Urbanization and the Viability of Local Agricultural Economies

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ABSTRACT. *Urbanization presents both opportunities and challenges for farmers and farm-supporting sectors on the urban fringe. This paper examines the effects of urbanization on the viability of input suppliers and output processors and on the cost and profitability of farming. An analytical model is developed to provide insights into such effects. This model motivates a multiple-equation empirical model that we estimate using county-level panel data for California, Idaho, Oregon, and Washington. Results provide evidence that urbanization has a significant impact on agricultural infrastructure, farm production costs, and net farm income and suggest that agriculture-related opportunities of urbanization outweigh the challenges.* (JEL O18)

I. INTRODUCTION

During the past 25 years, many regions in the United States have experienced rapid urbanization and farmland development. From 1982 to 2003, the total developed area in the United States increased by 48%, whereas the total cropland acreage decreased by 12%. The pace of urban development increased significantly during the period, from an average of 1.4 million acres developed per year between 1982 and 1992 to 2.0 million acres per year between 1992 and 2003 (USDA 2003). The American Farmland Trust (2002) reports that an average of 400,000 acres of prime farmland was converted to development per year in the 1980s and early 1990s (Sorrenson, Greene, and Russ 1997). A major cause of farmland development is the continuing dispersion of the population from cities to suburban and exurban areas. This form of development is less dense than urban development, affecting greater areas per unit of population. As a result of urban, suburban, and exurban development (henceforth urbanization), low-density and noncontiguous land use patterns have become a common feature of American landscapes.

Urbanization has presented both opportunities and challenges for farmers on the urban fringe. The emergence of a new customer base has provided farmers new opportunities for higher-value crops. Many farmers have shown remarkable adaptability in adjusting their enterprises to take advantage of new economic opportunities at the urban fringe. The explosion in many suburban areas of nurseries, vegetable farms, vineyards, and other high-value crop industries illustrates how quickly agricultural economies can evolve. Several studies have documented that farmers crop more intensively in areas with high population density and growth (Lockeretz 1986, 1988).

Urbanization also presents challenges to farmers. Negative externalities associated with urbanization increase the cost of farming and threaten the viability of the agricultural economy. Conflicts with nonfarm neighbors and vandalism, such as destruction of crops and damage to farm equipment, are major concerns of farmers at the urban fringe (Lisansky 1986). Conversely, being part of a large farming community (a cluster) can offer many benefits (Porter 1998). It allows a farm to operate more productively in sourcing inputs, and in accessing information, technology, and needed institutions. For example, farmers depend on neighboring farmers for many services, includ-

Land Economics • February 2011 • 87 (1): 109–125
ISSN 0023-7639; E-ISSN 1543-8325

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ing equipment sharing, land renting, custom work, and joint irrigation projects (Rashford et al. 2003). These services disappear when neighboring farms are converted to development. Therefore, with urbanization farmers may no longer be able to take advantage of economies of scale in production that come from information sharing and formal and informal business relationships between neighboring farms. In addition to enhancing productivity, being part of a large farming community can be conducive to innovations and new business formation (Porter 1998).

In addition to these "technological" externalities, urbanization also generates "pecuniary" externalities. Pecuniary externalities arise when urbanization causes a change in the prices of agricultural inputs or outputs. As the number of farmland acres drops below a threshold, the nearest input supplier may close or relocate because of insufficient demand for farm inputs. A farmer may have to pay more for inputs or spend more time to obtain equipment repairs (Lynch and Carpenter 2003; Lynch 2006). Competition for labor from nonagricultural sectors may raise farmers' labor costs. Likewise, as the number of farmland acres drops below a threshold, the nearest processor or shipper may close its business because of an insufficient supply of output, and farmers may face additional transportation costs or lower output prices. This suggests that even if individual farmers may have a constant return to scale technology, at an aggregate level, there may exist a critical mass of farmland below which the vertically linked nonfarm sectors may have to shut down, raising the cost of farming.

Urbanization may also cause the "impermanence syndrome," leading to a reduction in investment in new technology or machinery or to the idling of farmland (Lopez, Adelaja, and Andrews 1988). As urbanization intensifies, agricultural and nonagricultural land use conflicts become more severe. This may lead to an increase in local ordinances designed to force farmers to internalize some of the negative externalities normally generated by agriculture (Lopez, Adelaja, and Andrews 1988).[1]

The primary objective of this paper is to evaluate the effect of urbanization on the viability of farm-supporting sectors (i.e., input suppliers, output processors) and on the cost and profitability of agriculture. To achieve this objective, we first develop a theoretical model to analyze the interrelationship between agriculture and its supporting sectors and then examine how the relationship is affected by urbanization. We then conduct an empirical analysis to evaluate the effect of urbanization on local agricultural economies using county-level data from four western states of the United States (Oregon, Washington, Idaho, and California), focusing on the influence on (1) the number of input suppliers, (2) the number of output processors, (3) farmers' production costs, and (4) net farm income.

The issue of how urbanization affects agriculture has been studied in the literature. In a classic paper, Lopez, Adelaja, and Andrews (1988) analyzed the effects of suburbanization on agricultural production choices, prices, and profits. They found that although some subsectors of agriculture, such as vegetable production, may benefit from urbanization, others are adversely affected. They concluded that the overall impact on profits is positive when capital gains on land are included. Lockeretz (1986) examined the characteristics of counties by their distance to metro areas and found smaller farm sizes, a higher proportion of harvested cropland, a higher standard of living, and more reliance on crops than livestock in counties closer to metro areas than in those farther away. In a later study, Lockeretz (1989) examined agricultural trends in midwestern counties at varying distances from metropolitan centers and found that metropolitan counties experienced the most rapid

[1] Economic theory suggests pecuniary externalities have no efficiency significance in competitive markets; that is, a pecuniary externality does not cause misallocation of resources, nor does it reduce the net economic benefits to society as a whole. However, from an equity standpoint, pecuniary externalities matter: they clearly affect the profits of individual farmers and the viability of local agricultural economies. In addition, in the presence of imperfect competition and increasing returns to scale, pecuniary externalities have consequences for efficiency (Krugman 1991). In particular, if there is a critical mass of farmland needed to sustain an agricultural economy, agricultural profits may decline once a region has dropped below this threshold, and land use may be inefficient.

decrease in the amount of farmland. However, loss of farmland was partially offset by increasing intensity, a finding that conflicts with the prediction based on the impermanence syndrome. Gardner (1994) found that a 100% increase in the population resulted in an 11% decrease in farmland in metro counties in the Northeast. Larson, Findeis, and Smith (2001) reported that more than half the value of total U.S. farm production was derived from counties facing urbanization pressure. Lynch and Carpenter (2003) examined whether the farm sector has a critical mass by estimating three econometric models using data from six Mid-Atlantic states. They found that having less than 189,240 harvested cropland acres accelerates a county's rate of farmland loss. Yet when the data are divided into an early (pre-1978) and late (post-1978) period, this threshold effect disappears in the later period. Daniels and Lapping (2001) proposed a critical mass threshold definition of (1) at least 100,000 acres, (2) \$50 million in agricultural sales, and/or (3) 20,000 acres of preserved farmland. Rashford et al. (2003) developed a simulation model to analyze the degree of economic interconnectedness among neighboring farms and to assess the impact on neighboring farms when one farm in a small farming area is converted to alternative land uses. The present study makes a contribution to the literature by analyzing the effect of urbanization on local agricultural infrastructure as well as the costs and profitability of farming in urbanizing areas.

