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Jobs, Houses, and Trees: Changing Regional Structure, Local Land-Use Patterns, and Forest Cover in Southern Indiana

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ABSTRACT Land-use and -cover change is a topic of increasing concern as interest in forest and agricultural land preservation grows. Urban and residential land use is quickly replacing extractive land use in southern Indiana. The interaction between land quality and urban growth pressures is also causing secondary forest growth and forest clearing to occur jointly in a complex spatial pattern. It is argued that similar processes fuel the abandonment of agricultural land leading to private forest regrowth, changes in topography and land quality, and declining real farm product prices. However, the impact of urban growth and development on forests depends more strongly on changes in both the residential housing and labor markets. Using location quotient analysis of aggregate employment patterns, and the relationship between regional labor market changes, the extent of private forest cover was examined from 1967 to 1998. Then an econometric model of land-use shares in forty southern Indiana counties was developed based on the net benefits to agriculture, forestland, and urban uses. To test the need to control explicitly for changes in residential demand and regional economic structure, a series of nested models was estimated. Some evidence was found that changing agricultural profitability is leading to private forest regrowth. It was also uncovered that the ratio of urban to forest land uses is better explained by incorporating measures of residential land value and industrial concentration than simply considering population density alone.

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Introduction

As the interest in forest and agricultural land preservation grows, land-use and -cover change is a topic of increasing concern. Understanding land-use change requires a thorough, integrated approach, because such change is a product of many spatially and temporally complex factors. The case of southern Indiana is an excellent example of this complexity. Prior to European settlement in the early 1800s the landscape was primarily forested. After European settlement, most of Indiana was cleared for agricultural use. Much marginal farmland was gradually abandoned, and secondary regrowth has occurred.[1] The interaction between declining product prices and heterogeneous land quality, especially slope and soil type, has played a significant role in determining land use. In southern Indiana national and state forests are scattered among agricultural land and private forest. Unlike many other parts of the U.S., private land is the largest component of forest cover in southern Indiana with forest ownership divided among private farmers (39 percent), other private individuals (38 percent), public lands (13 percent), and private corporations (10 percent) (Birch 1996a). The objectives of these varied forest owners may range from the aesthetic to timber production. Contrary to some expectations, much forest regrowth has occurred on small, privately-owned, fragmented parcels (so-called non-industrial private forestry or NIPF). Successful policy to maintain and increase forest cover must thus focus on incentives for land-use change for private landowners (Birch 1996a, 1996b; Carlson et al. 2002; Kauneckis and Novac 2000).

Urban and residential land use is quickly replacing extractive land use in southern Indiana, causing conversion of agricultural and forested lands in peri-urban or rural areas. This counterurbanization trend, the tendency for people to move out from cities and suburbs into rural areas, often occurs because rural areas have greater natural resources, leisure opportunities, and ecosystem services (Deller 2001; Midmore and Whittaker 2000). Thus, the greatest threat to NIPF land use in Indiana is residential land conversion (Fischer et al. 1993).

To identify the relevant factors associated with change in forestland area, one can begin with a model of the returns to various land uses (e.g., agriculture, urban) to estimate the opportunity cost of forest land. Landowners choose an appropriate land use based on a variety of factors, including profitability of that use (given input and output prices), and individual preferences (considering factors such as the aesthetic value of forests). Ideally, one would be able to match changes in forest area to individual decision-making. However, data restrictions constrain individual-level modeling efforts, especially analyses covering more than one time point. Instead, forestry and agricultural economists have often constructed county level models, postulating that the observed changes in land use at the county level are the sum of individual landowner decisions.

The ultimate utility of these aggregate models depends strongly on the empirical application and the relevant questions addressed by the research. Prior empirical examples include the prediction of future forest area (Ahn et al. 2000; Mauldin et al. 1999), the allocation of land to forestry over time including timber and non-timber benefits (Parks and Murray 1994), estimation of the amount and cost of carbon sequestration (Plantinga et al. 1999), and measurement of the impact of agricultural land use on soil erosion (Miller and Plantinga 1999).

These studies have indicated that much of the variation in land uses at the county level can be modeled as a function of net present benefits. Correspondingly, there are two questions addressed in this research. First, can relevant factors be identified that are linked with changing land-use patterns in southern Indiana over time? It is known that declining agricultural revenues have led to the removal from production or abandonment of formerly agricultural lands in the region. The impact of changing agricultural profitability on private forestland is examined to determine whether abandonment is leading to secondary regrowth. Secondly, is the choice of urban land use (rather than agriculture or forest) fundamentally more complex? It is argued that variations in the spatial and hierarchical processes, such as the impact of rising land values in a nearby, growing metropolitan region, and regional employment patterns can greatly increase the opportunity cost of other land uses.

Overall, this study focuses on the past thirty years using county level land, economic, ecological, and demographic attributes from the United States Departments of Census, Commerce, and Agriculture, and United States Forest Service data. This study area covers forty southern Indiana counties in the Knobs, Lower Wabash, and Upland Flats Forestry Units, from 1967-1998. The next section summarizes the theoretical model of land use. Then an econometric model of land-use shares is constructed, incorporating measures of economic structural change. Lastly, conclusions and directions for future research are provided, as well as notations of the limitations of this study.

Conceptual Framework

To begin, a model of land-use shares, applicable to county-level studies (Plantinga and Buongiorno 1990; Parks and Murray 1994; Mauldin et al. 1999; Ahn et al. 2000) is developed. Under the assumption of competitive land markets, landowners allocate parcels of land to the use yielding the highest rent. The productive ability of the land is determined by market accessibility (von Thünian ideas), and Ricardian land rent, or the inherent value of land given soil fertility, topography, and other factors. Changes in land use are brought about by changing profitability of a particular use, which can be caused by changes in prices, economic conditions, policies, or infrastructure development.

The focus of this theoretical discussion is on a latent model of unobserved net benefits to land use often found in county-level land use studies (Ahn et al. 2000; Parks and Murray 1994; Plantinga et al. 1999; Plantinga and Buongiorno 1990). This model is motivated as the choice between agriculture and forestry, but then generalized to a three choice model with agriculture, forest, or urban use. Extension to the three-choice model may be limited by the spatial and hierarchical complexity of urban land use conversion. However, this approach is not at odds with other classic urban models, such as the Alonso bid-rent formulation (Alonso 1964), if it is assumed that the observed amount of urban land at the county level has at equilibrium “outbid” extractive land uses.

