Farmland Allocation along the Rural-Urban Gradient: The Impacts of Urbanization and Urban Sprawl

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Abstract

In the vicinity of a city, farmers are confronted with increasing agricultural land prices and rents along the rural-urban gradient, but they concurrently enjoy the advantages associated with proximity to a larger and wealthier consumer base. We hypothesize that farmers transition from low-value, land-intensive "traditional" crops to high-value, labor-intensive "specialized" crops on parcels located closer to urban centers. Once returns to development of a parcel exceed the profits associated with farming, exurban farmers may sell their land for conversion to urban use. Urban pressure in the rural-urban fringe intensifies as cities expand. We differentiate between a gradual process of urban growth (or urbanization) and urban sprawl. Utilizing farmland fragmentation measures as indicators of sprawl, we hypothesize that urban sprawl burdens "traditional" farms to the extent that they accelerate the transition to specialized crops or convert farmland to urban use. We use crop-specific land cover data at the level of grid cells and a state-of-the-art system of spatially correlated simultaneous equations with data for the metropolitan area of Indianapolis, IN and its immediate hinterland. Our initial empirical results corroborate that accelerated urban development around Indianapolis in the 1990s is associated with land uses characterized by fewer field crops and more idle land.

JEL codes: C31, O13, Q15, R14
Keywords: land use, urban sprawl, agriculture, specialized crops, spatial econometrics

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1 Introduction

As city populations across the United States (U.S.) have grown, the borders of cities have increasingly shifted outwards since the early twentieth century. This process of city growth has been fueled by demographic factors such as high birth rates, rural out-migration, and international in-migration. Between 1950 and 2000, urban expansion has outpaced urban population growth by a factor two, but this aggregate number hides even more pronounced disparities between urban areas. The ratio of the change in area over the change in population was over three in Philadephia, PA, while it was only one half in San Jose, CA. Since the growth of cities has often been qualified as "excessive", "out of control", or "sprawling", the phenomenon of urban growth has been the subject of vehement debate over the past few decades. This applies to many industrialized countries, but seems particularly relevant for the U.S. Urban sprawl is primarily perceived as undesirable because it contributes to pollution, traffic congestion, loss of environmental amenities, and destruction of agricultural land. The social and political apprehension of the issue in many developed countries of the world has triggered a variety of "smart growth" policies, including the institution of green belts, city growth boundaries, and national parks (Talen, 2005).

A direct consequence of city expansion is the conversion of farmland in the urban-rural fringe to residential and commercial usage. Under urban pressure, landowners in the urban-rural fringe, some of whom are farmers, have the choice between continuing agricultural activity on their land or selling the land for residential or commercial development. The choice to convert land and the time at which it occurs is at the core of the economic literature on urban growth and sprawl (Capozza and Helsley, 1990; Plantinga and Miller, 2001; Irwin and Bockstael, 2002). Once the decision to farm has been made, farmers allocate land to the production of specific crops so as to maximize profits. The primary objective of this paper is to determine how proximity to urban areas affects the crop choice of farmers in the urban-rural fringe.

This issue of crop choice constitutes one aspect of the behavior of farmers in peri-urban areas, which is relatively under-studied in the literature and primarily treated from a "philosophical" point of view. Berry (1978) and Heimlich and Anderson (2001) examine the behavioral response of peri-urban farmers to urbanization in terms of their choices regarding the desired source of income. They distinguish between income from agricultural production, agri-tourism, and off-farm employment. Heimlich and Anderson (2001) in particular classify rural-urban fringe farms into three categories: traditional, recreational, and adaptive farms. The first group comprises the "original" farms, which are practically unchanged in terms of production and management practices as compared to the situation prior to urban development. Recreational farmers work off-farm or are retired and maintain their farming activity as a hobby. The category of adapting farms has adjusted to urban pressure by switching from traditional to specialized crops (for instance, vegetables, fruits, and nurseries) and/or to agri-tourism. Our contribution to the literature is to identify and quantify the forces at stake in shaping the exurban agricultural landscape, adding to previous work on this topic by Lopez et al. (1988) and Livanis et al. (2006). Specifically, we test the hypothesis that farmers switch from low-value, land-intensive crops (field crops) to high-value, labor-intensive crops (specialty crops) as distance to urban areas diminishes. In addition, we investigate how this spatial distribution of crops is affected by gradual processes of urban growth and highly volatile and dynamic processes of urban sprawl.

We make an explicit distinction between the processes of urban growth and urban sprawl. Urban growth or urbanization is defined as the expansion of urban land or, to be more precise, the increase in the area utilized for urban activities. There is no consensus in the literature on the definition of urban sprawl, but it is generally agreed upon that urban sprawl and urban growth (or urbanization) are not synonymous. Despite the many facets of urban sprawl identified in the literature, a handful of characteristics is commonly acknowledged:[1]

(1) discontinuous development,
(2) decentralized population and employment,
(3) low density,
(4) scatteredness or fragmentation, and
(5) unlimited outward expansion.

In the present paper, we will compare the land use and farm management practices under both urban growth and urban sprawl.

Profits are determined by the difference between revenues and costs. Factors affecting either side of the budget sheet are drivers of a farmer's planting decisions. Land rents and land prices play a key role in an agricultural operation's budget sheet, partly through property taxes. Determinants of farmland values will therefore have an impact on the spatial distribution of crops. Economic theory on the determination of land values is well established as signified by a large body of literature. Positive land values result from the capitalization of the discounted returns to agricultural activities, and the potential of conversion farmland to urban use, adjusted by the one-time cost of development (Capozza and Helsley, 1989, 1990). The closer a land parcel is to an urban center, the higher the chance of conversion and hence the higher its value *ceteris paribus*. In reality, land valuation is likely to be more complex because of the interactions between land owners, farmers, urban developers, lawmakers and the urban population. For instance, open space such as farmland generates positive externalities for urban residents. However, livestock, swine or poultry operations generate smell and noise nuisance, which are perceived as negative externalities. These externalities have opposite effects on the value of the land conversion option. Apart from the possible impact of externalities, there is strong empirical evidence in the literature to suggest that higher land costs are a prime motivation for farmers to transition from traditional bulk crops to higher per-acre value crops (Cavailhes and Wavresky, 2003; Carrion-Flores and Irwin, 2004; Guiling et al., 2009). This paper focuses on the way in which urban areas impact farmers' choice of crops, and the extent to which the difference between gradual growth of urban areas and urban sprawl results in different farm management practices.