II. THE THEORETICAL MODEL

Consider a local agricultural economy that includes farmers, agricultural input suppliers, output processors, and consumers. The farmers purchase inputs from the input suppliers and sell their products to the output processors. All farmers are price takers in both the input and output markets, and produce an agricultural commodity using a constant return to scale production technology. The unit of output is normalized such that the production function takes the form $y = \alpha + \beta x - 0.5x^2$, where y is the yield per acre, x is the input application, and α and β are positive parameters. Assume that each farmer chooses input application to maximize profit. Then the optimal input application is $x^* = \beta - (w/p)$, where w and p are the input and output prices, respectively. The optimal yield is $y^* = \gamma - 0.5(w/p)^2$, where $\gamma = \alpha + 0.5\beta^2$; the per-acre net return is $\pi^a = \gamma p - \beta w + 0.5(w^2/p)$.[2]

Let A be the total acres of cropland in the region, then the total demand for the input and the total supply of the output in the region are

$$X = A\left(\beta - \frac{w}{p}\right), \qquad [1]$$

$$Y = A\left[\gamma - 0.5\left(\frac{w}{p}\right)^2\right]. \qquad [2]$$

Note that A is a function of the net return to agriculture π^a (therefore, p, w) as well as the net return to developed land π^d. Based on previous studies (e.g., Alig and Healy 1987; Hardie and Parks 1997), π^d is assumed to be a function of the existing level of urbanization, measured by population density (D) and total developed area (U) and location characteristics of the area (X), such as the distance to the nearest metropolitan center and the level of natural amenities in the area. Thus, $A = A(p,w,U,D,\mathbf{X})$.[3]

Consider the supply of the agricultural input. Suppose there are multiple input suppliers initially, and the suppliers engage in oligopolistic competition. The exit and entry decisions of the suppliers are conceptualized as a two-stage process following Mas-Colell, Whinston, and Green (1995, 405–7). In the first stage, all suppliers decide "in" or "out." If a supplier decides "in," it incurs a setup cost $K > 0$. Once the setup cost is sunk, all sup-

[2] The per-acre net return refers to the profit before the opportunity costs of land and labor are deducted.

[3] Note that population density itself is potentially endogenous because it is affected by the net return to agriculture, which affects the opportunity cost of development. However, previous studies suggest that urbanization is mainly driven by forces outside agriculture, particularly in recent history. To examine the effects of urbanization driven by the external forces, population density is treated as an exogenous variable in this section. In the empirical analysis, we lag the population density variable to avoid any potential endogeneity issues.

pliers that have decided "in" play an oligopolistic Cournot game in the second stage and supply the input at a constant marginal cost m. This two-stage model defines a dynamic game. In a subgame perfect Nash equilibrium, no supplier wants to change its exit decision given the decisions of the other suppliers. There is an equilibrium with N^{s*} suppliers choosing to stay in the input market if and only if $\pi^s(N^{s*}) \geq K$ and $\pi^s(N^{s*}+1) < K$, where $\pi^s(N)$ denotes the profit of a supplier in Stage 2 equilibrium when there are N input suppliers in the market.[4]

Given the input demand function [1], the second-stage output, $x^s(N)$, and profit, $\pi^s(N)$, for each input supplier can be derived as

$$x^s(N) = \frac{A(\beta p - m)}{p(N+1)}, \qquad [3]$$

$$\pi^s(N) = \frac{A}{p}\left(\frac{\beta p - m}{N+1}\right)^2. \qquad [4]$$

Note that given N and p, both $x^s(N)$ and $\pi^s(N)$ increase with A. Thus, if urbanization reduces the total amount of farmland, it will reduce the output and profit of an input supplier, at least in the short run. Solving for N at which $\pi^s(N) = K$ gives

$$\tilde{N}^s = \frac{\sqrt{A}(\beta p - m)}{\sqrt{pK}} - 1, \qquad [5]$$

The equilibrium number of input suppliers N^{s*} equals the largest integer that is less than or equal to $\tilde{N}^s$, but for simplicity, we simply treat $\tilde{N}^s$ as N^{s*} from now on. Note that given p, $\tilde{N}^s$ increases with A. Thus, with urbanization, there will be fewer input suppliers in the region if the output price is not affected. However, if urbanization also increases the output price p, it could potentially increase the number of input suppliers in the region. Solving for A at which $\tilde{N}^s(A) = 1$ gives the threshold of farmland acreage below which no input supplier will operate in the region. Specifically, when $A < 4pK/(\beta p - m)^2$, the demand for the inputs is so low that even if a supplier can charge a monopolist's price, it would still not be able cover its total cost.

The total supply of the agricultural input equals the output per supplier multiplied by the number of suppliers in the market, that is, $N^{s*} \cdot x^s(N^*)$. Setting the total supply equal to the total demand, the equilibrium price of the agricultural input, w^*, can be derived as

$$w^* = m + \sqrt{\frac{pK}{A}}. \qquad [6]$$

Equation [6] clearly shows that if the output price is not affected by urbanization, farmers will face higher input prices as more farmland is developed. Since $A = A(p,w,U,D,\mathbf{X})$, equation [6] implicitly defines w^* as a function of p, m, U, D, and $\mathbf{X}$, which is denoted by $w^* = w(p,m,U,D,\mathbf{X})$.

Farmers' output prices may also be affected by urbanization. Specifically, by substituting $A = A(p,w,U,D,\mathbf{X})$ and $w^* = w(p,m,U,D,\mathbf{X})$ into [2], the total supply of the agricultural output in the region can be derived as a function of $(p,m,U,D,\mathbf{X})$. If the output market is assumed to be dominated by a few processors and each of them engages in Cournot competition, the equilibrium output price for farmers can be derived as $p^* = p(U,D,\mathbf{X},\mathbf{M})$, where $\mathbf{M}$ is a vector of constant marginal costs for the input suppliers and the output processors. As in the input market, it can be shown that if urbanization does not increase the output price of the processors, there will be fewer processors in the region, and the equilibrium price of the agricultural output will be lower.[5] However, with urbanization, the processors will face increasing demand for their output because of a larger customer base. To obtain more input, the processors may also be willing to pay a higher price for agricul-

[4] For simplicity, we assume the input suppliers are identical. But the analysis can be extended to the case of heterogeneous firms. If the firms have different productivity, low-productivity firms will exit first. In equilibrium, the firm that is least productive earns zero profit, while the rest of the firms have a positive profit.

[5] This depends on the assumption that input and output markets are local. If markets are largely nonlocal, then urbanization will have less of an impact on the number of input suppliers and output processors in the region.

tural output supplied by the farmers. In sum, $\partial p^*/\partial U \leq 0$ if developed area has little effect on the demand for agricultural output, and $\partial p^*/\partial U > 0$ if development significantly increases the demand for agricultural output (likewise $\partial p^*/\partial D > 0$ if an increase in population density significantly increases demand for the agricultural output).