A price-taking risk neutral landowner will maximize his/her discounted expected net returns by allocating portions of his/her land to different uses, such as agriculture, forest, or development. This allocation process can be represented as follows:

$$\max_{(u_t),(v_t)} \sum_{t=0}^{T} \delta^t [R_t^f(a_t)v_t + R_t^a * (1-u_t)v_t] + \delta^{T+1} V_{T+1}(a_{T+1}), \qquad [1]$$

subject to:

$$u_t = \{0, 1\}; v_t = \{0, 1\}; a_{t+1} = a_t u_t (1 - v_t) + u_t; a_t \geq 0; R_t^f(0) = 0,$$

and a_0 given. The landowner first decides whether to harvest ($v_t = 0$) or leave to grow ($v_t = 1$) an existing forest stand, based on growth and yield functions for that species (Plantinga and Buongiorno 1990). Given an optimal v^*, the maximization problem is linear in the control u, indicating that a parcel can be allocated to forest ($u_t = 1$) or agriculture ($u_t = 0$). The age of a forest stand at the initial time period, t_0, is given by a_t. The expected net returns to forest at age a_t and agriculture and time t equals $R_t^f(a_t)$ and R_t^a, respectively. The land conversion costs are part of the net returns function according to this assumption. The constant discount factor is δ. The expected terminal value is $V_{T+1}(a_{T+1})$ (Ahn et al. 2000). This equation illustrates the tradeoff associated with either agriculture or forest use. Maximizing the value, W, of the optimally managed land parcel, where v^* is the optimal harvesting decision, yields the following equations:

$$\begin{aligned} W_t^f &= R_t^f(a_t)v_t^* + \delta V_{t+1}\left[a_t\left(1 - v_t^*\right) + 1\right] \\ W_t^a &= R_t^f(a_t) + R_t^a + \delta V_{t+1}(0) \end{aligned} \qquad [2]$$

The landowner then allocates a parcel (or portions of a parcel, without loss of generality) to forestry if $W_t^f \geq W_t^a$, and to agriculture if $W_t^a > W_t^f$[2] The observed land-use shares at the county level are the realization of this benefit maximization problem across all landowners. Next, the determinants of land rent for each type of land use (forest, agriculture, or urban) are defined.

Forest benefits. Forest rent is generally thought to be the net present value of an infinite series of timber rotations, which are determined by stumpage prices and yield by species. There is some variation within the forest science literature about the proper rotation type to be used for the most accurate measure of forest rent for private, nonindustrial forestry. Prior analyses raised a substantial question: Why is forestland slower to react to market forces than urban and agricultural land use? Parks and Murray (1994) hypothesize that forestland returns tend to be more heterogeneous, and timber payoffs come less frequently and in riskier markets. Thus, the potential benefits for the land owner may be harder to quantify. Ahn et al. (2000) and Plantinga and Buongiorno (1990) use a Faustmann rotation, which is based on estimated bare land values, assuming an infinite stream of rotations harvested at the optimal time period. The optimal time period occurs when yield is maximized given growth rates, and the value of the forest stock is equal to the opportunity cost of capital and land. Parks and Murray (1994) state that a Hartman rotation may be superior to the Faustmann approach, because the latter can overestimate actual harvesting. Landowners may harvest less often because of risk, and the potential capital gains that forestland represents.[3] However, data are not often available to impute the non-timber value of forestland, so the Faustmann approach is generally more feasible.

Thus, the net present value of returns to timber in forestland use does not reflect the full spectrum of utility, such as aesthetic value, received by private non-industrial owners. Several studies of land-use change have found that personal income was a significant variable in the explanation of both clearing and regrowth of forested land (Plantinga and Buongiorno 1990). Changes in per capita income may proxy for the differences in forest valuation, which may cause a subsequent utility change with forest use.

Agricultural rent. Agricultural rent is determined by the net present value of a perpetual stream of annual crop and livestock revenues. Current and historical revenue streams may be a proxy for the future revenue stream. Land quality information is a crucial factor in farm production (Parks and Murray 1994). Measures of agricultural rent are generated from deflated output prices, average yields, and land quality information, such as slope and soil type. Other factors to consider are farm profits and government transfer payments, which may indicate the financial solvency of a farm.

Urban rent. Urban land use in this study represents non-agricultural or non-forest use, including both industrial uses and residential purposes, as a residual land use. The value of urban land is reflected in direct competition to the other land uses. Plantinga and Buongiorno (1990), Parks and Murray (1994), Mauldin et al. (1999), and Ahn et al. (2000) all utilize population density as the sole proxy for non-forest use and nonagricultural use benefits. They argue that higher population levels indicate use of land for residential or industrial purposes, in comparison to relatively low population densities that are associated with agriculture and forestland use.

In contrast, few studies have attempted to capture the effect of an increasing pull to urban or suburban lifestyles on land use. Notable exceptions include an amenity benefit study, in which Lopez et al. (1994) used the distance from county seat to a Consolidated Metropolitan Statistical Area that had a population greater than three million as a distance to market variable. Irwin and Bockstael (2001; 2002) develop a model of individual land-use decisions that filters higher-order urban growth pressures via a hazards approach. In this formulation, the observed timing of development is a function of unobserved factors relating to overall urban land demand.

More research is needed to hypothesize how individual land use decisions relate to higher-level urban growth pressures explicitly. It is argued that changes in economic structure, reflected in employment patterns, impact land-use incentives. Changes in employment, for instance, reflect two possible effects on forest cover. First, as employment declines in the more extractive sectors (agriculture, fishing, and forestry), extractive land use may also decline.[4] Second, high employment in the service sectors of the economy may indicate growing preferences for forest recreation and aesthetics.

Trends in Economic Structure and Forest-Cover Change in Southern Indiana

In this section, the relationship between employment change and forest-cover change is examined in the southern Indiana counties. In the United States, and in southern Indiana, the most important factors leading to recent changes in land cover are urbanization and residential development (Karasov 1997). There are important policy implications for identifying areas where increased development is impacting private forest cover. Over the past thirty years, both secondary forest growth, due to agricultural abandonment, and forest clearing, due to residential conversion, have been jointly occurring in a complex spatial pattern. Figure 1 and Table 1 depict changes in private forestland by county between 1967 and 1998. Thirty-four counties lost private forest, while five gained forest area, and one county did not experience change. There is also significant bi-directional change. For instance, Monroe County, home to Indiana University, lost 30 percent of forest cover from 1967-1986, but regained 10 percent of forest cover from 1986 to 1998. At the same time, Bloomington, the Monroe County seat, went from the nineteenth largest to the eighth largest city in the state, with the largest overall percent change in its population between 1950 and 1996 (City of Bloomington Environmental Commission 1997). From 1967-1986 and 1986-1998, thirteen counties gained forest area. Net loss varied from 1 to 81 percent, while growth in forest cover ranged between 6 and 17 percent.