The remainder of this paper is organized as follows. Section 2 provides more detail on the various impacts of urbanization on farm land. In Section 3 we build on the theoretical model of Lopez et al. (1988) to develop an empirical farmland allocation model, which is operationalized as a spatial system of simultaneous equations for traditional crops, specialized crops, and idle land. Section 4 describes the USDA/NASS/RDD Cropland Data Layer, the choice of the study region, the spatial scale of the analysis, and variable definitions, in particular the measurement of urban growth and farmland fragmentation. Section 5 details how the model is estimated, and Section 6 presents the empirical results and a discussion of their implications. Our initial empirical results reveal that accelerated urban development is associated with land uses characterized by fewer field crops and more idle land. Section 7 concludes and suggests avenues for further research.

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[1] Reference to the different characteristics can be found in: (1) Harvey and Clark (1965), Mills (1981), Burchell et al. (1998), and Irwin and Bockstael (2002); (2) Glaeser et al. (2004); (3) (Harvey and Clark, 1965), Ewing (1997), Burchell et al. (1998), Theobald (2001), Irwin and Bockstael (2002), and Glaeser et al. (2004); (4) Ewing (1997), Burchfield et al. (2006), Irwin et al. (2006), and Irwin and Bockstael (2007); and (5) Burchell et al. (1998).

2 Effects of Urbanization

Agricultural returns are a function of land quality, farming practices, and market conditions, which in turn are all affected by urban influences (Livanis et al., 2006). There are many diverse channels through which urban development influences peri-urban farms, both positively and negatively. Andrews and Chetrick (1986) and similarly Lopez et al. (1988) distinguish four categories of indirect effects of urbanization on farmland use: regulatory, technical, speculative, and market effects.

Regulatory effects stem from the conflicting interests of city dwellers and farmers. Within the administrative boundaries of a city, farmers become subject to municipal regulations, in addition to state and federal laws. Water pollution, noise, pungent smells, and slow farm vehicles are common negative externalities associated with agriculture. As a result, local legislation often requires farmers to internalize these externalities through, for instance, monitored livestock effluent or chemical usage, and controls on the density of livestock and poultry operations (Libby, 1974). These ordinances create obvious financial and technical constraints on the operation of peri-urban farms, which may be sufficient to push farms out of business or to result in farms converting to more profitable and/or less constrained activities. In other words, these regulations divert farm management practices away from traditional crops and intensive livestock/poultry operations. In turn, this may positively impact the attractiveness of rural areas because the influx of city residents in rural areas is stimulated by the attraction of green landscapes molded in great part by small-scale farming activities. Migrating urban residents typically also share the sentiment that absorption of agricultural land by urban growth destroys livelihoods and jeopardizes long-term food security. They are therefore likely to argue in favor of farmland preservation programs (Lapping et al., 1983; Roe et al., 2004; Towe et al., 2008), and policies aimed at curbing sprawl, such as zoning (Glaeser and Gyourko, 2002) and growth controls (Engle et al., 1992; Brueckner, 1998).

Technical effects of urbanization on farmland use are multifold and primarily negative. Urban populations are known for their acts of vandalism on crops and equipment. Spatial fragmentation of farms and parcels reduces the economies of scale generated by big machinery on large fields, and increases the number of trips between fields in heavier traffic and less farm-equipment-friendly road networks. The latter is important in our empirical analysis, because it is the channel through which we argue urban sprawl affects farmers' management practices, particularly the crop choice decision. Furthermore, as some farming activities recede, for instance traditional crops and livestock operations, the upstream agribusiness industry shrinks concurrently and input procurement becomes a challenge for farms (Derr et al., 1977).

The prospect of a seemingly ineluctable sale and conversion to urban use pushes some traditional farmers to reduce maintenance cost on equipment and infrastructure to a strict minimum, and to bypass investments in new technologies. This phenomenon, known as the "impermanence syndrome", reaches its peak when speculative pressure leads to the decision to idle farmland. Similar to the regulatory and technical effects associated with urbanization, these so-called *speculative effects* are aggravated under conditions of urban sprawl as land market transactions become more frequent. In the empirical analysis this process stimulated us to consider idle land as one of the alternative "crops" or alternative farmland uses from which a farmer can choose.

Market conditions created by the proximity to urban developments may create detrimental or beneficial *market effects* depending on the type of farm activity. On the one hand, traditional farms specializing in field crops and livestock/poultry operations struggle as their outlets (cooperatives, elevators, and the food industry) are pushed further out, away from city centers, by expanding urbanization. On the other hand, labor-intensive specialized products and agri-tourism associated with non-traditional farms can take full advantage of the closer ties to a larger, more diverse, better accessible and wealthier consumer base. In view of cities constituting major population concentrations and employment centers, cities provide a pool of seasonal labor critical for specialized crops as well as off-farm job opportunities to support the farmer's household (Heimlich and Anderson, 2001).