Given the equilibrium prices of the input and output for farmers, the equilibrium number of input suppliers and the farmers' production cost and net return can be derived as

$$\tilde{N}^{s*} = \frac{\sqrt{A^*}(\beta p^* - m)}{\sqrt{p^* K}} - 1, \qquad [7]$$

$$C^{a*} = w^* x^* = \left(m + \sqrt{\frac{p^* K}{A^*}}\right)\left(\beta - \frac{m}{p^*} - \sqrt{\frac{K}{p^* A^*}}\right), \qquad [8]$$

$$\pi^{a*} = \gamma p^* + \frac{1}{2p^*}\left(m + \sqrt{\frac{p^* K}{A^*}}\right)^2 - \beta\left(m + \sqrt{\frac{p^* K}{A^*}}\right), \qquad [9]$$

where $\tilde{N}^{s*}$, C^{a*}, and π^{a*} are all functions of $(U,D,\mathbf{M},\mathbf{X})$. The effect of urbanization on the number of input suppliers can be derived by differentiating [7] with respect to U:

$$\frac{\partial \tilde{N}^{s*}}{\partial U} = \frac{(1 + \tilde{N}^{s*})}{2A^*}\frac{\partial A^*}{\partial U} + \frac{(1 + \tilde{N}^{s*})}{2p^*}\frac{\partial p^*}{\partial U}. \qquad [10]$$

If urbanization reduces the total amount of farmland (i.e., $\partial A^*/\partial U < 0$) but has no effect on the price of agricultural output (i.e., $\partial p^*/\partial U = 0$), [10] is negative, implying that urbanization reduces the number of input suppliers in the region. However, if urbanization also increases the demand for agricultural output and thus the output price p^* (i.e., $\partial p^*/\partial U > 0$), its impact on the number of input suppliers cannot be determined analytically because input use intensification may occur due to output price increases. Higher agricultural supply and input application per acre could lead to higher demand for agricultural inputs by farmers even if the total acres of farmland has been reduced.

Urbanization can also have a positive or a negative effect on farm net return, depending on its effect on the price of agricultural output. By Hotelling's rule,

$$\frac{d\pi^{a*}}{dU} = \frac{d\pi^{a*}}{dw^*}\frac{dw^*}{dU} + \frac{d\pi^{a*}}{dp^*}\frac{dp^*}{dU} = -x^*\frac{dw^*}{dU} + y^*\frac{dp^*}{dU}. \qquad [11]$$

If urbanization reduces the total amount of farmland but has little effect on the price of agricultural output, then $dw^*/dU > 0$ by [3]. In this case, $d\pi^{a*}/dU < 0$, implying that urbanization reduces farm net return. However, if urbanization increases the price of agricultural output, $d\pi^{a*}/dU$ can be positive or negative, depending on the relative magnitude of (dw^*/dU) and (dp^*/dU). Likewise, the effect of urbanization on farmers' production costs can be positive or negative, depending on the elasticity of the demand for agricultural inputs and the effect of urbanization on the input price.

So far, we have assumed that the local agricultural economy produces a single commodity. But the emergence of a new customer base with urbanization may provide opportunities for farmers to grow high-value crops such as flowers and vegetables. To examine such structural changes associated with urbanization, we expand the model to include two commodities; one is a traditional crop such as corn or wheat, and the other is a high-value specialty crop such as a flower or a vegetable. The high-value specialty crop is more input intensive and faces increasing demand with urbanization. The total demand for agricultural input is

$$X = A(s_1 x_1 + s_2 x_2), \qquad [12]$$

where x_1 and x_2 are the per-acre input use for the specialty and traditional crops, respectively; and s_1 and s_2 are the shares of land allocated to the two crops. Assume that each parcel is allocated to the crop that generates the highest profit; in equilibrium the land in the region will be allocated between the two crops such that their marginal profits are equalized:

$$\pi_1^{a*}(s_1,U,D,\mathbf{M},\mathbf{X}) = \pi_2^{a*}(s_2,U,D,\mathbf{M},\mathbf{X}), s_1 + s_2 = 1, \qquad [13]$$

where π_i^{a*} is the marginal profit of increasing land allocation to crop i, and $\partial\pi_i^{a*}/\partial s_i < 0$. If $\pi_1^{a*} < \pi_2^{a*}$ for $s_2 = 1$, then only the traditional crop is planted in the region.

Suppose the demand for the specialty crop increases with urbanization and, as a result, the profit from producing the specialty crop increases faster than the profit from producing the traditional crop. With equation [13], it is easy to show that more land will be allocated to the specialty crop. Since the specialty crop is more input intensive than the traditional crop (i.e., $x_1 > x_2$), the total demand for agricultural input increases even if the total amount of farmland A decreases, because the average input use per acre, $(s_1x_1 + s_2x_2)$, increases. Furthermore, if the two crops use different types of inputs, urbanization can also change the mix of agricultural inputs used in the region, by inducing farmers to convert some portion of their land to production of specialty crops.

In sum, urbanization can have a positive or a negative effect on agricultural infrastructure, farmers' production costs, and net farm returns. If urbanization has little effect on farmers' output prices, there will be fewer input suppliers in business with urbanization. The input markets will become less competitive and the prices of inputs may increase. However, with urbanization, the total demand for agricultural output may instead increase, which may lead to higher prices for agricultural outputs. In addition, farmers may switch to high-value, input-intensive specialty crops such as flowers and vegetables. In this case, the effects of urbanization on the number of input suppliers, farmers' production costs, and net farm returns cannot be determined analytically. In the next section, we conduct an empirical analysis to examine how urbanization affects agricultural support sectors, farm production costs, and net farm returns.

III. THE EMPIRICAL MODEL

The empirical model is specified based on the theoretical analysis. The model is the empirical counterpart of equations [7] through [9], which specify the number of input suppliers, the number of output processors, the per-acre production cost, and per-acre net return as functions of all exogenous variables included in each equation, including U, D, $\mathbf{M}$, and $\mathbf{X}$:

$$N_{it}^{s*} = \alpha_0^s + \alpha_1^s U_{n,t-1} + \alpha_2^s U_{n,t-1}^2 + \alpha_3^s D_{n,t-1} + \alpha_4^s D_{n,t-1}^2 + \alpha_5^s U_{n,t-1} D_{n,t-1} + \boldsymbol{\alpha}_6^s \mathbf{M}_{i,t-1} + \boldsymbol{\alpha}_7^s \mathbf{X}_{it} + \varepsilon_{it}^s, \quad [14]$$

$$N_{it}^{o*} = \alpha_0^o + \alpha_1^o U_{n,t-1} + \alpha_2^o U_{n,t-1}^2 + \alpha_3^o D_{n,t-1} + \alpha_4^o D_{n,t-1}^2 + \alpha_5^o U_{n,t-1} D_{n,t-1} + \boldsymbol{\alpha}_6^o \mathbf{M}_{i,t-1} + \boldsymbol{\alpha}_7^o \mathbf{X}_{it} + \varepsilon_{it}^o, \quad [15]$$

$$C_{it}^{a*} = \alpha_0^c + \alpha_1^c U_{n,t-1} + \alpha_2^c U_{n,t-1}^2 + \alpha_3^c D_{n,t-1} + \alpha_4^c D_{n,t-1}^2 + \alpha_5^c U_{n,t-1} D_{n,t-1} + \boldsymbol{\alpha}_6^c \mathbf{M}_{i,t-1} + \boldsymbol{\alpha}_7^c \mathbf{X}_{it} + \varepsilon_{it}^c, \quad [16]$$

$$\pi_{it}^{a*} = \alpha_0^\pi + \alpha_1^\pi U_{n,t-1} + \alpha_2^\pi U_{n,t-1}^2 + \alpha_3^\pi D_{n,t-1} + \alpha_4^\pi D_{n,t-1}^2 + \alpha_5^\pi U_{n,t-1} D_{n,t-1} + \boldsymbol{\alpha}_6^\pi \mathbf{M}_{i,t-1} + \boldsymbol{\alpha}_7^\pi \mathbf{X}_{it} + \varepsilon_{it}^\pi, \quad [17]$$

where i, n, and t index county, "neighborhood," and time, respectively. Following Holmes (1999), we define neighborhood as a given county and all counties having centers within 50 miles (as the crow flies) of that county's center.[6] The dependent variables of equations

