LA FRONTERA .pdf

Ministerio de Agricultura y Desarrollo Rural. (n.d.). *Zonas de reserva campesina*. Retrieved February 27, 2023, from https://www.minagricultura.gov.co/Normatividad/Paginas/Decreto-1071-2015/Zonas-de-reserva-campesina.aspx

Minten, B. (1999). Infrastructure, market access, and agricultural prices: Evidence from Madagascar. In *MSSD Discussion paper/ IFPRI* (Issue 26).

Minten, B., & Kyle, S. (1999). The effect of distance and road quality on food collection, marketing margins, and traders' wages: Evidence from the former Zaire. *Journal of Development Economics*, *60*(2), 467–495. https://doi.org/10.1016/S0304-3878(99)00049-8

Morando, B. (2021). Market access and inefficient cropping patterns in Uganda.

Müller, D., & Sikor, T. (2006). Effects of postsocialist reforms on land cover and land use in South-Eastern Albania. *Applied Geography*, *26*(3–4), 175–191. https://doi.org/10.1016/J.APGEOG.2006.09.002

Nelson, G., de Pinto, A., Harris, V., & Stone, S. (2004). Land use and road improvements: A spatial perspective. International Regional Science Review, 27(3), 297–325. https://doi.org/10.1177/0160017604266028

Neumann, K., Verburg, P. H., Stehfest, E., & Müller, C. (2010). The yield gap of global grain production: A spatial analysis. *Agricultural Systems*, *103*(5), 316–326. https://doi.org/10.1016/J.AGSY.2010.02.004

O'Kelly, M., & Bryan, D. (1996). Agricultural location theory: Von Thünen's contribution to economic geography. *Progress in Human Geography*, *20*(4), 457–475. https://doi.org/10.1177/030913259602000402

OECD. (2009). Farmland Conversion: The Spatial Dimension of Agricultural and Land Use Policies. In *Farmland Conversion*. https://doi.org/10.1787/ae50672e-en

OECD. (2022a). Agricultural Policy Monitoring and Evaluation 2022: Reforming Agricultural Policies for Climate Change Mitigation. In *OECD Publishing*. OECD Publishing, Paris. https://doi.org/https://doi.org/10.1787/7f4542bf-en

OECD. (2022b). *OECD Rural Policy Review of Colombia*. OECD Publishing, Paris. https://doi.org/https://doi.org/10.1787/c26abeb4-en

Parr, J. B. (2015). Overlooked Aspects of the von Thünen System. *Spatial Economic Analysis*, *10*(4), 471–487. https://doi.org/10.1080/17421772.2015.1076577

PNUD. (2011). Colombia rural: Razones para la esperanza. In *Informe Nacional de Desarrollo Humano 2011*. http://www.co.undp.org/content/dam/colombia/docs/DesarrolloHumano/undp-co-ic_indh2011-parte1-2011.pdf

Schielein, J., Ponzoni Frey, G., Miranda, J., Souza, R. A. de, Boerner, J., & Henderson, J. (2021). The role of accessibility for land use and land cover change in the Brazilian Amazon. Applied Geography, 132. https://doi.org/10.1016/j.apgeog.2021.102419

Schielein, J., & Börner, J. (2018). Recent transformations of land-use and land-cover dynamics across different deforestation frontiers in the Brazilian Amazon. *Land Use Policy*, *76*, 81–94. https://doi.org/10.1016/J.LANDUSEPOL.2018.04.052

Schmitt, K. M., & Kramer, D. B. (2009). Road development and market access on Nicaragua's Atlantic coast: Implications for household fishing and farming practices. Environmental Conservation, 36(4), 289–300. https://doi.org/10.1017/S0376892910000159

Staal, S. J., Baltenweck, I., Waithaka, M. M., DeWolff, T., & Njoroge, L. (2002). Location and uptake: integrated household and GIS analysis of technology adoption and land use, with application to smallholder dairy farms in Kenya. *Agricultural Economics*, *27*(3), 295–315. https://doi.org/10.1016/S0169-5150(02)00075-0

Towe, C., & Chen, Z. (2022). Recreational Homes' Impact on Agricultural Land Use. *Land Economics*, 090420-0140R1. https://doi.org/10.3368/LE.090420-0140R1

UPRA. (2021). Análisis Situacional De La Cadena Productiva Cárnica Bovina. In *Unidad De Planificación Rural Agropecuaria (Upra)*.

Van Leerzem, S., & Ur -, W. (2015). *Market Access and the Adoption of Integrated Soil Fertility Management in Mbeya Region, Tanzania*.