3 A Model of Farmland Allocation

To our knowledge, Lopez et al. (1988) is the only study that examines the question of farmers' production decisions under urban pressure. They use a multi-product, multi-input profit maximization setup, assuming perfect competition and function continuity, monotonicity, and differentiability. Under those assumptions, a normalized profit function Π can be expressed in reduced form as:

$$\Pi = \Pi\left(p\left(Z\right), Z\right), \tag{1}$$

where p is a vector of $n-1$ output and variable input prices, and Z is a series of fixed inputs and other exogenous factors.[2] Hotelling's Lemma applied to equation (1) yields a system of output supply and variable input demand functions $Y_i^*\left(p\left(Z\right), Z\right)$. After choosing a functional form for the profit function, the system of equations can be estimated using a seemingly unrelated regression estimator, and the total change in production choices from a change in any exogenous factor in $\tilde{Z}$ is derived as:

$$\frac{dY_i^*}{d\tilde{Z}} = \sum_{j=1}^{n-1} \frac{\partial Y_i^*}{\partial p_j} \frac{dp_j}{d\tilde{Z}} + \sum_{j=r+1}^{s} \frac{\partial Y_i^*}{\partial Z_j} \frac{dZ_j}{d\tilde{Z}}, \qquad i = 1, \ldots, n-1. \tag{2}$$

Using time series data for the state of New Jersey and covering the period 1949–1982, the authors were able to gather prices and quantities necessary to aggregate inputs and outputs into categories with their corresponding price indexes. The use of a profit maximization framework reveals that the theoretical model and concurrent empirical analyses are based on individual behavior and associated micro-data. This seems appropriate, also in view of the fact that urbanization is the result of direct individual transactions between landowners and urban developers. Data constraints imply that we cannot exactly follow the setup of Lopez et al. (1988). Instead, we will perform an analysis using data at an aggregate spatial scale. The use of state or county level data would result in what is known as the ecological fallacy problem in the sense that the true underlying economic process may not be identifiable from aggregate data. Ideally, a study at an aggregate spatial scale should utilize parcel data.[3] However, these type of data are scarce and often proprietary. More importantly, agricultural prices at spatial scales below the county level are virtually impossible to attain.

In order to consider the impact of urbanization and sprawl on farmers' production decisions at a smaller spatial scale, we therefore reformulate the problem into one of farmland allocation in which output and input prices do not enter. Based on the production decision model presented above, a farmer will consider the production option that yields the highest profits for each of his parcels. If the returns to farming a parcel do not exceed the returns to urban development, the

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[2] The reader should note that prices depend on Z.

[3] Even farm-level data would be imperfect as parcels cultivated by the same farmers may be separated in space.

parcel is sold. Allocating farmland to a specific type of production (or crop) is still subject to the criterion of profit maximization. Therefore we consider the question of whether to farm or to sell, and the decision of what to produce as sequential and independent, and focus exclusively on the production decision.[4] Given that we would like to consider multiple crops, we write the production problem as a system of m simultaneous equations, where m is the number of production choices. The j-th equation can be expressed as:

$$y_j = \boldsymbol{y}_{-j}\boldsymbol{\gamma}_{-j} + \boldsymbol{X}\boldsymbol{\beta}_j + \boldsymbol{K}_j\boldsymbol{\alpha}_j + \mu_j, \tag{3}$$

where y_j is the j-th dependent variable, $\boldsymbol{y}_{-j}$ is the vector of all other dependent variables, $\boldsymbol{X}$ is the matrix of exogenous regressors common to each equation, $\boldsymbol{K}_j$ is the matrix of explanatory variables unique to equation j,[5] and μ_j is a vector of spherical innovations. Lopez et al. (1988) considered production levels of four categories of outputs (vegetables, fruits, grain crops, and livestock) and the usage level of four variable inputs as dependent variables in their production choice framework. We are, however, limited to types of production for which we can explicitly define the use of land. We therefore define our dependent variables as the proportion of total agricultural land covered by field crops, specialty crops, hay/forage/pasture, and idle/fallow land. Further details are given in Section 4.

Since land use decisions and the resulting patterns of land use are explicitly spatial, we ensure that our modeling strategy accommodates spatially correlated omitted variables as well as spatial dependence in the dependent variables. We particularly expect spatial autocorrelation to be increasingly important at finer spatial scales. Indeed, if a farm extends over multiple spatial units of observation it is likely that production decisions are correlated over space. The basic framework for estimation of a model containing a spatially lagged dependent variable as well as spatially autoregressive errors—in the spatial econometrics literature typically known by the abbreviation SARAR—has been developed as a system of simultaneous equations by Kelejian and Prucha (2004).[6] The paper details the theoretical foundations and the estimation method for both two-stage and a three-stage procedures based on pre-existing general method of moments and instrumental variables techniques (Kelejian and Prucha, 1999). The j-th equation in this spatially explicit, extended model takes the following form:

$$y_j = \boldsymbol{y}_{-j}\boldsymbol{\gamma}_{-j} + \rho_j\boldsymbol{W}_j y_j + \boldsymbol{X}\boldsymbol{\beta}_j + \boldsymbol{K}_j\boldsymbol{\alpha}_j + \varepsilon_j, \tag{4a}$$

$$\varepsilon_j = \lambda_j\boldsymbol{M}_j\varepsilon_j + \mu_j, \tag{4b}$$

where $\boldsymbol{W}_j y_j$ is the spatially lagged dependent variable with the spatial weight matrix given by $\boldsymbol{W}_j$, and ε_j is a vector of errors, spatially correlated through the weight matrix $\boldsymbol{M}_j$. The parameters to be estimated are the vectors $\boldsymbol{\gamma}_{-j}$, $\boldsymbol{\beta}_j$, and $\boldsymbol{\alpha}_j$ and the scalars ρ_j, and λ_j. The weight matrices define

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[4] An attractive alternative modeling approach would be to first consider the farm/sell decision in a discrete selection equation, and the land use associated with a specific crop choice in a second equation. We would like to consider a system of equations comprising multiple crops. However, a spatially explicit "heckit" approach for systems with more than two equations has not been developed yet.

[5] At least $m-1$ variables need to be excluded from each equation for identification. This condition is exactly met if one exogenous variable is unique to each equation.

[6] The Kelejian and Prucha (2004) framework is actually even more general, because it also allows for cross-equation spatially lagged dependent variables as well as spatially lagged exogenous variables.

the spatial topology of neighboring relationships between locations. As evidenced by equation (4), the weights matrices in this model are not only allowed to differ between the spatial lag and the spatial error processes within equations, but also across equations. Since geographical criteria are commonly used to define who is a neighbor of whom, it is often difficult to empirically justify using multiple specifications for weight matrices. We therefore assume $\boldsymbol{W}_j = \boldsymbol{M}_j = \boldsymbol{W}$, although we obviously allow the magnitude of the spatial correlation to vary within and across equations.