[6] Our main objective in measuring developed land and population density at the neighborhood level in the equations of input suppliers and output processor is that we expect farmers buy farm inputs and sell farm outputs not just in their own county but also in locations within a given distance. In the absence of a survey to measure the distance farmers are willing to travel for marketing purposes, our choice of 50 miles is based on assumption rather than evidence. It seems reasonable to assume that farmers in the western states would drive about 50 miles, or one hour, to buy inputs or market outputs. From a practical standpoint, a second reason for measuring developed land at the neighborhood level is that the National Resources Inventory data are not intended for county-level analysis. When neighborhood is defined with a 50-mile cutoff, nearly all counties are grouped with other counties to form a neighborhood. This definition of neighborhood thereby reduces the problems associated with using NRI data for county-level analysis. For the cost and net income equations, a more substantive reason for our choice of 50 miles rather than a shorter distance such as 10 or 20 miles is that previous studies found that the favorable growth effects in nearby urban areas can spill over long distances. For example, Partridge et al. (2008) found that counties adjacent to metropolitan areas grew fastest during the 1990s, and the favorable growth effects in nearby urban areas spilled over for about 180 km into the countryside.

[14] through [17] are the number of agricultural input suppliers, the number of agricultural output processors, the average per-acre farm production cost, and the average per-acre net farm income, respectively. Based on equations [7] through [9], these variables depend on the level of urbanization, associated with the amount of developed acres U and population density D. We lag the developed acres and the population density explanatory variables in part because of a concern with potential endogeneity. A substantive reason for lagging these variables is that decisions to start up or shut down a business take time. For instance, as the amount of cropland in a given county declines and farm input suppliers lose their customer base, they may deliberate on the decision of whether to stay in business or exit. Similarly, external effects on farm production costs and net farm returns associated with urbanization and farmland development may occur with a lag. For example, one posited benefit to farmers of urbanization is the possibility of higher farm income from producing and marketing specialty crops to urban consumers. Moving out of more traditional crops and into such specialty crops may take time.

It should be noted that developed acres U and population density D are measured at the neighborhood level, while all other model variables are measured at the county level. We expect that the number of input suppliers, output processors, farm production costs, and net returns to farming in a given county are influenced by urbanization in that county as well as in neighboring counties. Thus, an important advantage of measuring developed acres U and population density D at the neighborhood level is to take into account potential spatial autocorrelation directly.

Equations [7] through [9] suggest that dependent variables are affected by the input suppliers' and output processors' constant marginal costs $\mathbf{M}$, including labor costs. Therefore, we include the lagged wage in wholesale trade and food manufacturing in equations [14] through [17]. Vector $\mathbf{X}$ is a set of factors hypothesized to affect the net returns to developed land, such as median household income, the level of natural amenities, road density, land quality, land area, and the distance to the nearest metropolitan center. Some of these variables may also attract or deter input suppliers and output processors from locating in a county (Goetz 1997).

An important question for this study is if there is a "critical mass" of farmland necessary to sustain the necessary agricultural infrastructure and local agricultural economies. To provide insights into this issue, equations [14] through [17] are specified as a quadratic function of U and D to identify any potential threshold effects and nonlinear relationships in the equations. In addition, a variable is added to capture the interaction between the effects of urban development and population density.

IV. DATA AND ESTIMATION

Data for this study come from several sources and concern years 1987, 1992, 1997, and 2002. Information on the number of farm input suppliers and farm output processors comes from the U.S. Census Bureau's County Business Patterns CD-ROM for years 1992, 1997, and 2002. The farm input suppliers variable is the number of establishments engaged in the wholesale distribution of agricultural machinery and equipment (Standard Industrial Classification code [SIC] 5083 or North American Industry Classification System code [NAICS] 421820) plus the number of establishments involved in wholesale distribution of animal feeds, fertilizers, agricultural chemicals, seeds, and other farm supplies (SIC 5191 or NAICS 422910). The farm output processors variable is the number of food manufacturing establishments (SIC 2000 or NAICS 311).[7]

The Census of Agriculture is the source of data on production cost per farmland acre, net farm income per farmland acre, and harvested cropland acres. Net cash farm income per farmland acre is used rather than net cash farm returns because the latter is unavailable for 2002. Net cash farm income is net cash farm returns plus government payments plus other farm income; net cash farm income does not

[7] Farm output processors is SIC 2000 except canned and cured fish and seafood (SIC 2091, NAICS 311711), prepared fresh or frozen fish and seafoods (SIC 2092, NAICS 311712), roasted coffee (SIC 2095, NAICS 31192), and manufactured ice (SIC 2097, NAICS 312113).

include income from off-farm employment. To account for inflation we deflate farm production cost and net cash farm income using the Consumer Price Index for All Consumers (CPI-U) (1982–1984 = 1).

From the Census of Population and Housing we obtain data on population density by year. We linearly interpolate values for years 1987, 1992, and 1997 using data for years 1980, 1990, and 2000. As mentioned earlier, we measure population density at the neighborhood level, that is, a given county and all counties having centers within 50 miles (as the crow flies) of that county's center. The distance weights matrix feature in Geoda software (Anselin, Syabri, and Kho 2006) is used to determine each county's neighbors. County boundary files for this procedure come from the U.S. Census Bureau. The county map comes unprojected and is projected in ArcGIS with the U.S. Contiguous Albers Equal Area projection as recommended by the U.S. Census Bureau. Total acres of developed (built-up) land at the neighborhood level were estimated using data from the National Resources Inventories.

The data on returns to agricultural land come from the Bureau of Economic Analysis. Returns per acre are measured as by Langpap, Hascic, and Wu (2008) using income from crops to represent revenue and production expenditures to measure costs. Some expenditures are allocated to crop production (e.g., purchase of seeds, fertilizer, and lime), but others (e.g., petroleum products, labor, and other expenditures) are not. To allocate these latter expenditures we calculate the share of total revenues that crop revenue represents and we allocate the same share of these expenditures to agricultural production costs. We adjust the resulting measure of returns by the CPI-U. Finally, to obtain returns per acre we use data from the National Resources Inventories to estimate the total acreage allocated to agriculture in each period and divide total adjusted returns in each county by this amount.

Wage variables are constructed from County Business Patterns data and are proxied by dividing a county's first-quarter payroll by total mid-March employees. The "wholesale wage" variable is for wholesale trade (SIC 5000/5100) as a whole. We do not focus on agricultural wholesale trade, due to the large number of missing values for this sector. The "manufacture wage" variable is for food manufacturing as a whole (SIC 2000). These wage variables are adjusted for inflation using the CPI-U (1982–1984 = 1).

