Demographic, Economic, Environmental, and Political Determinants of Developed Land Area in the U. S.

by

Scott R. Templeton (Associate Professor and Contact)
259 Barre Hall
Department of Applied Economics and Statistics
Clemson University
Clemson SC 29634-0313
864-656-6680 (o), 864-656-5776 (f), and stemple@clemson.edu
and
Ritu Sharma (Postdoctoral Researcher)
Department of Environmental Sciences
University of California at Riverside

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Abstract

Four fixed-effects models of developed land area were estimated with data from the National Resources Inventory and other government sources for 49 states in four years during 1982-1997. The non-linear model of the natural logarithm of the ratio of developed land's share of non-federal, non-CRP land to one minus the share best fits the data. Increases in a state's previous five-year average population, non-agricultural and non-mining output per capita, and annual growth rate of this output per capita induce land development. Developed land area also increases as the mean agricultural and mining output per capita, inflation rate, interest rate, and gas price during the previous five years decrease. The smaller is the previous five-year average area enrolled in the conservation reserve program, payment per enrolled hectare, and share of Democrats in a state's lower house, the larger is a state's developed area. In non-western states, increases in federal land stimulate conversion of undeveloped land.

Keywords: determinants of developed land area by state and year, fixed-effects model, land development in the United States

Demographic, Economic, Environmental, and Political Determinants of Developed Land Area in the U.S.

Introduction

Land development has occurred throughout the U.S. The area of urban, built-up, and rural transportation land increased 34%, from 29.6 million hectares to 39.8 million hectares, during 1982-1997 in the U.S. except Alaska (NRCS 2000, p. 36). Conversion of land from forestry, annual-crop production, and other undeveloped uses to residential, commercial, and other developed uses accompanies economic growth. However, this land-use change can adversely affect wildlife, water quality, and other natural resources (e.g., Heimlich and Anderson 2001, pp. 31-35). For example, land development led to a gross loss of 100,162 hectares of Palustrine and Estuarine wetlands on nonfederal land in all states except Alaska during 1992-1997 (NRCS 2000, p. 73). Vehicle miles can increase with urban expansion (e.g., Kahn, 2000) and, thus, emissions of greenhouse gases can too. For this and other reasons, urban and rural uses of land affect climate in the U.S. (e.g., Bonan 1999) and the world (e.g., Bounoua et al. 2002). Models of land-use change for continents and large countries have become important for forecasting climate change (e.g., DeFries et al. 2002).

Policies to reduce these negative externalities and forecasts of climate change as a function of land-use change should be grounded in appropriately-scaled and theoretically-motivated empirical models. In theory, the area of urban land depends on demands for urban and rural land, which, in turn, depend on, among other things, population and income per capita (Muth 1961, pp. 3, 16-20). Given constant agricultural rents, the area of developed land also depends on growth rates of population (Capozza and Helsey 1989, p. 301), expected housing rents (Arnott and Lewis 1979, p. 164), expected returns to urban use (Capozza and Li 1994, p. 897), and real interest rates. In early empirical analyses (e.g., Clawson 1971; Vesterby and Heimlich 1991), economic or demographic growth is also the main determinant of increases in urban areas but the quantitative impact in a multivariate statistical model was not estimated. In an exceptional paper, Brueckner and Fansler (1983) estimated an empirical model of the size of the urbanized area in a county in 1970 as a function of the county's population, average household income, agricultural rent, and proxies for commuting cost.

In recent empirical models of an individual's decision of whether (e.g., Bockstael 1996) or when (e.g., Irwin and Bockstael 2002) to develop a parcel of land, the quantitative effects of factors that determine differences in financial returns to residential and agricultural uses of the parcel have been estimated. These factors include zoning, other land-use restrictions, or distance of parcel to nearest highway or urban center. In these models, however, the effects of population, real economic production per capita, associated growth rates, real gas prices, and other factors that federal or state policy makers can influence have not been estimated. Use of parcel-level, spatially-explicit data makes such estimation relatively difficult, if not prohibitively expensive. In this paper the effects of demographic, economic, environmental, and political factors on the area of developed land in any state in the U.S. except Alaska are estimated and analyzed.