4 Data and Empirical Model

The theoretical and operational models developed in the preceding sections allow for testing the hypothesis of a transition from traditional to specialized farms along the rural-urban gradient. We use data for the extended Metropolitan Statistical Area (MSA) of Indianapolis, IN pertaining to 2009. The area comprises 23 counties, ten of which are in the MSA of 1+ million people (Indianapolis), six are in metro areas of fewer than 250,000 people, two in non-urban adjacent counties of 20,000+ people, and five in non-urban counties of 2,500 to 20,000 people, according to the rural-urban continuum definition of the Economic Research Service of the United States Department of Agriculture (ERS-USDA).

The choice of the city of Indianapolis, IN is motivated by the fact that the state of Indiana is predominantly covered by agricultural land and the local specialty crop production is primarily destined to local markets as opposed to the large fruit and vegetable operations in, for instance, California, Florida and Georgia. The choice of the spatial scale for the analysis recognizes the trade-off between computational feasibility and ecological fallacy. As will become evident in section 5, the techniques developed by Kelejian and Prucha (2004) to estimate systems of spatially correlated equations involve the inversion of matrices with dimensions equal to the total number of locations (or grid cells) in the sample. With an aggregated cell size of 2.6 by 2.6 km, we divided the area of study into 2890 identical spatial units, each containing 2500 grid cells from the underlying CDL raster. The practical advantages of using a regular lattice are obvious, since the various data sources we use to define the variables are based on raster grids. In addition, utilizing a regular raster of grid cells does not impose a possibly endogenous selection criterion related to existing administrative borders of parcels on the spatial structure used for the analysis.

Figure 1 provides a clear illustration of why this area is relevant for the question at hand. The maps on the top represent the share of field crops (top left) and specialty crops (top right) as a proportion of total agricultural land use. Low, medium and high density urban areas are also displayed. Both maps clearly show the impact of the rural-urban gradient on farmers' planting decisions. Field crops are relatively more abundant at larger distances from cities, whereas the opposite pattern can be observed for specialty crops. In addition, it appears that the inverse relationship between field and specialty crops would justify the use of a simultaneous equation approach.

≪ Figure 1 about here ≫

For the land cover data we use the Cropland Data Layer (CDL) developed by the Research and Development Division of the National Agricultural Statistics Service (NASS) at the United States Department of Agriculture (USDA). These data consist of gridded land cover maps for select years for all 48 contiguous U.S. States. Each 56-by-56 meter cell is assigned a land cover type based on a combined analysis of satellite images from the Foreign Agricultural Service and the U.S. Geological

Survey, and from the Farm Service Agency Common Land Unit surveys. We aggregate the agricultural land cover classes into four categories: fields crops (e.g., corn, soybean, wheat), specialty crops (e.g., vegetables, fruits), hay/forage/pasture, and idle/fallow. The dependent variables in the system of four equations (4) are subsequently defined as the share of each crop class category in the total area of land used for agriculture. By construction, $0 \leq y_j \leq 1$.

On the right-hand side of the system of equations in (4) we include the set of three simultaneous endogenous variables $\boldsymbol{y}_{-j}$ and the "own" spatially lagged dependent variable $\boldsymbol{W}_j y_j$ as well as a set of exogenous variables both common (X) and unique (K) to each equation. In addition, we include a measure of the distance to urban centers, which is included to capture the general effect of moving along the rural-urban gradient, and a group of variables characterizing urban growth and farmland fragmentation.

The dependent variables are defined in terms of the four categories of crops to be allocated by farmers over the available agricultural. *Field crops* are characteristic of traditional farms, and typically cultivated on large parcels with large machinery. We expect their dominance to fade as distance to urbanized areas decreases. The *hay/forage/pasture* category is directly or indirectly linked to livestock and dairy production. We consider these crop types to be, at least in part, related to recreational farms in the rural-urban fringe, because recreational farmers typically have a small herd of cattle or horses in addition to an off-farm job or a position as retiree. *Specialty crops* are intensive in terms of labor and variable inputs, and characterized by a high value per unit of output. Fresh produce is typically associated with higher transportation costs, which makes delivery to marketing locations more sensitive to distance. We anticipate our empirical analysis to show that the proportion of specialized crops increases as distance to urban areas decreases. Figure 1 illustrates that the data seem to exhibit such a relationship. We also expect specialized crops to be more common as parcels shrink and become more complex in shape, which are both indicative of farmland fragmentation. Finally, we suspect that the *idle/fallow* category is related to the impermanence factor. As farmers see their surrounding land inexorably being converted to urban uses, they have a tendency to give up all investments to maintain their activity and let their land idle until a developer is interested in purchasing it. As a result, we expect idle land to become more frequently observed as distance to urban centers decreases. In addition, we anticipate farmland fragmentation to exacerbate this phenomenon because of the associated increased exposure to developed land.

It is important to note that for each location, the four dependent variables add up to unity. As a result, there is a restriction across equations, which is however difficult to implement. Furthermore, the proportion of field crops and the proportion of hay/forage/pasture are almost perfectly negatively correlated, because these two crop types together cover over 95 percent of agricultural land use in all but a few locations. We therefore remove the equation corresponding to the hay/forage/pasture category from the system of equations, and estimate the model with the remaining three equations.[7]

With respect to the set of exogenous variables we include geo-physical variables that we suspect may affect a farmer's land allocation decision from an agronomical point of view. Rainfall, elevation and slope are variables commonly used in crop yield response models. Average elevation and slope are derived from the 1-arc second National Elevation Dataset published by the U.S. Geological Survey (USGS). Elevation is measured in meters, relative to the lowest point in the study region.

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[7] An alternative but non-trivial approach that deserves further attention is to implement the restriction of the y's summing to one.

Given that rainfall does not vary significantly over the region of study, we do not include it in the model.