Data on road mileage come from the Bureau of Transportation Statistics. The land area variable comes from the U.S. Census of Population and Housing. The USDA ERS is the source of data for the natural amenity scale, a variable that summarizes natural amenities on the basis of six factors: warm winter (average January temperature), winter sun (average number of sunny days in January), temperate summer (low winter-summer temperature gap), summer humidity (low average July humidity), topographic variation (topography scale), and water area (water area proportion of total county area).

One drawback of the ERS amenity measure is it aggregates across many dimensions such that one is uncertain what dimensions are responsible for a measured effect. Another is it does not capture the richness of local amenities, and recent research in the rural economic development literature suggests that the nature of amenity matters to local economic growth. In the present paper, however, the natural amenity variable is a control variable of only secondary interest, and it more than adequately controls for amenity influences in this circumstance. It is thus unnecessary to include disaggregated amenity variables, particularly since this would potentially introduce collinearity problems.

The compiled GIS database consisting of all variables described above is used for the empirical analysis. Table 1 presents descriptive statistics for these variables.

The estimation of the empirical models exploits the panel nature of the data and uses the random-effects specification. By treating the data as a panel, degrees of freedom are gained and estimation efficiency is thus improved. The basis of our choice to use a random-effects model rather than a fixed-effects model deserves mention.[8] There are some important

[8] Random-effects and fixed-effects models, which differ in their treatment of omitted variables, are commonly used to analyze panel data. In the fixed-effects model, individual-

TABLE 1
Descriptive Statistics of Model Variables ($N = 531$)

Variable Name	Variable Definition	Mean	Std. Dev.
Dependent variables			
Input suppliers	The number of farm input suppliers	15.34	23.17
Output processors	The number of farm output processors	22.47	60.57
Production cost	Farm production cost per farmland acre ($/acre)	402.24	2,472.28
Net farm income	Net farm income per farmland acre ($/acre)	125.74	1,037.18
Independent variables			
Developed land	Built-up land (in 10,000 acres) in neighborhood, lagged 5 years	21.60	24.04
Population density	Population density (people per square mile) in neighborhood, lagged 5 years	225.83	574.32
Government payment	Total government payments received ($1,000), lagged 5 years	2,755.41	4,637.93
Wholesale wage	Wholesale trade wage (payroll $/employees), lagged 5 years	3.84	1.11
Manufacture wage	Food manufacturing wage (payroll $/employees), lagged 5 years	4.44	1.11
Median income	Median household income ($1,000), adjusted for cost of housing differences, lagged 5 years	29.19	5.05
Population 65 and older	Percent population aged 65 and older, lagged 5 years	13.49	3.54
Adults without high school	Percent persons 25 years and older with less than high school degree, lagged 5 years	21.71	6.85
Fair market rent	Fair market rent index (FMR/average FMR), lagged 5 years	1.00	0.22
Average land quality	Average land quality in neighborhood (LCC = 1 or LCC = 2), lagged 5 years	0.24	0.14
Natural amenities	Natural amenities scale	4.09	2.65
Highway density	State roads, federal roads, and interstates as a share of total land area	0.31	0.32
Distance to cities	Distance to metro areas and large cities (miles)	59.76	144.34
Land area	Land area (square miles)	2,266.93	2,336.56

Note: Descriptive statistics are generally for three-year averages or time-period averages: 1992, 1997, and 2002 for nonlagged variables; 1987, 1992, and 1997 for lagged variables; and 1987–1992, 1992–1997, and 1997–2002 for change variables. The exceptions are amenities, highway, distance to cities, and land area, which concern a single year only. All monetary values are adjusted for inflation using the Consumer Price Index for All Urban Consumers (1982–1984 = 1). Developed land and density are measured at the neighborhood level; all other variables are at the county level.

advantages of the random-effects approach relative to a fixed-effects model. One, random effects is more efficient, because it uses more information than does fixed effects. Two, unlike the fixed-effects model, time-invariant variables can be included in the random-effects model (Johnson 1995). Alongside its advantages, the random-effects model has an important drawback: it assumes the error term is uncorrelated with all explanatory variables (Hsiao 1986). Random effects are thus an appropriate specification to the extent that we have included the relevant explanatory variables in the models.[9]

varying, time-invariant (e.g., gender or "motivation") and time-varying, individual-invariant (e.g., interest rates) omitted variables are assumed to be constants and enter as binary variables in the regression equation. In random effects, omitted variables are viewed as random and the error term has three components: the usual error term; randomness due to individual, time-invariant omitted variables; and a random variable reflecting time, individual-invariant omitted variables (Hsiao 1986).

[9] The error terms in the regression models may be spatially correlated. It is difficult to estimate a random-effects model with a spatial error term. We attempt to take into account potential spatial autocorrelation directly by measuring developed acres U and population density D at the neighborhood level. It is also expected that the variable for distance to the nearest city captures part of the spatial dependency. Spatially dependent panel data estimators are available (e.g., LeSage and Pace 2009), but the use of these complex estimators is beyond the scope of the present study. Further, as pointed out by an anonymous reviewer, a recent study of land use decisions in Indonesia found that accounting for spatial dependency resulted in only small changes in the study's empirical results and no changes in the study's policy implications (Robertson, Nelson, and De Pinto 2009). We should also point out that there is a "spike" at zero for the distributions of number of input suppliers (17% have zero values) and number of output processors (14% have zero values), which may suggest that use of a zero-inflated model is appropriate.

V. RESULTS

Regression results for the empirical model are presented in Table 2. Our discussion of the results starts with the overall fit of the model and then focuses on the results for control variables and finally on the findings for the explanatory variables of primary interest–developed acreage and population density reflecting urbanization. *R*-squared terms reported in Table 2 indicate that 57% of the variation in input suppliers and 56% of the variation in output processors are explained by the independent variables included in the models. *R*-squared measures for production cost (34%) and net farm income (18%) are much lower, suggesting that important determinants of these outcomes may be missing from the equations.

Findings for the control variables generally agree with prior expectations. As shown in Table 2, counties that receive a large amount of government payments tend to have more input suppliers. At the county level, production costs have a positive correlation with the food manufacturing wage. Counties with a higher percentage of adults that are less than 65 years of age and who do not possess a high school degree tend to have more output processors. Counties with a higher natural amenities scale are found to have more input suppliers, more output processors, and higher farm production cost. Net farm income in the study counties has a positive association with highway density. Proximity to cities is associated with higher production costs and higher net farm income. Larger counties, in terms of area, have more farm input suppliers and more farm output processors. The time dummies indicate that counties in the four western states had fewer input suppliers, more output processors, and higher production cost per acre in 2002 than in 1992 and 1997. Both time dummies are statistically insignificant in the net farm income equation, indicating that there is no statistical difference in net farm income between 2002 and 1992 or 1997 other than that explained by the other explanatory variables.

We turn now to the results of primary interest–those that concern developed acres and population density.[10] Findings in Table 2 provide strong empirical evidence that urbanization affects input suppliers, output processors, farm production costs, and farm income. Of the 20 coefficients on developed acres and population density and their quadratic terms and interaction in the four equations, [17] are statistically significant at the 10% level or better.