Conceptual Framework

Markets for developed and undeveloped land in a state are perfectly competitive.

Utility, profit, and social-welfare maximizers—households, businesses, and government—demand developed land for residential, commercial, industrial, transport-related, and other 'urban' uses. Farmers, government agencies, and, to a lesser extent, households demand undeveloped land for agricultural, environmental, recreational, and other 'rural' uses. As household income or business profits increase, the demands for developed and undeveloped land increase, but not necessarily in equal amounts. Parcels of developed land tend to be clustered around a central business district, environmental amenity, or other point of interest for various reasons (McCann 2001, pp. 93-136) that depend on costly transport of goods, people, or information across space (McCann 2001, p. 1). *Ceteris paribus*, the marginal willingness to pay and, thus, rent for developed land is higher, the lower are these transport costs. Although rents for undeveloped land also depend on location, business profitability and household utility of urban activities are more sensitive to transports costs than rural activities are (McCann 2001, pp. 104-105). Federal farm programs typically increase rents for some types of undeveloped land.

Landowners determine the stock of developed land. They maximize the net present value of their holdings and, thus, allocate land to the highest valued use(s). If so, an owner of a parcel will develop it or sell it to a developer in an arbitrary year T provided that two conditions hold. First, the sum of the discounted (to T) net benefits of current and future use of developed land, say residential use, $\sum_{i=0}^{\infty}\frac{R(T+i)}{(1+r)^i}$, exceeds the sum of the forgone discounted net benefits of undeveloped land use, such as agricultural production, $\sum_{i=0}^{\infty}\frac{A(T+i)}{(1+r)^i}$, and the costs of land conversion in that year, $C^R(T)$. That is,

$\sum_{i=0}^{\infty} \frac{R(T+i) - A(T+i)}{(1+r)^i} - C^R(T) > 0$. Second, the discounted net income of this conversion in T, $\left[\sum_{i=0}^{\infty} \frac{R(T+i) - A(T+i)}{(1+r)^i} - C^R(T) \right]$, is at least as large as the sum of returns from use of the undeveloped land in that year plus the discounted net income from conversion a year later, $A(T) + \left[\sum_{i=1}^{\infty} \frac{R(T+i) - A(T+i)}{(1+r)^i} - \frac{C^R(T+1)}{(1+r)} \right]$. This second condition simplifies to $R(T) - A(T) - C^R(T) \geq A(T) - \frac{C^R(T+1)}{(1+r)}$. [These two conditions are similar to those in Irwin and Bockstael (2002)]. Furthermore, a landowner will not convert in *T* a previously developed parcel if the sum of the present values of returns from developed uses exceeds the sum of the present values of returns from undeveloped uses net of the costs of conversion back to undeveloped uses. In symbols, a landowner keeps a parcel in its developed state if $\sum_{i=0}^{\infty} \frac{R(T+i)}{(1+r)^i} > \sum_{i=0}^{\infty} \frac{A(T+i)}{(1+r)^i} - C^A(T)$.

The sum of the areas of the individual parcels that landowners develop in a particular year or developed in previous years and did not convert back is the area of developed land in a state in that year. If owners manage land to maximize discounted wealth, then developed area depends on interest rates and factors that determine undiscounted returns to developed and undeveloped uses of parcels, conversion costs, and land-use regulations.

Variables and Data Sources

The U. S. Department of Agriculture's Natural Resources Conservation Service conducted the National Resources Inventory (NRI) every five years from 1982 to 1997.

In each NRI, the NRCS used aerial photographs, other remote-sensing methods, and ground truthing for 800,000 sample sites to estimate, among other things, the area of developed land for each state of the U.S. except Alaska (NRCS 2000, p. 3). Sampled and estimated areas reflected 'growing season conditions' (NRCS 2000, p. 3) in individual states in those years.