It is obvious that changes in population and changes in land use are linked, but as the case of Monroe County demonstrates, the relationship is not always a straightforward one. It is hypothesized that more subtle changes are also taking place. Urbanization and residential conversion are most likely to happen in areas where there are significant changes in the sectoral make-up of employment. Location quotient analysis is employed to quantify changes in economic structure. The location quotient for activity *i* in a given region is defined as:

$$LQ_i = \frac{e_i / \sum e_i}{E_i / \sum E_i}, \qquad [3]$$

where e is regional employment and E is national employment (Burt and Barber 1996). This index ranges from 0 to infinity, and measures the relative concentration of economic activity in a particular sector relative to a base (in this case, national employment). Other researchers have used this measure to look at regional comparative advantage in a particular industry and forest cover (Hanink 2001). Service sector economies may attract revenue from tourist industries, for example, and the tourist industry may play an important role in the protection of forest cover and promotion of development (Deller et al. 2001).

The data come from the Regional Economic Information Systems Web site (U.S. Department of Commerce 2001), total full and part-time employment per 1,000 people, by industry, at the one-digit SIC level. A common factor analysis of employment across all sectors was performed, and a clear break among primary and secondary, and higher-level activities was found. The employment data were grouped into two categories, "primary/secondary" (agriculture, forestry, and fishing; mining; construction; and manufacturing) and "tertiary and higher" (all other sectors).

To compare the changes in employment patterns to changes in forest cover, the percent change for each county was calculated in the location quotients for both the primary/

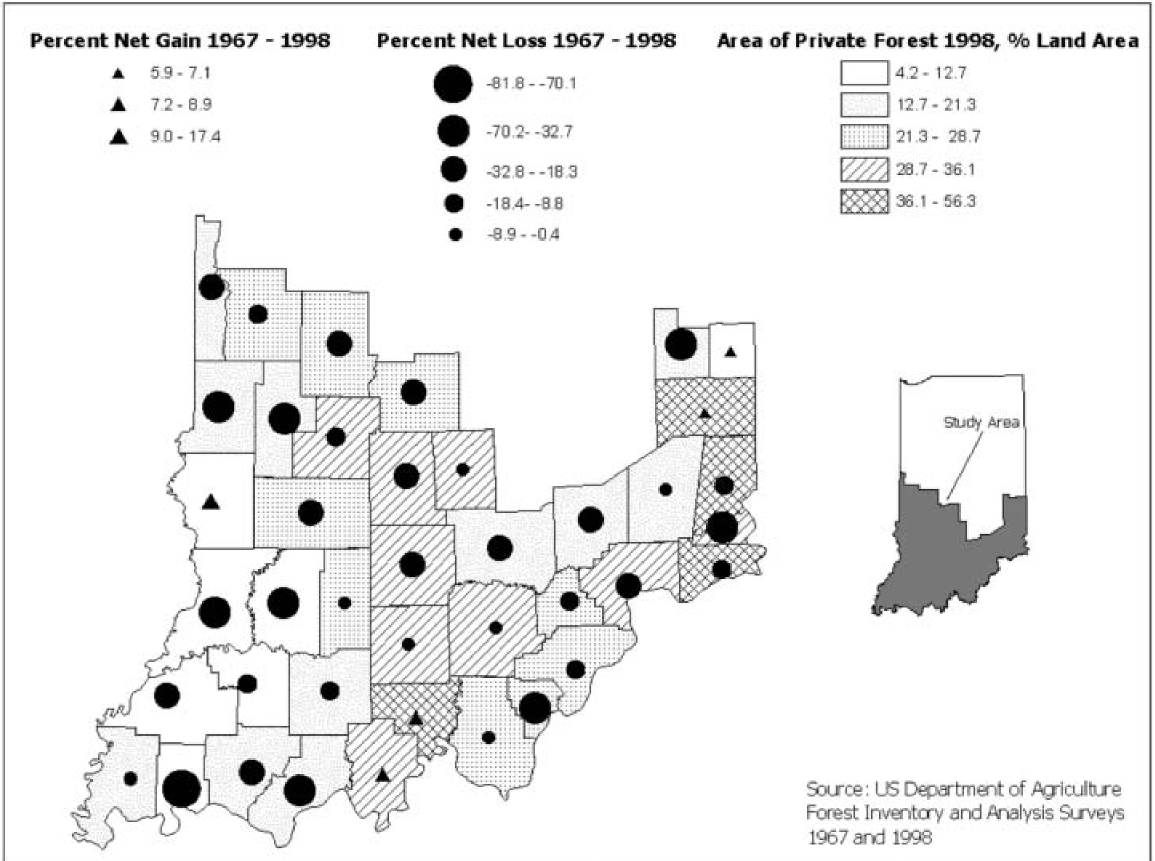

FIGURE 1. TRENDS IN PRIVATE FOREST COVER IN SOUTHERN INDIANA, 1967-1998.

TABLE 1. TRENDS IN AREA OF FOREST COVER ON PRIVATE LAND, THOUSAND ACRES.

County	1967 1,000 Acres	1986 1,000 Acres	1998 1,000 Acres	Percent Change 1967-86	Percent Change 1986-98	Percent Change 1967-98
Brown	68.73	76.2	64.71	11%	–15%	–6%
Clark	78.53	59.9	65.81	–24%	10%	–16%
Clay	71.31	35.3	36.69	–50%	4%	–49%
Crawford	89.15	96.2	97.14	8%	1%	9%
Daviess	34.65	38.0	21.95	10%	–42%	–37%
Dearborn	102.18	105.4	83.41	3%	–21%	–18%
Dubois	61.2	58.8	51.29	–4%	–13%	–16%
Fayette	37.98	30.9	21.75	–19%	–30%	–43%
Floyd	35.59	28.5	23.38	–20%	–18%	–34%
Franklin	101.66	91.2	107.68	–10%	18%	6%
Gibson	38.32	27.2	28.64	–29%	5%	–25%
Greene	127.51	118.4	100.21	–7%	–15%	–21%
Harrison	96.68	102.3	89.44	6%	–13%	–7%
Jackson	86.86	85.4	69.31	–2%	–19%	–20%
Jefferson	104.01	84.3	80.14	–19%	–5%	–23%
Jennings	63.38	64.6	48.16	2%	–25%	–24%
Knox	59.52	31.4	17.73	–47%	–44%	–70%
Lawrence	125.6	96.9	98.63	–23%	2%	–21%
Martin	57.63	57.2	54.75	–1%	–4%	–5%
Monroe	112.22	78.7	86.24	–30%	10%	–23%
Morgan	86.11	67.9	63.76	–21%	–6%	–26%
Ohio	31.56	22.3	18.64	–29%	–16%	–41%
Orange	95.3	76.9	91.5	–19%	19%	–4%
Owen	97.88	92.3	87.42	–6%	–5%	–11%
Parke	88.75	79.8	75.61	–10%	–5%	–15%
Perry	83.09	88.6	89.11	7%	1%	7%
Pike	26.49	35.1	24.12	32%	–31%	–9%
Posey	42.77	40.2	42.59	–6%	6%	0%
Putnam	101.6	77.0	76.69	–24%	0%	–25%
Ripley	63.04	61.7	60.88	–2%	–1%	–3%
Scott	34.18	42.4	30.47	24%	–28%	–11%
Spencer	74.62	57.0	50.13	–24%	–12%	–33%
Sullivan	31.59	38.7	37.09	22%	–4%	17%
Switzerland	92.5	59.7	80.22	–35%	34%	–13%
Union	12.65	14.9	13.49	18%	–9%	7%
Vanderburgh	34.57	15.9	6.31	–54%	–60%	–82%
Vermillion	36.85	27.1	27.75	–26%	2%	–25%
Vigo	69.54	42.1	42.07	–39%	0%	–40%
Warrick	62.23	63.9	48.47	3%	–24%	–22%
Washington	108.65	111.4	107.95	3%	–3%	–1%