Similarly to Livanis et al. (2006) we wish to explicitly test the Von Thünen hypothesis of the distribution of land uses in concentric circles centered around urban centers. Faced with increasing agricultural rents along the rural-urban gradient, farmers replace low-value with high-value per acre crops as distance to urban clusters diminishes (Livanis et al., 2006). We therefore calculate the euclidian distance between each agricultural raster cell from the original land cover dataset to the nearest cell of high density urban development and average this measure over our aggregated grid cells. In the specialty crops equation we also include the distance to the nearest farmers' market, calculated as the average "flight-of-the-crow" distance using geocoded addresses found in the 2009 Indiana Farmers' Market, U-Pick and Agritourism Directory from the Indiana State Department of Agriculture (ISDA). This variable is intended to capture the impact of more diverse marketing opportunities in proximity to urban centers of which farmers' markets are a prime example. The map on the bottom left-hand side of Figure 1 shows the distance of each grid cell to the nearest farmers' market.

Studying the impact of urban growth and sprawl on farmers' crop choice is at the core of the present paper. Urban growth is the expansion of developed urban areas. We use the SocioEconomic Data Application Center (SEDAC) U.S. Census grids as a source of highly disaggregated information on urban development.[8] The SEDAC data contain census tract level socio-economic statistics allocated to 30-by-30 arc-seconds raster grid cells (approximately 1 km for the appropriate latitude) for the 1990 and 2000 Census.[9] There are many variables available, including population and housing unit density. Population is commonly associated with the extent of cities (Brueckner and Fansler, 1983; McGrath, 2005) and is used in many official definitions of urban areas. However, as Theobald (2001) emphasizes, such a metric underestimates the level of urbanization because it fails to account for secondary, vacation, and empty houses. A better representation of developed areas may therefore be obtained by using information on the spatial distribution of housing units. Despite potential concerns about the temporal disconnect between the SEDAC and the LDC data used in this paper, we calculate the change in the number of housing units per 30-by-30 arc-second raster cell between 1990 and 2000 and average this indicator over our larger grid cells. Assuming the patterns of growth of the city of Indianapolis did not change drastically over the first decade of the 21st century, we can capture the impact of gradual city development on peri-urban agricultural land allocation decisions with this variable.

Increasingly the availability of geographically referenced micro-scale data has triggered interest in characterizing and quantifying land use/land cover patterns in the economics literature (Burchfield et al., 2006; Irwin and Bockstael, 2007). We would like to use spatial fragmentation measures as an indicator for the occurrence of urban sprawl. However, finding appropriate operational definitions of spatial fragmentation is difficult. We consider farmland spatially fragmented if it is characterized by patches, and define a patch as a discrete and continuous area with the same land use. Patches are usually relatively small in size and scattered across space. It is therefore natural to

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[8] Similar CDL data sets are available for Indiana for each consecutive year during the period 2000–2009. However, there is no consistency over time in the classification of certain land cover types into urban and non-urban categories. In particular, the CDL recently incorporated information from the National Land Cover Database (USGS) to improve the characterization of developed land cover types, but that unfortunately prevents comparing older and newer CDL data sets.

[9] The 1990 data are still a beta version and hence not available for download from the SEDAC website. We wish to thank Gregory Yetman from SEDAC for making the 1990 data available.

rely directly on patch level information to measure land use patterns (Irwin and Bockstael, 2007). Alternatively, cluster and spatial autocorrelation measures are appropriate to quantify spatial fragmentation.[10] Irwin and Bockstael (2007) suggest using mean patch size and mean perimeter-to-area ratio as measures of spatial fragmentation. Both measures capture a different facet of fragmentation, the former focusing on area, the latter on shape. Given the particular nature of our data in the sense that many patches are made of a single 56-by-56 meter grid cell, most shape-based metrics would not capture fragmentation in a satisfying way. We therefore tie on to our definition of spatial fragmentation as spatially scattered patches of a relatively small size and operationalize our fragmentation measures as the average area of agricultural land cover patches, and the proportion of like-adjencies. The latter metric counts the number of neighboring pixels of identical crop type and divides this number by the total number of possible links. The spatial distribution of this variable in our sample is illustrated in the bottom right-hand side map in Figure 1.

5 GS2SLS and GS3SLS estimation

The dependent variables are defined as the share of a location's agricultural land covered by a specific crop type. This implies that each dependent variable is double-censored at zero and one. Linear regression techniques will therefore lead to inconsistent estimates of the parameters of our model. The preferred solution for fractions in the [0,1] interval is a fractional logit model (Papke and Wooldridge, 1996). This framework would be interesting for a number of reasons. First, a fractional logit model ensures that predicted values are within the zero-one interval. Second, this model can appropriately handle the situation where the dependent variable is exactly zero or one, even if large probability masses appear at either extremes. This seems particularly important for our empirical analysis because 83 percent and 94 percent of the grid cells in our data set do not contain any specialty crops and idle/fallow observations, respectively. There is however no method available currently to estimate such a model in an appropriate spatial context, and even less so in the form of an estimator for a system of spatially correlated simultaneous equations. We therefore resort to a second-best solution that is based on converting the fractional dependent variables into log-odds ratios, adjusted to ensure the existence of the log-odds ratio when the dependent variable is exactly equal to one or zero (Maddala, 1986). The transformed dependent variables are calculated as follows:

$$\breve{y}_{ij} = log\left(\frac{y_{ij} + (2n_i)^{-1}}{1 - y_{ij} + (2n_i)^{-1}}\right), \qquad j = 1, \ldots, 3 \text{ and } i = 1, \ldots, n, \tag{5}$$

where y_{ij} is the value of the fractional dependent variable y for crop j at location i, $\breve{y}_{ij}$ indicates the adjusted log-odds ratios of y_{ij}, and n_i is the number of agricultural raster cells at location i. We then move on to estimate the system of three spatially correlated equations introduced in Section 3 by the Generalized Spatial Two (GS2SLS) or Three (GS3SLS) Stage Least Squares estimators developed in Kelejian and Prucha (2004).