The Natural Resources Conservation Service has also not collected financial data from individual owners of parcels in their samples. Moreover, to keep identities of owners confidential, NRCS does not release longitude and latitude coordinates of the exact locations of sampled parcels. Hence, data on financial returns from uses of specific parcels, conversion costs, discount rates of individual owners in the NRI sample, and non-pecuniary benefits and costs to owners of these uses cannot be collected. However, data on variables that affect these returns, costs, and discount factors are available.

Table 1 contains descriptive statistics for the variables in this analysis. DEVAREA represents the area of non-federally owned large urban and built-up areas, small built-up areas, and rural transportation land in a state in 1982, 1987, 1992, and 1997 (NRCS 2000, p. 82). Urban and built-up areas include residential, industrial, commercial, and institutional land, construction sites, railroad yards, cemeteries, airports, golf courses, landfills, sewage treatment plants, and urban roadways (NRCS 2000, p. 88). Rural transportation land includes all highways, roads, railways, and other rights-of-way outside of urban and built-up areas (NRCS 2000, p. 86).

To reflect the periodicity of the NRI and non-instantaneous land conversion, demographic, economic, and political variables were constructed to summarize conditions during the five or four years prior to the year in which areas of developed land were sampled and estimated. This construction also reduces the possibility that these variables could be endogenous. For example, POP represents the mean of the mid-year populations in a state for 1977-1981, 1982-1986, 1987-1991, and 1992-1996 (Census Bureau, 2002, 1996, and 1995). POPGRATE is the mean of the annual growth rates of state population for 1978-1981, 1982-1986, 1987-1991, and 1992-1996.

Traditional agriculture, which includes commercial forestry, and mining are the primary uses of undeveloped land. To account for differences in the loci of productive activities and, thus, potential impacts on rents, economic production per capita is separated into real agricultural and mining output per capita and all other real production per capita. In particular, AGMINEPC and NONAGMPC represent the means of real (1996 $s) agricultural and mining output per capita of agricultural and all other production per capita in a state for the five years prior to 1982, 1987, 1992, and 1997 (BEA 2003). NAGMPCSQ is the square of NONAGMPC. Real agricultural production per capita, by construction and data availability, includes real output of forestry and fishing. AGMGRATE and NAMGRATE are the means of the annual growth rates of real agricultural and mining output per capita and all other real production per capita for 1978-1981, 1982-1986, 1987-1991, and 1992-1996.

The Federal Home Mortgage Corporation was the source of data on fixed interest rates for 30-year conventional mortgages for the U.S in each year for 1977-1997 (FHMC 2003). The real interest rate in a particular state and year was calculated as this nominal interest rate for the nation in that year minus the state's inflation rate in that year. A state's inflation rate equals the ratio of state's price index in a given year to the index in the previous year minus one. The price index equals the state's nominal gross state product divided by its real (1996 $s) gross state product. INTERATE and INFLRATE represent the mean real interest rate for 30-year conventional mortgages and the average inflation rate in a state for '78-'81, '82-'86, '87-'91, and '92-'96.

The Energy Information Administration of the US Department of Energy publishes annual, statewide data on the nominal price of motor gasoline, measured in dollars per million British Thermal Units (EIA 2001). There are 0.12407 million BTUs per gallon of gasoline (EIA 2003) and 0.26417 gallons per liter. The real (1996 $s) price of motor gasoline equals the nominal price in a particular state and year divided by the state's price index for that year. GASPRICE represents the average real price of a liter of motor gasoline in a state for the five years prior to 1982, 1987, 1992, and 1997.

There is no available published information that summarizes the degree of zoning in a particular state and year. However, reputations and legislative records of the two major political parties suggest differences in their approach to regulation (Friedman 2000). The degree to which state legislators belong to the Democratic Party might reflect the degree to which citizens in that support regulation of land uses. SHAREDEM equals the mean of the shares of Democrats in the lower house of a state's legislature for the five years prior to 1982, 1987, 1992, and 1997. These shares were calculated with data on the number of state legislators by political party affiliation after each state election (Census Bureau 2001, 1999, 1992, 1986, and 1984).