secondary and tertiary and higher groupings for the time periods 1967-86, 1986-98, and 1967-98 (see Table 2). These changes, along with changes in the percent change in private forest cover, were then ranked in quartiles. The rankings of percent change in each of the location quotients were cross-tabulated with percent change in private forest area, and tested for statistical significance using contingency table analysis (Burt and Barber 1996). There was no statistically significant relationship between rankings of changes in employment concentration in primary/secondary activities relative to a national base and the rankings of percent change in private forest area. There was, however, a statistically significant relationship between high concentrations of tertiary and higher employment and counties that experienced forest regrowth between 1986-98 (though not from 1967 to 1986). Thus, counties with the greatest growth in tertiary and higher employment concentration also experienced forest regrowth during this period, which is a significant finding. As mentioned earlier, the protection and regrowth of forest may coincide with developing areas with a strong service sector and sale of amenity benefits through tourism and residential growth.

Econometric Model

The analysis in the previous section presented some initial ideas to link changes in economic structure to changes in forest cover. A complementary econometric analysis studies the covariates of the observed shares of land use.

Data. First, forest, agricultural, and urban rent determinants are defined. Data integration of disparate time series is a serious impediment to land-use change analysis. Care was given to match disparate data as closely as possible. Table 3 delineates the data sources that were not available for every year, and indicates which years were used for each time period. At most there was a four-year mismatch among years. Land was assigned to three categories: forest (private, non-industrial forest area), agriculture, and urban/residual. Urban/residual land was defined as the total land area less the other two categories, water areas, and public land. In each time period, the total shares of land summed to 1.

Following the methodology described in detail in Mauldin et al. (1999) a bareland forest rent calculation was derived for each county in the study area using growth and yield models calibrated for southern Indiana (Carmean et al. 1989; Schroering 1982). Using the assumptions of a Faustmann rotation, the ideal forest rotation length was calculated given an assumed interest rate of 5 percent. Given the optimal rotation forest length and the deflated prime lumber prices (delivered to mills) found in Hoover (2000), the net present value of an infinite series of rotations on bare land for the major forest species groups found in southern Indiana was calculated. A county-level average was derived by weighting this measure by the area of total forestland in each forest species group for each county.[5]

Agricultural rent is determined by the net present value of a perpetual stream of annual crop and livestock revenues. Crop revenue and net farm profits were calculated from the Agricultural Census (U.S. Department of Agriculture 1969, 1974, 1978, 1982, 1987, 1992, 1997) and from REIS (net realized farm income) (U.S. Department of Commerce 2001) to represent agricultural land rent.

The relative profitability of agricultural land use is mediated by land quality. For each county the percentage of land was calculated for the two most suitable classes for

TABLE 2. PERCENT CHANGE IN LOCATION QUOTIENTS FOR EMPLOYMENT, PRIMARY/SECONDARY SECTORS, AND TERTIARY AND HIGHER SECTORS, RANKINGS OF PERCENT CHANGE IN PRIVATE FOREST COVER.

County	Change in LQ Primary/Secondary			Change in LQ Tertiary/Higher			Ranking, % Decrease in Private Forest Area 1967-98*
	1967-86	1986-98	1967-98	1967-86	1986-98	1967-98	
Brown	22.65%	–34.51%	–19.67%	–1.67%	1.57%	–0.12%	30
Clark	–61.17%	–32.38%	–73.75%	82.76%	9.31%	99.76%	23
Clay	–10.53%	4.01%	–6.94%	5.32%	–10.93%	–6.19%	3
Crawford	–11.97%	–58.67%	–63.62%	7.47%	–30.34%	–25.13%	39
Daviess	–17.38%	–11.90%	–27.21%	10.73%	–1.35%	9.23%	7
Dearborn	–33.20%	–45.50%	–63.59%	25.98%	18.84%	49.72%	21
Dubois	–5.97%	–1.29%	–7.19%	5.78%	1.11%	6.95%	22
Fayette	–17.12%	–21.12%	–34.62%	23.97%	18.45%	46.84%	4
Floyd	–30.45%	0.49%	–30.11%	13.85%	–1.65%	11.98%	8
Franklin	–14.16%	–49.36%	–56.53%	12.01%	29.38%	44.92%	36
Gibson	–23.73%	–13.49%	–34.02%	17.05%	6.31%	24.44%	13
Greene	–15.95%	–16.04%	–29.43%	8.32%	6.49%	15.35%	18
Harrison	–19.15%	–14.08%	–30.53%	12.15%	6.44%	19.37%	29
Jackson	–24.14%	–9.89%	–31.65%	20.87%	4.80%	26.68%	20
Jefferson	–10.91%	–15.10%	–24.36%	5.78%	0.30%	6.09%	15
Jennings	–7.14%	–3.96%	–10.82%	1.39%	7.48%	8.98%	14
Knox	–30.64%	–31.58%	–52.54%	12.12%	7.73%	20.78%	2
Lawrence	–17.35%	–10.64%	–26.15%	12.10%	5.47%	18.24%	19
Martin	17.74%	–6.68%	9.87%	1.68%	–4.91%	–3.31%	31
Monroe	–44.57%	–15.33%	–53.07%	18.59%	2.99%	22.13%	16
Morgan	–14.18%	–27.77%	–38.01%	5.02%	8.03%	13.45%	10
Ohio	–2.12%	–65.06%	–65.80%	2.73%	–68.78%	–67.93%	5
Orange	–13.30%	–4.94%	–17.59%	0.60%	12.38%	13.05%	32
Owen	–7.45%	0.96%	–6.56%	11.25%	–3.46%	7.40%	26
Parke	–4.81%	–17.75%	–21.71%	1.88%	5.34%	7.32%	24
Perry	–28.90%	–22.15%	–44.65%	30.17%	8.28%	40.94%	38
Pike	–0.27%	–19.40%	–19.62%	–34.49%	67.78%	9.91%	28
Posey	–25.14%	–15.16%	–36.49%	23.57%	4.52%	29.16%	35
Putnam	–47.08%	12.86%	–40.28%	28.04%	–3.16%	23.99%	12
Ripley	–13.58%	–11.75%	–23.74%	14.25%	7.03%	22.28%	33
Scott	–25.45%	–1.38%	–26.48%	11.79%	7.88%	20.60%	27
Spencer	–9.28%	–18.46%	–26.03%	5.28%	9.05%	14.80%	9
Sullivan	–40.78%	–22.26%	–53.96%	27.36%	6.94%	36.20%	40
Switzerland	–3.45%	–27.83%	–30.31%	24.43%	31.63%	63.79%	25
Union	–36.70%	–12.75%	–44.77%	23.07%	–4.33%	17.74%	37
Vanderburgh	–37.24%	–30.10%	–56.13%	19.08%	8.13%	28.76%	1
Vermillion	81.63%	–87.36%	–77.05%	–22.79%	24.28%	–4.05%	11
Vigo	–29.75%	–27.54%	–49.10%	11.50%	6.70%	18.98%	6
Warrick	–31.69%	–32.42%	–53.84%	32.62%	17.19%	55.41%	17
Washington	–15.88%	–15.47%	–28.89%	17.18%	9.49%	28.30%	34