Both developed land and population density have a positive coefficient on their linear term in the number of farm input suppliers equation, but have a negative coefficient on their quadratic term. This suggests that the number of farm input suppliers increases at a decreasing rate with land development and population density. In addition, the effects of land development and population density on the number of input suppliers reinforce each other, as indicated by the positive and significant coefficient on their interaction term. One possible explanation for these results is that increasing land development and population create opportunities for farmers to grow high-value specialty crops such as flowers and vegetables. Such operations tend to be more intensive and thus need more inputs. The effect of urban development on the demand for the high-value crops is reinforced by higher population density. This effect will eventually turn negative, because when all farmland is developed, there will be no need for input.

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[10] To assess sensitivity of the empirical results to the choice of neighborhood cutoff, we redefined neighborhood as a given county and all counties having centers within 25 miles of that county's center. We reestimated the empirical models with developed land and population density measured using the 25-mile definition of neighborhood. For the input suppliers' model, the parameter estimate for one variable changes: developed land (statistically significant at the 0.05 level). For the output processors' model, three variables are no longer statistically significant at the 0.05 level: developed land squared, year 1992, and year 1997. For the production cost model, the parameter estimates for three variables change: developed land (negative coefficient, statistically significant), manufacture wage (not statistically significant), and distance to city (not statistically significant). For the net farm income model, the parameter estimates for six variables change: developed land squared (not statistically significant), population density (not statistically significant), developed land times population density (not statistically significant), median income (statistically significant), fair market rent index (statistically significant), and year 1997 (statistically significant).

TABLE 2
The Effects of Urbanization on Local Agricultural Economies and Their Support Sectors, Random Effects Models

Variable	Number of Input Suppliers		Number of Output Processors		Production Cost per Farmland Acre		Net Farm Income per Farmland Acre	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Developed land	0.1239	0.1143	−0.1050	0.1985	1.1291	20.9829	−2.8213*	1.4923
Developed land squared	−0.0017**	0.0008	−0.0027**	0.0013	0.2938*	0.1596	0.0426***	0.0092
Population density	0.0285***	0.0098	0.1007***	0.0187	4.0062***	1.7950	1.4736***	0.2767
Population density squared	−0.00002***	0.000003	−0.00004***	0.00001	0.0017***	0.0006	0.0003***	0.0001
Developed land* Population density	0.0003***	0.0001	0.0011***	0.0001	−0.0891***	0.0115	−0.0121***	0.0021
Government payment	0.0013***	0.0002	0.0002	0.0002	0.0156	0.0314	0.0007	0.0017
Wholesale wage	0.7196	0.5062	−0.6755	0.7172	97.9534	119.3271	−4.0734	4.8861
Manufacture wage	0.8286	0.5242	−0.7145	0.7596	236.9341**	118.2896	−1.1434	5.5360
Median income	0.3293	0.2181	−0.2743	0.3432	−129.1384***	44.7158	1.0726	2.4658
Population 65 and older	−0.4078	0.3133	−1.0958*	0.6205	−64.5830	52.1556	−0.3055	5.6562
Adults without high school	0.1700	0.1537	0.6752**	0.2834	25.0329	26.8199	3.8695	2.3991
Fair market rent	−5.8859	6.4920	−2.9874	10.5095	−4,302.3510***	1,299.9150	7.0849	81.2749
Average land quality	−4.9928	9.2208	−9.8947	22.8610	−1,446.8580	1393.1240	−387.8890	445.5675
Natural amenities	1.6812***	0.5226	2.8394**	1.3126	135.3783*	80.2179	25.2272	37.4755
Highway density	−1.7988	3.9404	6.4524	10.1438	880.5647	583.3031	579.0277*	302.5155
Distance to cities	0.0112	0.0096	−0.0300	0.0244	−3.3502**	1.4425	−1.4324*	0.7559
Land area	0.0024***	0.0005	0.0032**	0.0014	−0.0264	0.0798	−0.0044	0.0414
Year 1992	5.2666**	2.5412	−8.3162*	4.2572	−1,613.3880***	497.9336	−13.9915	33.6861
Year 1997	8.9118***	1.3309	−5.3515**	2.1047	−798.6421***	280.6364	11.5146	15.7173
Intercept	−17.9759	15.5934	10.7685	26.8220	7,307.7770**	3014.9170	−226.6499	311.7459
R-squared	0.57		0.56		0.34		0.18	
Observations	508		508		505		338	

* Statistical significance at the 0.10 probability level; ** at the 0.05 level; *** at the 0.01 level.

Both developed land and its quadratic term have a negative coefficient in the equation of the number of output processors, suggesting that the number of output processors decreases with land development. In contrast, the number of output processors increases with population density initially, although it decreases eventually. These results likely arise from the fact that farmland development reduces the supply of input for the processors, while higher population density increases the demand for their output. However, when population density reaches a certain level, it may no longer be suitable for a food processor to locate in the region, because pollution and noise from food processing would affect a large population. The negative effect of land development on the number of output processors is offset by a higher population density, as indicated by the positive and significant coefficient on the interaction term in the equation of the number of output processors.

Both population density and its quadratic term have positive and statistically significant coefficients in the equations of production cost and net farm income. These results suggest that higher population density increases both production costs and net farm income at an increasing rate. The increase in production costs is likely caused by the negative externalities that are posited to accompany urbanization. The finding that production costs increase at an increasing rate may be due to an increasing-return-to-scale production technology among the input suppliers. When input suppliers have a fixed setup cost and a constant marginal cost, as assumed in the theoretical model, their average costs increase at an increasing rate as the total output decreases. In this case, the price of agricultural input increases at an increasing rate, as shown by equation [6]. Further, net farm income increases because urbanization creates new opportunities for high-value crops. The increasing rate of net farm income may be because of the agglomeration effect and since the increased scale economy enhances the efficiency of specialty crop enterprises. Increasing land development also increases farming costs but reduces net farm income. This result arises when land development reduces the number of farm input suppliers without increasing the demand for farm output. The effect of land development on farm production costs and net farm income is offset by the increasing population density, as indicated by the negative and highly significant coefficient on the interaction term in both the equation of production costs and the equation of net farm income.

Figure 1 calibrates the relationship between the amount of developed land and the four dependent variables. Each panel in Figure 1 represents the relationship between a given dependent variable (e.g., number of input suppliers) and urban development holding other explanatory variables at their mean values for the whole sample, the first-quartile subsample, and the fourth-quartile subsample, respectively (quartiles are ranked according to population density). The upper-left panel shows that, for an "average county" in the sample, the input supply sector would shut down when developed land in the county and its neighboring counties reaches around 1.7 million acres or 27% of total land area. This is about five times more than the average in the year 2002. The thresholds of urbanization in terms of developed land area for an average county in the first and fourth quartile are 1.3 and 2.7 million acres, or 21% and 43% of total land area, respectively. These results suggest that the lower the population density, the lower the threshold level of land development at which the input supply sector would shut down. As demonstrated in the upper-right panel, the threshold of developed land regarding the viability of output processors is around 1.3 million acres or 21% of total land area at the sample mean (and 0.5 million and 3.4 million acres or 8% and 54% of total land area for the first and fourth quartile of population density, respectively). Again the intuition behind these results is that land development creates opportunities for high-value specialty crops. Because such crops tend to be more input intensive, the demand for farm input and output processors may go up initially with land development. However, the effects will eventually turn negative, because when all farmland is converted to development, there will be no need for input suppliers and output processors.