The Conservation Reserve Program (CRP) provides farmers who sign the 10 to 15 year contracts with rental payments and cost-share assistance to plant trees or other resource-conserving vegetative covers to improve the quality of water, control soil erosion, and enhance wildlife habitat (FSA 2003). CRPPAY and CRPAREA represent average real (1996 $s) net outlays per enrolled hectare and the enrolled area of the CRP during the five years prior to 1982, 1987, 1992, and 1997 (Barbarika 2003). CRPPAYSQ is the square of CRPPAY.

The 1997 National Resources Inventory was also the source of data for two possible environmental determinants of developed land use. WATER represents the surface area of streams, rivers, lakes, bays, and other permanently open bodies of water in a state in these four different years (NRCS 2000, p. 89). FEDAREA and FEDARESQ are the area and squared area of land that the federal government owns (NRCS 2000, p. 85) and, thus, are not readily developable. The areas of federally owned land and surface water can change over time due to purchase, sale, donation, and exchange by federal agencies of land and creation of lakes (NRCS 2000, p. 36-39). The sum of the areas of water, federal land, and non-federally owned land equal a state's surface area, which is time invariant.

NOFEDCRP, the area of non-federal land in 1982, 1987, 1992, and 1997 minus the average area of CRP land during each of the previous five years, represents the stock of developed and developable land. Developed land's share of non-federal and non-CRP land, DEVDEN equals DEVAREA/NOFEDCRP. DEVDEN/(1-DEVDEN) is the 'odds' of developed land. POPDEN, CRPDEN, WATDEN, FEDDEN, and FEDSQDEN equal POP, CRPAREA, WATER, FEDAREA, and FEDARESQ divided by NOFEDCRP. Descriptive statistics for these density variables are available upon request.

Econometric Models and Estimation Procedures

Let lnDV_{it} be the natural logarithm of the share (DEVDEN$_{it}$) or 'odds' [DEVDEN$_{it}$/(1-DEVDEN$_{it}$)] of developed land in state i and year t. A fixed-effects model of either dependent variables is $\ln DV_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it}$, in which i = state 1, 2, …, and 49, t = time period 1, 2, 3 and 4, X'_{it} is a 1 x K row vector of exogenous variables in state i and year t, and β is a K x 1 parameter vector. The intercept α_i represents a state i-specific effect and, more importantly, embodies unobserved state-specific factors that might be correlated with X_{it}, observed characteristics of state i in time period t (Greene 2000, p. 576). The error term ε_{it} represents random processes and also researcher ignorance. Assume $\mathrm{E}(\varepsilon_{it}) = 0$. Hence, $\alpha_i + X'_{it}\beta$ is a linear-in-parameters approximation of the unknown functional form of a reduced-form model of the natural logarithm of the area, share, or 'odds' of developed land in state i and time t. In contrast to a random-effects model, a fixed-effects model is likely to be appropriate for a sample of all cross-sectional units—all states except Alaska, in this case—at specific points in time (Greene 2000, p. 567).

Fixed-effects models were estimated with PANEL commands in Time Series Processor, Version 4.5 (Hall and Cummins 1999). Natural logarithms of the share (DEVDEN) and odds [DEVDEN/(1-DEVDEN)] of developed land induced homoskedastic and normal residuals that would have not been otherwise. The dependent variables were based on DEVDEN and DEVDEN/(1-DEVDEN) to standardize for different sizes of non-federal, non-CRP areas. The model of the log of DEVDEN/(1-DEVDEN) was also estimated because predicted shares never exceed one or are negative.

Linear-in-exogenous-variables and nonlinear-in-a-few-exogenous-variables versions of each of the two models were estimated. The inclusion of NAMPCSQ, CRPPAYSQ, and FEDSQDEN in the log-of-share and log-of-odds models makes them nonlinear. Skewness and kurtosis are 3.65 and 21.15 for CRPPAY and 4.88 and 26.48 for FEDDEN; these variables have the most skewed and least peaked distributions among the variables in the linear-in-exogenous-variables models. NAMPCSQ was included to capture a possible reversal in the effect NONAGMPC on land development.