NOTE: e.g., Vanderburgh County lost the most forest area in this time period, the lowest four counties experienced a net forest gain.

agriculture: land capability classes 1 and 2 (U.S. Department of Agriculture 2001). Using a 1:24,000 scale digital elevation model (DEM) from the U.S.G.S., a slope coverage (in degrees) was derived (U.S. Department of the Interior 2001). Then, for each county, the total area of land, in square kilometers, that falls in the class of greater than 12 degree slope was calculated. Inclusion of a raw slope variable caused extreme multicollinearity, but an interaction term with slope and forest rent did not. This effect would capture the impact of "junk" land (land that is not suitable for either agricultural or urban land use) being by default relegated to forestry.

A gravity measure, the ratio of the population of key urban areas to travel distance from the center of population in 1970, 1990, and 2000 of each southern Indiana County, captures the effect of an increasing pull to urban or suburban lifestyles. A gravity measure was calculated for nearby cities with a population greater than 50,000: Bloomington, Cincinnati, Evanston, Indianapolis, and Louisville. These cities may offer employment opportunities, cultural influence, suburban pressures, and tourist populations, all of which affect the land use throughout the region. It was hypothesized that the gravity measure would be positively correlated with the proportion of land in urban usage, and negatively correlated with land in agricultural usage.

As in prior analyses, it was assumed that population density is one indicator of urban land demand. There is substantial variability in population density, with a mean value of 162, and a range from 41 to 1,234 people per square mile. Median housing value and the variance in housing values are included to estimate the value of residential property (U.S. Department of Commerce 1970, 1980, 1990, 2000). A variance measure was estimated for each county in each year by means of grouped frequency techniques.

Each county has different employment opportunities. A location quotient was included for the tertiary and higher sectors discussed in the previous section (all sectors excluding agriculture, forestry, and fishing; mining; construction; and manufacturing), which reflects the county's share of employment in that industry relative to the share of employment in that sector at the national level. The location quotient was constructed with REIS data, employment of 1,000 people (U.S. Department of Commerce 2001).

Estimation. Following the framework of prior studies (Parks and Murray 1994; Hardie and Parks 1997; Mauldin et al. 1999; and Ahn et al. 2000), the expected shares of land use were specified and derived from the aggregation of [2] at the county level, as a logistic function linear in the decision variables, X, and the unknown parameters, β_k:

$$p_k(t,i) = \frac{e^{\beta_k X(i,t)}}{\sum_{k=1}^{3} e^{\beta_k X(i,t)}}, \qquad [4]$$

where p_k is the probability that land use k is chosen from an exhaustive set of possible uses: agriculture, forest, and urban for individual i at time t. Equation [4] was transformed to construct a semi-log formulation:

$$\ln\left({y_k(t,i)} \big/ {y_1(t,i)} \right) = \beta_k X(t,i) - \beta_1 X(t,i) + \varepsilon_k, \qquad [5]$$

where y_k is the area in land use, k, y_1 is the area in private forest, and ε is the error term. This model is identified if β_1 was constrained to equal zero (Ahn et al. 2000). In this manner, the trade-off between agriculture and forest, and urban and forest land use, was estimated by specifying their ratios as a dependent variable. This framework is useful in the identification of the relative effect of land use profitability and suitability on the observed shares of land use, as well as the relative effects on urban growth and agriculture (Mauldin 1999).

Spatial autocorrelation among cross-sectional units is a potentially serious specification error, and the presence of spatial autocorrelation in all three time periods was extensively tested for. Using the diagnostics in SpaceStat v1.91 (Anselin 1995), no significant evidence of spatial dependence for either land-use ratio was found. Table 3 presents descriptive statistics for each variable used in the analysis. To test for non-linearities and interactions among variables, interaction and squared terms were computed for all variables. However, such a specification could lead to significant multicollinearity. The methodology of Parks and Murray (1994) was followed, and those variables that were significant at the 70 percent level in an OLS equation were included in the analysis. To correct for underlying heteroskedasticity, always a concern in cross-sectional analysis, all regressions were weighted by the relative frequency of land in forest for each county (Parks and Murray 1994).

Estimation and Results

Equation [5] can expressed as:

$$\begin{aligned} \ln\left(y_{ag}/y_{for}\right) &= \beta_{ag0} + \beta_{ag1}x_{1it} + \beta_{ag2}x_{2it} + \ldots + \varepsilon_{it} \\ \ln\left(y_{urb}/y_{for}\right) &= \beta_{urb0} + \beta_{urb1}x_{1it} + \beta_{urb2}x_{2it} + \ldots + \varepsilon_{it} \end{aligned}, \qquad [6]$$

TABLE 3. DATA INTEGRATION.