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[10] This is particularly true when dealing with highly disaggregated spatial data such as the raster grids used in this study. The general idea is that the more fragmented a spatial distribution is, the less likely the neighborhood of a grid cell of a certain land cover is to contain cells of the same type. Spatial autocorrelation statistics allow calculation of this probability for each grid cell or for an aggregated spatial unit. Tsai (2005) specifically mentions Moran's I and Geary's c as clustering metrics in his review of spatial pattern metrics. There are many more measures available to quantify clustering, for instance in terms of deviations from the mean density of a focus land use (Galster et al., 2001).

The GS2SLS procedure is a limited information estimation method because it ignores potential cross-equation correlation in the errors. The estimation procedure can be decomposed in three steps:

1. Estimate each equation j by 2SLS using a matrix of instruments $\boldsymbol{H} = \{\boldsymbol{X}, \boldsymbol{K}, \boldsymbol{WX}, \boldsymbol{WK}\}$ and making sure that $\boldsymbol{H}$ is full-rank. Given our model specification, there are three endogenous variables on the right-hand side of each equation j, specifically $\boldsymbol{\breve{y}}_{-j}$ and $\boldsymbol{W}\breve{y}_j$). As long as three $\boldsymbol{WX}$ are excluded from all equations, the model is at least exactly identified. The estimated parameters are given by:

$$\tilde{\boldsymbol{\delta}}_j = (\tilde{\boldsymbol{Z}}_j' \boldsymbol{Z}_j)^{-1} \tilde{\boldsymbol{Z}}_j' \breve{y}_j, \tag{6}$$

   where $\tilde{\boldsymbol{\delta}}_j$ is the inital 2SLS estimator of $\boldsymbol{\delta}_j = \{\boldsymbol{\gamma}_{-j}, \rho_j, \boldsymbol{\beta}_j, \boldsymbol{\alpha}_j\}$, $\boldsymbol{Z}_j = \{\boldsymbol{\breve{y}}_{-j}, \boldsymbol{W}\breve{y}_j, \boldsymbol{X}_j, \boldsymbol{K}_j, \}$, and $\tilde{\boldsymbol{Z}}_j = \boldsymbol{P}\boldsymbol{Z}_j$ with $\boldsymbol{P} = \boldsymbol{H}(\boldsymbol{H}'\boldsymbol{H})^{-1}\boldsymbol{H}'$.

2. Generalized Methods of Moments (GMM) estimation is applied to the residuals from Step 1 to derive $\tilde{\lambda}_j$ as a consistent estimator of the spatial error autocorrelation parameters (Kelejian and Prucha, 1999).

3. With $\tilde{\lambda}_j$ in hand, perform a Cochrane-Orcutt transformation of all variables, hereby defining $\breve{y}_j^* = \breve{y}_j - \tilde{\lambda}_j \boldsymbol{W}\breve{y}_j$ and $\boldsymbol{Z}_j^* = \boldsymbol{Z}_j - \tilde{\lambda}_j \boldsymbol{W}\boldsymbol{Z}_j$. Subsequently, estimate $\hat{\boldsymbol{\delta}}_j$, the GS2SLS estimator of $\boldsymbol{\delta}_j$, by two-stage least squares regression of $\breve{y}_j^*$ on $\boldsymbol{Z}_j^*$ using H as the matrix of instruments.

A consistent estimator of the variance-covariance matrix for $\hat{\boldsymbol{\delta}}_j$ can be derived by using the error variances estimated during the GMM step (Kelejian and Prucha, 2004). The GS3SLS method builds upon the GS2SLS estimation and explicitly takes into account inter-equation error correlation, and as such qualifies as a full information estimator. Specifically, the GS3SLS estimator builds on Step 3 in the GS2SLS estimation procedure, and is performed on all m stacked equations and weighted by the variance-covariance matrix of the Step 3 residuals. Standard errors are available and hence inference is feasible for all but the spatial error autocorrelation coefficients as they are treated as nuisance parameters.[11]

6 Results

When evaluating the estimation results it is important to realize that the estimated parameters cannot be interpreted directly, because of two different reasons. First, one needs to solve for the reduced form of the system in which each dependent variable is a function only of the exogenous variables of the model. In a system in which cross-equation spatially lagged dependent variables are included, this may well be impossible. In the case of our model in which we only used the

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[11] See Kelejian and Prucha (2004) for details about the estimation procedure. As mentioned in the beginning of this section a fractional logit approach would be preferable. However, we note that a spatial fractional logit estimator has not been developed for simultaneous equation systems. An additional complication occurs in a fractional logit setup because the dependent variables are no longer left-censored at zero after applying the Cochrane-Orcutt transformation. In future work we will consider utilizing the linearized GMM procedures developed by Klier and McMillen (2008), and the Murphy-Topel covariance estimator (Murphy and Topel, 1985). See Lambert et al. (2010) for a similar approach to statistical inference.

"own" spatially lagged dependent variables, while the derivation of the reduced for is considerably more complex, it is still feasible. Second, the fact that the dependent variables are specified as adjusted log-odds ratios makes it impossible to calculate marginal effects without making additional assumptions (Papke and Wooldridge, 1996). For interpretation of the results we therefore initially rely on a close examination of signs, relative magnitudes and statistical significance.

The estimations results for our empirical model given in equation (4) are reported in Table 1. We used a first-order queen contiguity weight matrix to represent the spatial topology of the regular grid system. This means that we consider two cells to be neighbors and assign a value of unity (instead of zero) if they share a common border line or a vertex. In order to facilitate interpretation, the elements of the weights matrix are row-standardized, so that all row sums are equal to unity. We report both GS2SLS and GS3SLS parameter estimates to illustrate the efficiency gain resulting from the full information estimation procedure. For interpretation we focus solely on the GS3SLS results, and we organize our discussion around the issue of crop choice in view of urbanization and urban sprawl, the impact of access to farmers' markets, and interrelatedness of crop choice decisions according to crop type and across space.