The statistic to test whether the state-specific constants differ from each other is

$$F(48,147-K)=\frac{(R^2_{Fixed}-R^2_{Pooled})/(48)}{(1-R^2_{Fixed})/(147-K)} \text{ (Greene 2000, p. 562),}$$

in which *Fixed* indicates the fixed-effects model and *Pooled* indicates a pooled model with only a single intercept for all 49 states and 4 time periods. Under the null hypothesis that the state-specific constants are the same, this statistic is an *F* random variable with 48 numerator and 147-K denominator degrees of freedom.

Although comparison of the $\overline{R}^2$s of the linear and nonlinear versions of each of the three types of models is valid, comparison of $\overline{R}^2$s across types of models is not (Greene 2000, p. 241). To compare types of models, each of the four models was used to estimate the area of developed land in state *i* and year *t*, $\hat{Y}_{it}$, and then calculate a measure analogous to R^2, namely $R^2(\hat{Y}_{it})=1-\frac{\sum_{i=1}^{49}\sum_{t=1}^{4}\left(Y_{it}-\hat{Y}_{it}\right)^2}{\sum_{i=1}^{49}\sum_{t=1}^{4}\left(Y_{it}-\overline{Y}\right)^2}$ (Greene 2000, p. 241). The estimate of this area is $Z_{it}\exp\left(\widehat{\ln Y_{it}}\right)$ in the log-of-share models and $Z_{it}\dfrac{\exp(X_{it}\hat{\beta})}{1+\exp(X_{it}\hat{\beta})}$ in the log-of-odds models.

The sample-mean marginal effects of variables of interest and associated elasticities are not obvious. Let Y_{it} be DEVAREA$_{it}$. and Z_{it} be NOFEDCRP$_{it}$. In the non-linear, log-of-the-share model, $\ln\left(\dfrac{Y_{it}}{Z_{it}}\right)=\alpha_i+\beta_1\dfrac{X_{it}}{Z_{it}}+\beta_2\dfrac{X_{it}^2}{Z_{it}}+\beta_3 W_{it}+\beta_4 W_{it}^2+\cdots+\varepsilon_{it}$, the estimated mean marginal effects of X_{it} and W_{it} on Y_{it} are $\overline{\dfrac{\partial \hat{Y}_{it}}{\partial X_{it}}} = \hat{\beta}_1\overline{\left(\dfrac{Y}{Z}\right)}+2\hat{\beta}_2\overline{\left(\dfrac{XY}{Z}\right)}$ and $\overline{\dfrac{\partial \hat{Y}_{it}}{\partial W_{it}}} = \hat{\beta}_3\overline{Y}+2\hat{\beta}_4\overline{WY}$. The estimated mean elasticities of Y_{it} with respect to X_{it} and W_{it} are $\overline{\dfrac{\partial \hat{Y}_{it}}{\partial X_{it}}\dfrac{X_{it}}{Y_{it}}} = \hat{\beta}_1\overline{\left(\dfrac{X}{Z}\right)}+2\hat{\beta}_2\overline{\left(\dfrac{X^2}{Z}\right)}$ and $\overline{\dfrac{\partial \hat{Y}_{it}}{\partial W_{it}}\dfrac{W_{it}}{Y_{it}}} = \hat{\beta}_3\overline{W}+2\hat{\beta}_4\overline{W^2}$.