Time Period	Forest Inventory and Analysis, USDA	REIS, Bureau of Economic Analysis	Census, US Department of Commerce	Census of Agriculture, USDA, NASS
1	1967	1969	1970	1969
2	1986	1986	1990	1987
3	1998	1998	2000	1997
Variables	Private forest area	Employment, Farm Profits	Population, Income, Housing values	Cropland, Yields

TABLE 4. DESCRIPTIVE STATISTICS, ECONOMETRIC MODEL, 1967-1998.

Variable, units	Mean	Std.Dev.	Minimum	Maximum
Crop Revenue, bushels x price, \$1,000[+]	15.930	12.388	1.107	70.408
Farm Profits, \$1,000/farms	3.926	7.811	–12.714	32.681
Ratio of LCC 1&2	31.023	25.254	2.210	100.000
Ratio of Area > 12 degrees Slope	4.489	5.103	0.010	16.480
Forest Rent, \$100	17.484	75.460	0.000	809.344
LQ Tertiary and Higher Sectors	0.959	0.28	1.47	0.18
Median House Value, \$1,000	52.174	12.616	30.280	87.916
Per Capita Income, \$1,000/person	18.285	3.174	12.850	28.658
Population Density (population/mile^2)	162.388	196.893	41.317	1124.370
*Accessibility to Indianapolis, pop/d_{ij}	0.120	0.142	0.020	0.901
Accessibility to Cincinnati, pop/d_{ij}	0.181	0.332	0.016	1.656
Accessibility to Evansville, pop/d_{ij}	4.509	28.146	0.003	206.150
Accessibility to Bloomington, pop/d_{ij}	6.384	40.841	0.003	311.859
Accessibility to Terre Haute, pop/d_{ij}	12.305	112.848	0.000	1209.340
Accessibility to Louisville, pop/d_{ij}	0.425	1.398	0.019	7.050

NOTE: [+] All prices are in 1997 dollars, 1982 = 100; * Population is total number of people and distance is in meters.

for all i and t, where y_{ag} represents the share of agricultural land use, y_{for} is the share of private non-industrial forest land use, y_{urb} represents the urban/residual land use class, and X is the vector of independent variables listed in Table 2. Panel techniques were employed to account for structural differences among individual observations. The models were tested and adjusted to account for temporal and/or individual variation. Such corrections included dummy variables (fixed effects), and error component (random effects) models.

The fixed effect model includes a set of county-specific dummy parameters or intercept terms. In this formulation, constant terms and time-invariant variables (percentage LCC 1&2) were left out to avoid multicollinearity between these variables and the county dummies. The fixed-effects model is most appropriate when the differences across units (in this case, counties) are known or hypothesized structural differences, or parametric shifts in the regression function (Greene 2001). Random-effects formulations also account for variation across units, but as an individual disturbance, similar to the error term, for each county. In this case, the county-specific differences are thus randomly distributed across counties (Greene 2001). This formulation is most appropriate when the unmeasured or unmodeled variation across counties is due to exogenous, random shocks (such as climate, business cycle fluctuations, etc.).

All regressions were estimated using LIMDEP software v 7.0. Estimation results are presented in Tables 5 and 6. LIMDEP calculates two sets of diagnostics for the significance of group effects.[6] There was no evidence for serial autocorrelation in the error terms, probably due to the time gap between each period. Specification testing indicated that a fixed-effects formulation was most appropriate for the agriculture/forest share, whereas the random-effects formulation was more appropriate for the urban/forest share. This finding confirmed initial suspicions regarding the role of land use in the wider economic structure of each county. Trade-offs between urban and forestland are not completely a function of the characteristics of the county (e.g., slope and soil quality), but are likely also affected by external forces. The impact of changing regional economic structure and spatial/hierarchical changes in proximate urban regions and employment centers also may play out differently over space.

A nested set of four models was constructed to test the necessity of incorporating measures of residential land demand, the relative concentration of tertiary and higher sectoral employment, and accessibility to proximate urban regions. The base model included only population density as a measure of the profitability of urban land use, and the remaining variables were progressively added in. Comparisons across models were made via likelihood ratio tests, subject to an χ-squared distribution. These likelihood ratio tests indicate that the model relating the share of agricultural to forest land did not benefit by the inclusion of additional variables, but the urban to forest land share did yield better results when the measures of housing values (median and variance) and the location quotient for tertiary/higher sectors were included.

The share of agricultural to forest land. For this formulation, a fixed-effects model was shown to be most appropriate via a Hausmann test (Greene 2001). Most variables were insignificant, indicating that the county dummy variables in the fixed effects formulation captured much of the underlying variation in the observed agriculture to forest ratios in these counties. The amount of explained variation was high, with a constant R^2 value of 0.95 across all models. The value of the log-likelihood function at model convergence went down with the addition of more explanatory variables related to the profitability of urban land use, which indicates that these variables did not add explanatory power. A likelihood ratio test confirmed that Model 1 yielded the best overall fit.

The variables related to the profitability of agricultural land use, farm profits, and crop revenue were not significant across models. Median house value was significant and positive, but mediated by variance in housing values. This finding indicates that areas with a higher median house value had higher shares of agriculture relative to forest, except for areas where the variance in housing values was quite substantial. The LQ variable was not significant, but its inclusion pulled down the magnitude of the housing

TABLE 5. ESTIMATED RESULTS, AGRICULTURE TO FOREST SHARE.

Dependent variable ln(agriculture/forest)								
Fixed Effects	Model 1		Model 2		Model 3		Model 4	
	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*
Forest Rent	0.0001	*(0.002)*	–0.0003	*(0.002)*	–0.0003	*(0.002)*	–0.0005	*(0.002)*
Forest Rent * Slope	0.0033	*(0.017)*	0.0027	*(0.017)*	0.0034	*(0.017)*	0.0042	*(0.018)*
Farm Profits	0.6647	*(0.476)*	–0.0940	*(0.583)*	–0.2137	*(0.637)*	–0.3972	*(0.712)*
Crop Revenue	–1.1398	*(0.866)*	–1.3076	*(0.896)*	–1.3076	*(0.901)*	–1.1159	*(1.043)*
Population Density	0.0005	*(0.001)*	0.0006	*(0.001)*	0.0008	*(0.001)*	0.0012	*(0.001)*
Median House Value			0.0060**	*(0.000)*	0.0012**	*(0.000)*	0.0002*	*(0.000)*
Variance in House Value			–0.0392**	*(0.017)*	–0.0392**	*(0.017)*	–0.0390**	*(0.018)*
LQ Tertiary/Higher Sector					–0.1700	*(0.353)*	–0.3143	*(0.399)*
Accessibility to Cincinnati							–1.6309	*(1.790)*
Accessibility to Indianapolis							–1.4141	*(4.581)*
Accessibility to Terre Haute							0.0328	*(0.444)*
Accessibility to Louisville							0.2063	*(0.325)*
Accessibility to Evansville							–0.0038	*(0.012)*
Accessibility to Bloomington							0.0009	*(0.002)*
R^2-adjusted	.95		.95		.95		.95	
Log-likelihood	35.84		40.74		40.95		42.44	
Critical Value, Model 4 vs. Model 1							13.62	

NOTE: * Indicates significance at the 90 percent level, ** at 95 percent, and *** at 99 percent.