Verburg, P. H., Ritsema van Eck, J. R., de Nijs, T. C. M., Dijst, M. J., & Schot, P. (2016). Determinants of Land-Use Change Patterns in the Netherlands. *31*(1), 125–150. https://doi.org/10.1068/B307

Verburg, P. H., Ellis, E. C., & Letourneau, A. (2011). A global assessment of market accessibility and market influence for global environmental change studies. *Environmental Research Letters*, *6*(3). https://doi.org/10.1088/1748-9326/6/3/034019

Verburg, P. H., Ritsema van Eck, J. R., de Nijs, T. C. M., Dijst, M. J., & Schot, P. (2004). Determinants of land-use change patterns in the Netherlands. Environment and Planning B: Planning and Design, 31(1), 125–150. https://doi.org/10.1068/b307

Villoria, N. B., Byerlee, D., & Stevenson, J. (2014). The effects of agricultural technological progress on deforestation: What do we really know? *Applied Economic Perspectives and Policy*, *36*(2), 211–237. https://doi.org/10.1093/aepp/ppu005

Villoria, N. B., & Liu, J. (2018). Using spatially explicit data to improve our understanding of land supply responses: An application to the cropland effects of global sustainable irrigation in the Americas. *Land Use Policy*, *75*(March), 411–419. https://doi.org/10.1016/j.landusepol.2018.04.010

Yin, R. S., Xiang, Q., Xu, J. T., & Deng, X. Z. (2010). Modeling the driving forces of the land use and land cover changes along the upper yangtze river of China. *Environmental Management*, *45*(3), 454–465. https://doi.org/10.1007/s00267-009-9377-6

Appendix

Table A. 1. Regression results for the share of crop, pasture, mixed, and infrastructure uses.

VARIABLES	(1) Crop use	(2) Pasture use	(3) Mixed use	(4) Infrastructure
Market influence	-0.0046***	-0.0127***	-0.0173***	-0.0003***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-1.3121***	2.4081***	1.0960***	0.1660***
	(0.053)	(0.052)	(0.051)	(0.007)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.109	0.116	0.028	0.026

All regressions include physical, soil and municipality controls.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations

Table A. 2. Regression results for self-consumption and family labor usage.

VARIABLES	(1) Family economy	(2) Self-consumption 1	(3) Self-consumption 2	(4) Family economy	(5) Self-consumption 1	(6) Self-consumption 2
Market access	-0.1722***	-0.0675***	-0.1361***			
	(0.002)	(0.002)	(0.003)			
Market influence				-0.0136***	-0.0127***	-0.0218***
				(0.000)	(0.000)	(0.000)
Market population (logs)	-0.0128***	-0.0147***	-0.0234***			
	(0.000)	(0.000)	(0.001)			
Market value added (logs)	-0.0024***	-0.0245***	-0.0371***			
	(0.001)	(0.001)	(0.001)			
Constant	0.0068	1.7377***	1.3759***	0.3181***	1.8993***	1.6736***
	(0.063)	(0.050)	(0.089)	(0.063)	(0.050)	(0.088)
Observations	1,946,805	950,799	950,799	1,946,805	950,799	950,799
R-squared	0.038	0.163	0.108	0.036	0.161	0.106

All regressions include physical, soil and municipality controls. Self-consumption 1 corresponds to exclusive self-consumption and Self-consumption 2 also consider other use of production different to commercialization.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations

Table A. 3. Regression results for the shares of usable land, crop, pasture, and mixed uses with municipality controls.

VARIABLES	(1) Usable land	(2) Crop use	(3) Pasture use	(4) Mixed use
Market influence*city	-0.0207***	-0.0156***	-0.0051***	-0.0207***
	(0.000)	(0.000)	(0.000)	(0.000)
Market influence*intermediate	-0.0083***	0.0007**	-0.0086***	-0.0078***
	(0.000)	(0.000)	(0.000)	(0.000)
Market influence*rural	-0.0117***	-0.0422***	0.0294***	-0.0128***
	(0.001)	(0.001)	(0.001)	(0.001)
Intermediate munic.	-0.1212***	-0.1628***	0.0391***	-0.1237***
	(0.003)	(0.003)	(0.003)	(0.003)
Rural munic.	-0.0236***	-0.0792***	0.0531***	-0.0261***
	(0.003)	(0.004)	(0.003)	(0.003)
Constant	0.8574***	-1.9900***	2.5937***	0.6037***
	(0.052)	(0.054)	(0.053)	(0.053)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.025	0.113	0.121	0.029

All regressions include physical, soil and municipality controls.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors’ calculations.

Table A. 4. Regression results for the shares of usable land, crop, pasture, and mixed uses for reference markets from 25,000 and 100,00 inhabitants.

VARIABLES	(1) Usable land	(2) Crop use	(3) Pasture use	(4) Mixed use
	25,000 inhabitants			
Market access	-0.0817***	0.1275***	-0.2028***	-0.0752***
	(0.003)	(0.004)	(0.003)	(0.003)
Constant	2.4143***	-1.2859***	3.3954***	2.1095***
	(0.050)	(0.052)	(0.051)	(0.051)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.020	0.115	0.122	0.025
	100,000 inhabitants			
Market access	-0.0669***	0.0938***	-0.1619***	-0.0681***
	(0.002)	(0.002)	(0.002)	(0.002)
Constant	1.5434***	-1.7118***	3.0661***	1.3543***
	(0.052)	(0.055)	(0.054)	(0.053)
Observations	2,229,725	2,229,725	2,229,725	2,229,725
R-squared	0.026	0.112	0.120	0.031

All regressions include physical, soil and municipality controls.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Source: authors' calculations.