In the nonlinear, log-of-the-odds model,

$\ln\left(\dfrac{Y_{it}}{Z_{it}}\Big/1-\dfrac{Y_{it}}{Z_{it}}\right)=\alpha_i+\beta_1\dfrac{X_{it}}{Z_{it}}+\beta_2\dfrac{X_{it}^2}{Z_{it}}+\beta_3 W_{it}+\beta_4 W_{it}^2+\cdots+\varepsilon_{it}$, the estimated mean marginal effects of X_{it} and W_{it} on Y_{it} are

$$\overline{\frac{\partial \hat{Y}_{it}}{\partial X_{it}}}=\hat{\beta}_1\left[\overline{\left(\frac{Y}{Z}\right)}-\overline{\left(\frac{Y}{Z}\right)^2}\right]+2\hat{\beta}_2\left[\overline{\left(\frac{XY}{Z}\right)}-\overline{\left(\frac{XY^2}{Z^2}\right)}\right] \text{ and}$$

$$\overline{\frac{\partial \hat{Y}_{it}}{\partial W_{it}}}=\hat{\beta}_3\left[\overline{Y}-\overline{\left(\frac{Y^2}{Z}\right)}\right]+2\hat{\beta}_4\left[\overline{WY}-\overline{\left(\frac{WY^2}{Z}\right)}\right].$$

The estimated mean elasticities of Y_{it} with respect to X_{it} and W_{it} in this model are

$$\overline{\frac{\partial \hat{Y}_{it}}{\partial X_{it}} \frac{X_{it}}{Y_{it}}} = \hat{\beta}_1 \left[\overline{\left(\frac{X}{Z} \right)} - \overline{\left(\frac{XY}{Z^2} \right)} \right] + 2\hat{\beta}_2 \left[\overline{\left(\frac{X^2}{Z} \right)} - \overline{\left(\frac{X^2 Y}{Z^2} \right)} \right] \text{ and}$$

$$\overline{\frac{\partial \hat{Y}_{it}}{\partial W_{it}} \frac{W_{it}}{Y_{it}}} = \hat{\beta}_3 \left[\overline{W} - \overline{\left(\frac{WY}{Z} \right)} \right] + 2\hat{\beta}_4 \left[\overline{W^2} - \overline{\left(\frac{W^2 Y}{Z} \right)} \right].$$

Of course, in the linear versions of these models, the terms $\hat{\beta}_2$ and $\hat{\beta}_4$ do not appear.

Results

Parameter estimates, standard errors, and *p*-values associated with the implied *t*-statistics are reported in Tables 2 and 3. The $\overline{R}^2$, *F* statistic for the test of differences in state-specific constants, Schwarz Information Criterion, and $R^2(\hat{Y}_{it})$ of each model are also reported at the bottom of these tables. Tables 3 and 4 contain the estimated sample-mean marginal effects and elasticities.

The $\overline{R}^2$ of each model exceeds 0.996. The nonlinear version of each of the two types of model has a higher $\overline{R}^2$ and smaller Schwarz information criterion than the linear version (Tables 2 and 3). Moreover, the values of the *F* statistic are extremely high and the null hypotheses of sameness of state-specific intercepts are decisively rejected. Furthermore, these fixed-effects models are more appropriate than random-effects models. Given the large value of Hausman's χ^2 statistic for the random-effects version of each of the four models, one rejects the null hypothesis that the state-specific constants are uncorrelated with the other exogenous variables, an assumption of the random-effects model, in favor of the alternative that these constants are correlated. The $R^2(\hat{Y}_{it})$ for the linear and nonlinear odds models are slightly higher than the $R^2(\hat{Y}_{it})$ for the share models (Tables 2 and 3). Thus, the fixed-effects, nonlinear odds model best fits the data.

The positive effect of POPDEN is statistically significant in the nonlinear version of the share model (Table 2) and both versions of the odds model (Table 3). In the nonlinear odds model, the estimated mean marginal effect of an additional person is 0.028 hectares, or 0.068 acres, of developed land (Table 4). In that model, a one percent increase in a state's average, previous five-year population leads to a subsequent 0.23% increase, on average, in the state's developed land area (Table 5).

The negative effect of AGMINEPC is statistically significant in the nonlinear versions of the share and odds models (Tables 2 and 3). The estimated marginal effects and elasticities are similar across models (Tables 4 and 5). In the nonlinear odds model, if average real agricultural and mining output per capita in the previous five years is $100 more in one state than another, the former state will have 1,780 fewer hectares of developed land. A 1% decrease in mean agricultural and mining output per capita in the previous 5 years leads to a 0.029% increase in developed land area.