TABLE 6. ESTIMATED RESULTS, URBAN/RESIDUAL TO FOREST SHARE.

Dependent variable ln(urban-residual/forest)								
Random Effects	Model 1		Model 2		Model 3		Model 4	
	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*	Coeff.	*Std.Err.*
Constant	–1.2337***	*(0.200)*	–0.9444***	*(0.337)*	–0.5504	*(0.440)*	–1.2799***	*(0.392)*
Forest Rent	0.0046	*(0.004)*	0.0042	*(0.004)*	0.0044	*(0.004)*	0.0042	*(0.004)*
Forest Rent * Slope	–0.0284	*(0.028)*	–0.0268	*(0.027)*	–0.0263	*(0.027)*	–0.0308	*(0.026)*
LCC 1&2	0.0031	*(0.003)*	0.0020	*(0.003)*	0.0031	*(0.003)*	0.0087***	*(0.003)*
Farm Profits	2.6489***	*(0.785)*	1.8538**	*(0.889)*	1.3700	*(0.966)*	1.8461**	*(0.918)*
Crop Revenue	2.8018**	*(1.211)*	2.2876*	*(1.229)*	2.5829**	*(1.191)*	2.3006**	*(1.062)*
Population Density	0.0016***	*(0.000)*	0.0015***	*(0.000)*	0.0016***	*(0.000)*	0.0026***	*(0.001)*
Median House Value			0.0000	*(0.000)*	0.0000	*(0.000)*	0.0000	*(0.000)*
Variance in House Value			–0.0320	*(0.020)*	–0.0323*	*(0.020)*	–0.0615***	*(0.019)*
LQ Tertiary/Higher Sector					–0.7570	*(0.501)*	–0.2732	*(0.461)*
Accessibility to Cincinnati							1.1530***	*(0.221)*
Accessibility to Indianapolis							–0.9782**	*(0.447)*
Accessibility to Terre Haute							0.3238	*(0.515)*
Accessibility to Louisville							–0.0851	*(0.062)*
Accessibility to Evansville							–0.0071	*(0.005)*
Accessibility to Bloomington							–0.0020	*(0.001)*
R^2-adjusted	.41		.46		.66		.80	
Log-likelihood	–42.25		–36.03		–36.02		42.44	
Critical Value, Model 3 vs. Model 1					169.38**			

NOTE: * Indicates significance at the 90 percent level, ** at 95 percent, and *** at 99 percent.

value variable, indicating that areas with a greater concentration of tertiary and higher sectoral employment have less agricultural land. None of the accessibility variables were significant.

The share of urban to forest land. The estimated coefficients from the regression on the share ratios of urban/residual to forest land uses are found in Table 6. Overall, these models explained less of the variation in the dependent variables than in the agriculture/forest share model, as evidenced by the R^2 diagnostics, but many more variables were significant due to the random effect formulation. As evidenced by the value of the log-likelihood function, Models 2 and 3 explained more variation in the dependent variable than Model 1, but Model 4 was not superior. A likelihood ratio test comparing Model 3 to Model 1 was significant at the 95 percent significance level, and Model 3 was the only specification with a statistically insignificant constant term.

Thus, the addition of the median value and variance in housing values, and the location quotient for tertiary/higher sector greatly improved the model. This finding indicates that areas with wealthier individuals and higher residential land values have a higher share of urban land use. It is believed that increased urbanization and rural residential land conversion in southern Indiana is linked to changes in the regional labor market, namely, tertiary/quaternary sector job growth increases, and the effect of relatively wealthier individuals moving into rural areas.

Surprisingly, farm profits and crop revenue had a significant positive impact in these models, indicating that counties with higher profits and revenues have higher shares of urban land. The land quality variable (LCC) was highly significant in Model 4. Land that is suitable for agriculture is generally also highly suitable for urban conversion (e.g., good soils and flatter slopes make construction easier). Population density was significantly positive across all models, indicating that it is indeed a good proxy for urban land demand. The effect becomes even stronger when controlling for accessibility to regional centers. Accessibility to Cincinnati was positively related to the share of urban land, whereas accessibility to Indianapolis was negatively related to the share of urban land. Cincinnati has a greater land area than Indianapolis, and is serviced by many interstates, whereas Indianapolis only has one interstate running through the southeast region of the study area to Louisville, Kentucky.

Outlier analysis. Overall, the final models fit the data reasonably well, but there were a few notable outliers. Those counties for which the error terms exceeded in absolute value 1.5 times the interquartile distance were identified for Model 1 of the agriculture/forest ratio, and Model 3 for the urban/forest ratio. Because the error term is the predicted, minus the actual value of the dependent variable, observations with a positive error term had a *lower* land use ratio than predicted, whereas observations with a negative error term had a *higher* land use ratio than predicted.

For the agriculture to forest ratio, Ohio County, Indiana, (next to Cincinnati) had a persistently negative error term, indicating a much higher share of agriculture than was predicted. Clark County (close to Louisville), Vanderburgh (county that contains Evansville) and Vigo (contains Terre Haute) Counties were positive outliers, and thus had a lower share of agriculture than predicted. The specification testing did not favor inclusion of the accessibility variables for this land use ratio, but it appears that in these isolated cases, proximity to large urban areas was related to these persistent outliers.

For the urban to forest ratio, Brown and Crawford Counties were negative outliers, indicating a higher share of urban land than predicted, and Floyd and Knox Counties were positive outliers, indicating a lower share of urban land. Brown County has the greatest amount of public forestland (in the form of state parks) in the state, and its exceedingly steep slopes probably led to the early establishment of these parks as farms on these marginal lands were the first to fold early in the twentieth century. Since public forestland was not included in the estimation it might be expected that within this tourism-oriented county there is a relatively high proportion of urban land relative to private forest land.