Figure 1 shows that both the per-acre production costs and the net farm income in-

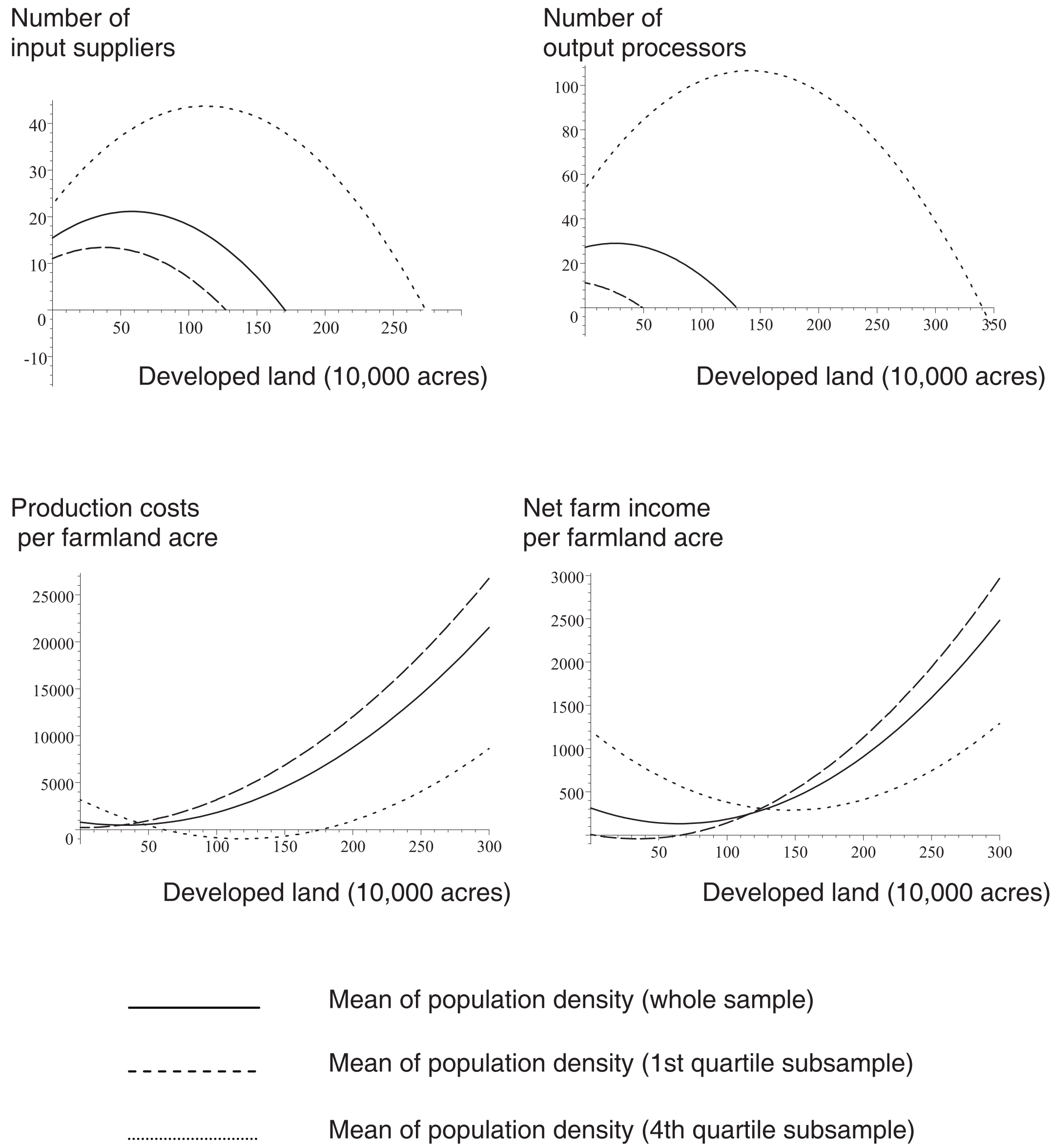

FIGURE 1
The Effect of Increasing Urban Development on Agricultural Infrastructure, Production Costs, and Net Farm Income

crease with the amount of developed area (see the bottom two panels). The higher production cost per acre is likely caused by higher input prices. Note that although the number of input suppliers increases initially, farmers still face a higher input price because of the increased demand, which is likely due to some land being switched to specialty crops. In addition, a reduction of the distance between expanding urban boundaries and the location of farm operations requires farmers to further internalize various external costs such as odors

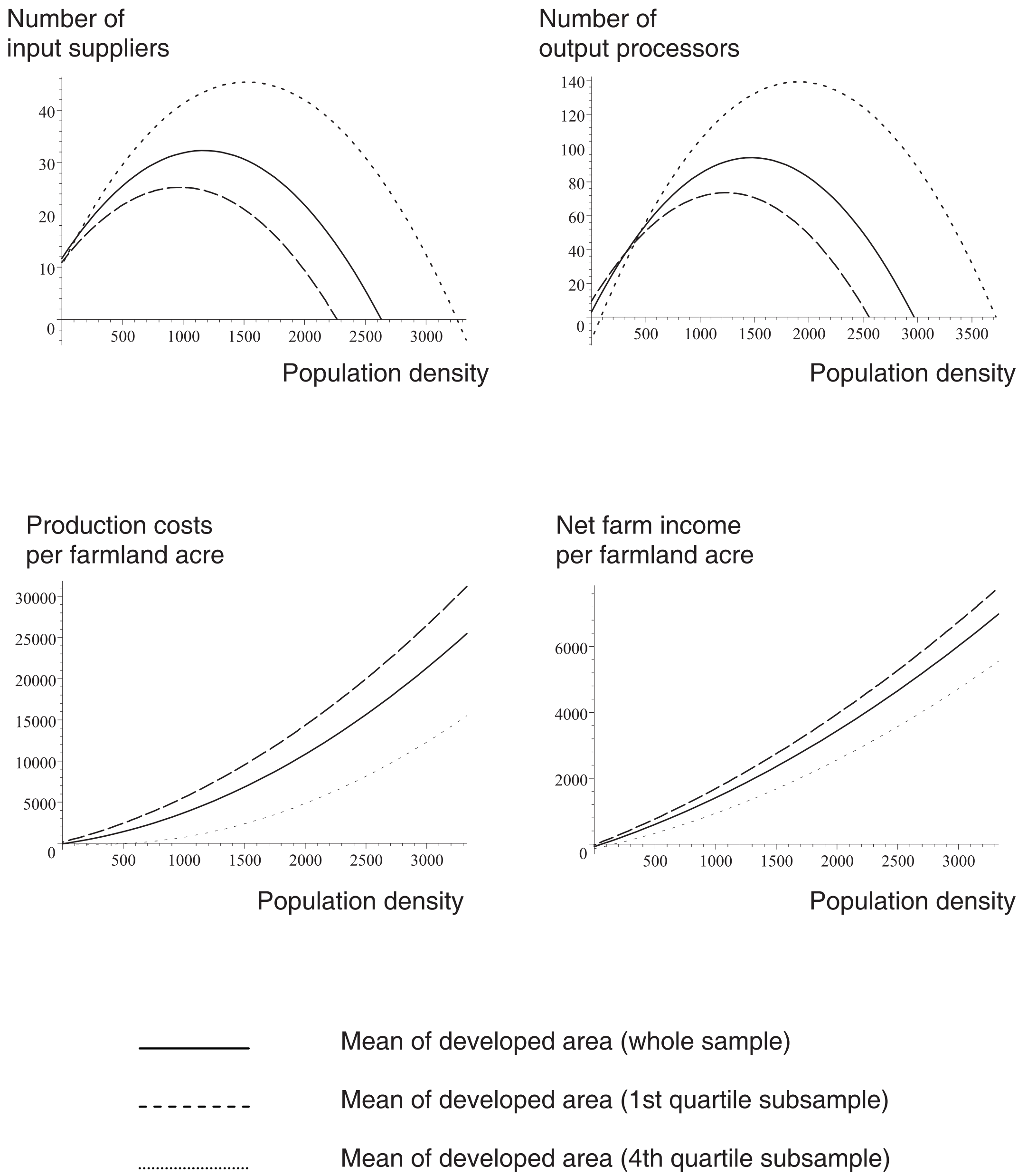

FIGURE 2
The Effect of Increasing Population Density on Agricultural Infrastructure, Production Costs, and Net Farm Income