The inclusion of NAGMPCSQ reduces the standard errors of the estimators for NONAGMPC, although the latter's positive effect is still statistically significant in linear versions (Tables 2 and 3). In the nonlinear odds model, an increase of $100 in average real per capita output other than agriculture or mining in the previous five years induces, on average, 940 more hectares of developed land (Table 4). However, an increase beyond $32,522, which is more than two standard deviations above the sample mean, makes the area of developed land smaller than it would have otherwise been. Also, a one percent increase in non-agricultural and non-mining output per capita in the previous five years induces a subsequent 0.29% increase, on average, in developed land area (Table 5).

NAMGRATE always has a positive and statistically significant effect. In the nonlinear odds model, a one percentage point increase in the mean annual growth rate of real non-agricultural and non-mining output per capita in the previous four or five years leads to, on average, a subsequent increase of 5,336 hectares of developed land (Table 4).

The negative effects of INTERATE and INFLRATE are statistically significant in all models. In the nonlinear odds model, a decrease of one percentage point in a state's mean real mortgage interest rate during the previous five years induces, on average, 17,510 hectares of land development (Table 4). A decrease of one percentage point in a state's mean inflation rate during the previous five years induces, on average, an increase in developed land of 22,949 hectares (Table 4). Moreover, the effects of these two variables differ; one decisively rejects the null hypothesis that these effects are the same on the basis of likelihood ratio statistics that far exceed critical values for $\alpha = 0.005$.

The negative effect of GASPRICE is significant in all models. If the average price of gas decreases \$1 during a five-year period, a state's area of developed land will subsequently be 196,104 hectares larger. A 1% decrease in GASPRICE subsequently increases developed land area by 0.11%, on average.

SHAREDEM negatively affects urbanization of land use and is statistically significant in all models. The estimated effect is lower in each of the nonlinear versions than in the corresponding linear versions of the two types of model. The estimated effect among linear versions and separately among nonlinear versions is highest in the odds model. In the nonlinear odds model, a one percentage point decrease in the average share of Democrats in the state's lower legislative house leads to an average increase in developed land area of 1,849 hectares.

Both the enrolled area and payments per hectare of the Conservation Reserve Program have negative and statistically significant effects on developed area. In the nonlinear odds model, a decrease of $10 in the previous five-year average real conservation reserve program payment per enrolled hectare leads to an average increase of 1,451 hectares of developed land. The effect becomes positive beyond a CRP payment of $616.72 per hectare, which exceeds four standard deviations above the mean CRP payment. The area of developed land is 100 hectares larger, on average, in a state with 1000 fewer hectares enrolled in the CRP during the previous five years.

The inclusion of FEDSQDEN in the models substantially reduces the standard errors of the parameter estimators for FEDDEN. The effects of FEDDEN and FEDSQDEN are significant in the nonlinear models. In the non-linear odds model, the positive effect of a state's federal area on the area of developed land decreases as the federal area increases. The effect becomes negative if the federal area exceeds 10,304 hectares, approximately one standard deviation above the mean. In this model, an increase of 1000 hectares of federal land induces development, on average, of 206 additional hectares. In contrast to the mean marginal effect, the mean elasticity is negative because of the influences of western states for which the marginal effects are negative and the ratios of FEDAREA to DEVAREA exceed 8. The median ratio is 0.9 and the maximum is 220.