Discussion

Though declining farm profits may lead to residential conversion, this impact is also coupled with a decrease in forest cover. Research into non-industrial private forestry (NIPF) has demonstrated that to preserve forestland in the Midwestern U.S., these particular landowners must be targeted. However, they may be especially hard to target through traditional government incentive programs because profitability of forest land use does not appear to be a major factor. In none of the models was the forest rent variable significant. This finding is contrary to applications of this model in other regions, such as Ahn et al. (2000) and Mauldin et al. (1999). One possible explanation for this difference is that non-timber forestland benefits are more important than the timber profitability for non-industrial private forest landowners, especially for the relatively small parcels common in Indiana. There also may be a speculative aspect of land use decisions that was not captured in this model, as some NIPF owners, in the face of urban growth pressure, may hold on to land in order to gain from sale to developers in the future (Hardie et al. 2001). Therefore, there is a particular need to understand the profitability of competing land uses relative to changes in NIPF extent.

Forestland provides positive externalities ranging from wildlife habitat to aesthetic beauty that may not be factored into land-use decisions in a pecuniary manner. Thus local governments may also need to create non-market based solutions to the forestland conversion issue, such as rules regarding land use. The policy objective may be to protect forests on the urban-rural fringe to reduce or slow urban conversion and preserve green space. Several local governments have designed zoning and planning regimes to protect such lands through the establishment of Forest Reserve and Agricultural/Rural Reserve designations (Monroe County Zoning Ordinance 2000).

It is hypothesized that changes in economic activity at the county level have significant implications for local land-use patterns, in that they determine both the amount of land used in extractive sectors (agriculture, pasturing, and forestry), and the amount of residential land conversion by their impact on land rents. Moreover, employment patterns are an important indicator of the demographic makeup of the counties and preferences that landowners may have for land use.

The share of both agricultural and forest land at an individual level is also greatly impacted by policies designed to promote those land uses, including government transfer payments to farmers,[7] and the classified forest program in Indiana, which reduces the assessed property value (Indiana Department of Natural Resources and Division of Forestry 2002). There is a panacea of policies promoting forest growth, conservation, and preservation, which aim at both increasing the profitability of forest use, as well as increasing amenity benefits from forests (Carlson et al. 2002).

This model indicates that the impact of the Indianapolis urban area on land use decisions is different from that of Evansville. Evansville is highly accessible with several interstates. Recently there has been statewide debate regarding proposed construction of I-69 to extend the interstate from Indianapolis to Evansville. The extension is a highly controversial issue in southern Indiana, as proponents argue that it will bring much-needed economic development opportunities to southwestern Indiana, whereas opponents fear sprawl. These findings may provide support for the notion that this proposed construction might greatly increase the profitability of urban land use, potentially leading to both growth and sprawl.

Conclusions and Directions for Future Study

Changes in secondary forest cover in southern Indiana are dynamic and bi-directional. In the latter half of the twentieth century, farm abandonment led to much regrowth in forests. More recently, urbanization and increased rural residential development are the most substantial causes of forest loss. This research built on a methodology used in previous analyses, by modeling observed county-level changes in land-use shares as a function of net benefits to each type of land use. To this analysis, measures were added to capture the impact of a growing, proximate urban region and changing regional comparative advantage in tertiary and higher sectors of the economy. It was hypothesized that changes in regional labor markets have significant implications for land-use patterns, in that they determine the amount of land used in extractive sectors (agriculture, pasturing, and forestry), and also the amount of residential land conversion. In general, areas that are losing employment and have lower regional comparative advantage experienced more forest regrowth. On the other hand, areas that are growing rapidly and experiencing employment growth in high-growth sectors are losing forest cover, most likely to urbanization. However, there are anomalies, like Monroe County, where employment growth and increasing regional competitiveness is coupled with forest regrowth. Some evidence was also found to suggest that there is a complex interplay between the opportunity costs of agricultural and forest land in the face of increasing urbanization.

Prior studies have made an important contribution in modeling land-use allocations at the county level by accounting for the opportunity cost of extractive land uses relative to urban or residential land (Plantinga and Buongiorno 1990; Parks and Murray 1994; Mauldin et al. 1999; Ahn et al. 2000). However, these studies have most often used simplistic measures, such as population density, to represent urban land rent. Some evidence was found for hierarchical processes, most evident in the impact of accessibility (population, adjusted for distance) to urban areas, and in changing regional employment.

Growing urban areas most likely exhibit spatial spillovers to land markets in neighboring areas, increasing the opportunity cost of land uses other than urban. This finding was not consistent for all urban areas in this study, however. The true impact of urban growth depends on the nature of that growth. Again, the economic structure of these cities and their impact on regional labor markets is a likely factor in explaining some of the variation.

Lastly, it must be stated that using aggregate, county-level data is a limiting factor in determining the overall impact of land-use change on Indiana's forests. County-level census data suffer from aggregation biases; for instance, median housing value is only one indicator of residential land market activity, and it is sensitive to outliers. One-digit SIC data misses much of the variation in sectoral employment patterns. Most importantly, measures of composition (percent private forest area) do not reflect the spatial pattern of the forest. As residential pressures increase, private forest area is likely to become increasingly fragmented. Urban sprawl results in a loss of natural vegetation and a general decline in the spatial extent and connectivity of wetlands, wildlife habitat, and agricultural lands (Buchanan and Acevedo 1997). This study illuminates the need to understand multi-level spatial processes that impact local land-use decisions. The union of analyses at different scales enhances understanding of complex decision-making leading to better urban land use conversion policies.

NOTES

1. This process of abandonment of nonprime agricultural lands continues today.
2. See Ahn et al. (2000) for the full derivation of the landowner's allocation problem.
3. As land appreciates in value, the value of the forest stands on that land may appreciate as well.
4. We are not accounting for the distribution of agricultural output among farms. Agriculture may employ fewer people as farms become larger (due to increasing returns to scale). In Indiana, employment and output have both decreased, indicating that even if land has been redistributed to larger scale farms, the net impact is still a reduction in agricultural production.
5. Total forestland was used, not just NIPF area, under the assumption that timber sales by NIPF landowners, timber industry, and national and state parks, collectively determine the price paid to mills. The species groups included poplar, elm-ash, beech, red and white oak, and maple.
6. There is a trade-off between fixed- and random-effects models in practice. Fixed-effects models do not require the limiting assumption that the county-specific effects are uncorrelated with the regressors, as the random-effects model does. On the other hand, the consistency of the fixed-effects estimator depends on t, or the number of time periods, and thus may be more unreliable for fewer temporal observations (Greene 2001). In some cases, one may have theoretical reasons to justify fixed or random effects, but these reasons may not always conform to the data.
7. One anonymous reviewer made the comment that transfer payments made to farmers can mitigate low or declining farm profits. Tax incentives, such as the Indiana Classified Forest Program, are probably more important, but unfortunately, such data are not available.

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