≪ Table 1 about here ≫

The variable used to represent gradual urban expansion or urban growth is the change between 1990 and 2000 in the number of housing units in a spatial unit of reference (see above for details). Areas in which more rapid urban development took place during the 1990s tend to be characterized by less field crops and more idle/fallow land. This corroborates our hypothesis concerning the tendency for farmers to substitute away from traditional crops in the face of urbanization. The impact of this variable is however inconclusive when it comes to specialty crops.

Farmland fragmentation, which is at least in part caused by urban sprawl, is represented in our model by the variables average area of agricultural patches, and the so-called proportion of like adjacencies. We anticipate that as farmland becomes more fragmented, implying that average area and probability of like adjacency are smaller, specialized farms become more prevalent. Moreover, under the impermanence syndrome, we expect the proportion of idle/fallow land to increase. The results show that again the estimates and our hypotheses go in the same direction. Aside from the probability of like adjacency not being statistically significant in the specialty crop equation, our results seem to indicate that farmland fragmentation acts as a catalyst in the transition from field crops to specialty crops, and it also tends to be associated with higher proportions of idle/fallow land.

The validity of Von Thünen's theory, which predicts (agricultural) land uses to be spatially organized in concentric bands centered on the urban core, is tested using the average distance to the nearest zone of highly developed urban land. Von Thünen uses the argument of transportation costs to support his hypothesis but we previously argued that many more factors affect farm management decisions along the rural-urban gradient. The theory is validated in many empirical studies, and also our results provide evidence in this direction. There is a statistically significant positive relationship between the distance to urban centers and the proportion of agricultural land used for field crops. In the case of speciality crops, the coefficient is just above the ten-percent statistical significance threshold, and should hence be interpreted with caution. However with a negative sign, our results also supports the hypothesis that field crops, as opposed to specialty crops, will be more likely observed further away from urban centers.

Another factor which we hypothesize affects a farmer's decision to plant specialty crops is the additional marketing opportunities offered by farmers' markets. When considering participation in farmers' markets, the perishability of fresh produce and transportation costs are major factors. The average distance to the neareast farmers' market variable, unique to the specialty crop equation, is negative and statistically significant which supports our initial hypothesis.

Finally, we discuss the parameter estimates associated with simultaneity of crop planting decisions and the spatial dependence of planting decisions. The positive and significant coefficients regarding idle land in the field crops equation and with respect to field crops in the idle/fallow equation are plausible when we consider that traditional farms are the most likely to suffer from the impermanence syndrome. Furthermore, and this may actually be the main reason, field crop rotations are often associated with periods in which land is fallow in order to allow the land to "rest".

There does, however, not seem to be any particular association between field crops and specialty crops. This may be caused by a farm being either traditional or specialized, but not a mix of both. In comparing field crops to specialty crops we also find that only the former exhibit substantive spatial correlation in the dependent variable. This finding is plausible, because traditional farms cover a much larger area than specialized farms. Given the level of spatial aggregation, the area covered by a first-order contiguity matrix is 8.4 km^2. A large corn/soybean farm in Indiana may easily extend beyond these dimensions, whereas a specialized farm will tend to be much smaller and only rarely extend beyond the size of a 2.8-by-2.8 km grid cell. A field crop farmer will therefore make planting decisions that automatically affect several neighboring cells, while this would be highly unlikely for a specialized farmer.

7 Conclusion

This paper is based on the premise that farmers allocate land to the production of specific crops so as to maximize profits. Obviously, in the vicinity of cities farmers are confronted with two countervailing effects: along the rural-urbam land gradient prices for agricultural land will be higher, but farmers can concurrently economize on transportation cost because of the proximity of a large, relatively wealthy consumer base. We therefore hypothesized that the prevalence of low-value, land-intensive traditional crops would be less than for high-value, labor-intensive specialized crops on parcels located closer to urban centers. Our empirical analysis utilizes a system of spatial simultaneous equations for field crops, specialty crops and idle/fallow land with data for an extended area comprising the metropolitan area of Indianapolis and its extended hinterland. The empirical results corroborate our hypothesis regarding the occurrence of different crop types, even to the extent that the theoretical prediction of Von Thünen is replicated in the data.

Once returns to development of a parcel exceed the profits associated with farming, exurban farmers may sell their land for conversion to urban use. Urban pressure in the rural-urban fringe intensifies as cities expand. We therefore explicitly differentiated between a gradual process of urban growth, and urban "sprawl". Urban growth refers to a gradual expansion of urban areas as they consume more agricultural land and other open space. Urban sprawl, however, is a much more dynamic process of urban growth, frequently associated with spatial fragmentation of urban areas, and in turn of agricultural land. We argue that smaller, less geometrically well-shaped fields negate the economies of scale that traditional farms enjoy through the use of large machinery. Our second hypothesis was therefore that sprawling areas further burden traditional farms in the sense that they accelerate the transition to specialized crops or trigger the conversion of farm land to urban use. In our empirical analysis we do find some evidence for these hypothesized effects of urban growth and urban sprawl, but the effects are not statistically different from zero for specialty crops.

In this paper we use crop-specific land cover data at the level of grid cells and a state-of-the-art system of spatially correlated simultaneous equations to model how crop production decisions are affected by the distance to local markets as well as by the differential response of exurban farmers to urban growth and agricultural land fragmentation. In order to do so we used an adjusted log-odds ratio as the dependent variable, but we identified an approach based on fractional logit as an attractive alternative. We will focus additional work in this area on developing a spatial econometric fractional logit model that can be applied in a simultaneous equation system as well.

The empirical results of this research can inform the debate on whether and how exurban agriculture should be protected, and has identified the pivotal role of specialty crops, access to farmers' markets and the relevance of the type of urban growth for the impacts on agriculture. The next step in extending the approach developed in this paper will center on deriving marginal effects, supported by simulation experiments in which policy scenarios will be developed by varying access to farmers' markets and different types of urban growth processes.