from animal operations, spreading manure, and use of local roads by farm machinery due to regulation, thus adding to the per-acre production costs both in terms of operating and labor costs. The higher production cost is mostly outweighed by higher prices for the new agricultural output mix. As a result, net farm income increases due to urbanization.

Figure 2 shows the relationship between the four dependent variables and population density. Each panel of Figure 2 also includes three curves constructed in a manner similar to those of Figure 1, but now population density is allowed to vary, while developed land is held constant at the mean, and the first- and fourth-quartile subsamples (ranked according to the amount of developed acres). Regarding input suppliers, the population density threshold is 2,334 people per square mile for the sample mean, which is about 10 times the average of actual population density in the whole sample, suggesting that this population threshold is relatively distant from current conditions. Likewise, the effect of population density on the number of output processors follows a nonlinear relationship. The threshold is, however, outside the range of population density in the sample, suggesting that for counties in California, Idaho, Oregon, and Washington, the number of farm output processors increases with population density. Similarly, production cost per acre and farm income per acre increase monotonically with population density. The intuition behind these results is similar to that behind Figure 1.

VI. CONCLUSION

Urbanization presents both opportunities and challenges for farmers and farm-supporting sectors on the urban fringe. The literature, however, has paid little attention to the spillover effects of farmland conversion on the sectors that support agriculture. There is also a gap in knowledge that is critical to the development of land use policy: how urbanization affects farmers' production costs and net farm income. Land use policy makers are particularly interested in the issue of how much land is needed to retain a viable local agricultural economy, in other words, whether there is a critical mass of farmland for agricultural sector viability.

This paper attempts to fill the gaps in the literature by examining the effects of urbanization on the viability of input suppliers and output processors and on the cost and profitability of farming. An analytical model was developed to provide insights into such potential effects. The analytical model reveals ambiguous relationships: whether urbanization presents mainly opportunities or primarily challenges for agriculture is found to depend on a number of factors, including the elasticity of demand for agricultural inputs and the effect of urbanization on prices of agricultural commodities. Based on the theoretical analysis, an empirical model was specified to estimate the effect of urbanization on agricultural infrastructure and farm production cost and net income using county-level data for Oregon, Washington, Idaho, and California.

The number of input suppliers and the number of output processors are found to increase with urbanization initially, but decrease when urbanization reaches a certain level. The level of urbanization is measured using the amount of land developed and population density. There are threshold effects for the urbanization variables, which, once reached, are associated with a rapid decline in the number of input suppliers and output processors; but the thresholds are well beyond the ranges of developed land and population density in the four western states counties. Urbanization is found to be associated with higher farm production cost, which is consistent with the negative externalities, both technological (e.g., conflicts with nonfarm neighbors and vandalism) and pecuniary (e.g., farm labor costs rise owing to competition for labor with nonfarm sectors), that are posited to accompany urbanization. But, the higher costs of production in urban versus rural localities are outweighed by higher prices for agricultural output and increased off-farm job opportunities. As a result, net farm income is found to increase with urbanization. Our finding that urbanization may have beneficial effects on agriculture and agricultural support sectors was identified and discussed by Theodore Schultz (1953). More recently, empirical studies have provided evidence in support of this relationship. Lopez, Adelaja, and Andrews (1988), for example, found that the effect of suburbanization on agricultural profits is positive when capital gains on land are included. Likewise, Lockeretz (1986) examined the characteristics of counties by their distance to metro areas and found evidence of a higher standard of living in counties closer to metro areas than in those farther away. More recently, Partridge et al.

(2007) found that distance is a key factor underlying employment and population growth in nonmetropolitan counties in the United States; those adjacent to metropolitan areas grew fastest during the 1990s.

Our results have an important implication. Urbanization is not necessarily a bad thing for struggling rural communities, particularly when the objective is to increase net farm income. Urbanization may increase farmers' production costs, but it also creates new opportunities for farmers (growing high-value crops, off-farm employment opportunities, etc.). Our results suggest that the benefits of urbanization outweigh the costs, and net farm income increases with urbanization. However, in rural communities that have already experienced a high degree of urbanization, continuing urban sprawl may indeed threaten agriculture as a viable way of living. For an average county, when population density in the county and its neighborhood (all counties having centers within 50 miles of the county's center) reaches about 1,250 people per square mile or urban development reaches about 8% of the total land area, the local agricultural economy may begin to lose its agricultural support sectors, such as seed and agrochemical input dealers as well as output processors. The decline of the agricultural support sectors will, in turn, make farming more costly. Eventually, agriculture will disappear when most cultivable land has been converted to development and other nonfarm uses.

The results of this study can assist policy makers and local agricultural leaders in assessing the likely economic impacts of an increase in the speed at which farmland is converted to urban development and other nonfarm uses. Land retirement programs, such as the Conservation Reserve Program, effectively reduce the amount of harvested cropland or working farmland. Such a program can reduce the number of input suppliers and output processors, particularly in areas experiencing rapid loss of farmland to urbanization. Such a program could also have a significant impact on farm production costs and net returns. In addition to the direct effects on farm production costs and net returns, land retirement programs can also affect farm production costs and net returns through their impacts on agricultural infrastructure. In contrast to the cropland retirement programs, land use policies that aim at slowing down urbanization and farmland loss, such as exclusive farm-use zoning and development impact fees, can reduce the degradation of agricultural infrastructure and the cost of farming, although such policies may not necessarily increase net farm income.

This study could be extended in several directions. As discussed in the introduction, urbanization may provide opportunities for farmers to grow high-value specialty crops at the rural-urban fringe. To examine such structural changes associated with urbanization, it may be more fruitful to recast the whole theoretical framework in a multiple-crop setting and capture the spatial and temporal effects of urbanization and dynamic adjustments in rural areas. Empirical analysis could also be extended to capture the shift in production from traditional agriculture (e.g., corn) to specialty crops. Such analysis would require more detailed crop-specific data. It would also benefit from data at a less aggregated level (e.g., township-, municipal-level data). Currently, crop-specific, subcounty-level data are unavailable for a large area. But, the question of whether urban pressure causes a structural change in agriculture is a compelling topic for future research.

Acknowledgments

We thank Bruce Weber for discussing agricultural critical mass issues with us, and two anonymous referees for their thoughtful comments on this paper.

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