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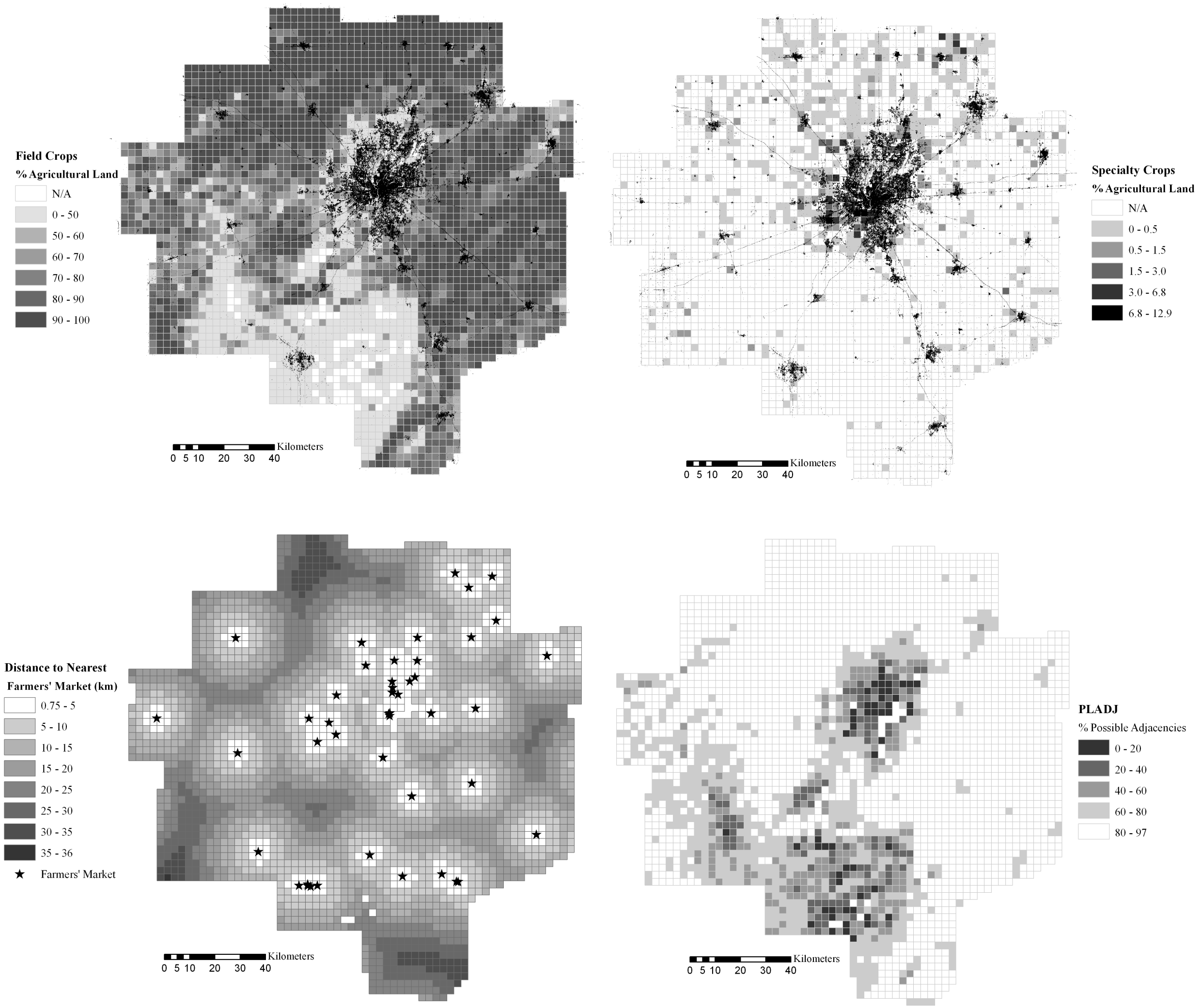

Figure 1: Field and specialty crops as a percentage of agricultural land use, distance to nearest farmers' market, and percentage of like adjacencies

Table 1: GS2SLS and GS3SLS estimation results

	GS2SLS		GS3SLS	
	Estimate	Std. error	Estimate	Std. error
Field crops				
Specialty crops	–0.07145	0.25049	–0.19562	0.20651
Idle land	1.81815**	0.82173	2.09351***	0.56299
W·Field crops	0.38795***	0.03308	0.38545***	0.02885
Intercept	3.97552	2.60422	4.5519**	1.83306
Elevation	–0.0044	0.00133***	–0.00435***	0.00112
Slope	–0.2947***	0.05321	–0.30932***	0.03921
Distance urban center	0.01028*	0.00559	0.00949*	0.00498
Change housing units	–0.01136***	0.00343	–0.01223***	0.00261
Area	0.01463***	0.00129	0.01437***	0.00111
Prob. like adjacency	13.36184***	3.67223	14.16515***	2.60009
Specialty crops				
Field crops	0.22851**	0.10481	0.15103*	0.08976
Idle land	1.23777	0.84723	1.60916**	0.66186
W·Specialty crops	0.13565	0.09386	0.07656	0.07847
Intercept	2.7098	2.61415	3.45717*	2.05871
Elevation	0.00137	0.00143	0.00094	0.00117
Slope	0.00124	0.06905	–0.03801	0.0552
Distance urban center	–0.00752	0.00519	–0.00681	0.00446
Change housing units	–0.00303	0.00353	–0.00453	0.00285
Area	–0.00583***	0.00193	–0.00459***	0.00168
Prob. like adjacency	0.33019	4.59417	2.57856	3.59474
Distance farmers' markets	–0.0107**	0.00484	–0.00926**	0.00373
Idle land				
Field crops	0.05663	0.04334	0.14811***	0.03329
Specialty crops	0.08608	0.09225	0.11546	0.07887
W·Idle land	0.03227	0.03357	0.08747***	0.02618
Intercept	–2.74164***	0.33164	–2.0146***	0.30898
Elevation	0.00117**	0.0005	0.00114**	0.00046
Slope	0.07012***	0.01347	0.08588***	0.01198
Distance urban center	–0.00246	0.00238	–0.00245	0.00223
Change housing units	0.00372***	0.00074	0.00406***	0.00073
Area	–0.00053	0.00091	–0.00208***	0.00073
Prob. like adjacency	–4.94396***	0.58371	–5.20291***	0.47034