Discussion

The largest estimated marginal effect of population on developed land area, 0.028

hectares, is approximately one-fourth smaller than 0.088 hectares, the marginal urban land-use consumption in 135 fast-growth counties of the U.S. between the early 1970s and the early 1980s (Vesterby and Heimlich 1991, p. 285) and one-tenth smaller than 0.28 hectares, the urban land-use coefficient in the continental U.S. during 1974-1987 (Reynolds 2001, p. 277). These other two estimates are integer multiples larger than the largest estimate in this paper primarily because they are not based on regression models. Instead, these two estimates equal the change in the urban population during the respective time periods divided by the corresponding change in urban area, however defined. The increases in developed land area and population in the coterminous states and Hawaii between 1982 and 1997 were 10.0254 million hectares and 40.885 million people. Thus, each additional person during 1982-1997 'consumed' 0.245 of a hectare of newly developed land. However, each additional person did not cause an additional 0.245 of a hectare to be developed. The estimate of 0.245 hectares and the other two non-regression-model estimates incorporate effects of changes in other determinants that occurred at the same time that population grew. For example, the average increase in the mean of real non-agricultural and non-mining output per capita during the previous five years, NONAGMPC, was $1,883 during 1982-1997. Thus, based on the nonlinear odds model, the developed area in a state would have increased, on average, 53,363 hectares (= 9.4 x $1,883 x 3) by 1997, even without population growth.

Population-induced increases in developed land area imply that rents grow faster for uses of developed land than uses of undeveloped land. This differential pattern of rent increases is consistent with one or both of the following hypotheses. First, demand increases proportionately more for uses of developed land than for uses of undeveloped land as population grows. Second, even if these population elasticities of demand were the same, farmers are more willing and able to substitute fertilizers, pesticides, new varieties of seeds, and other inputs for land to increase production in response to increases in demand for undeveloped land than developers are willing and able to substitute vertical space and horizontal space-saving inputs for land to increase production of sites for residential, commercial, industrial and other 'urban' activities in response to increases in demand for developed land. As a result, the increase in rent for parcels of land along the old spatial margin(s), if converted to developed uses, exceeds the increase in rent for those same parcels, if kept undeveloped.

Increases in the demand for a state's agricultural or mining exports or weather-related decreases in supply of agricultural and mining products, given price inelastic demand, are two possible reasons for increases in real agricultural and mining output per capita. In turn, increases in the previous five-year average real agricultural and mining output per capita, holding population constant, probably imply increases in present and future real net earnings from uses of undeveloped land.

Real non-agricultural and non-mining output per capita constitutes, on average, 95% of real gross state product per capita. The sample correlation coefficient between these two variables is 0.96 and the linear association between them is strongly positive (p-value $< 10^{-10}$). Thus, increases in real non-agricultural and non-mining output per capita in a state are likely to have the same effects that increases in real income per capita would have. Suppose that at most levels of real income per capita the income elasticity of demand for the highest-valued developed use of land along the spatial margin(s) exceeds the income elasticity of demand for the highest-valued undeveloped use of that land. For example, the income elasticity of demand for housing in the long run exceeds that for food (e.g., Deaton and Muellbauer 1980, pp. 319-320; Muth 1961, p. 19). If so, increases in real non-agricultural and non-mining output per capita and its growth rate would imply greater increases in real current and future rents for uses of developed land than rents for uses of undeveloped land. As a result, the area of developed land would increase.

However, as the results from the nonlinear models suggest, the positive excess of the increase in rents for uses of developed land over the increase in rents for uses of undeveloped land diminishes as real non-agricultural and non-mining output per capita increases. Beyond an unusually high threshold, the excess becomes negative and the income elasticity of demand for the highest-valued developed use of land along the spatial margin(s) is less than the income elasticity of demand for the highest-valued undeveloped use of that land.

The decrease in and reversal of the relative magnitudes of these elasticities is consistent with at least two complementary explanations. First, although both the opportunity cost of travel and the demand for urban space increase with income (McCann 2001, pp. 109-113), the marginal willingness to pay for space dominates the marginal willingness to pay for accessibility as income increases but the domination diminishes. Above the threshold, however, the income-dependent preference for accessibility dominates the income-dependent preference for space. Second, the demand for preservation of certain types of undeveloped land for its own sake or for nature-based recreation, such as hiking and wildlife sightseeing, also increases with income (e.g., Kristrom and Riera 1996). Above the threshold, the marginal willingness to pay for undeveloped land exceeds the marginal willingness to pay for urban space.

As the real interest rate increases, the real discounted cost of converting land in the future, $\frac{C^R(T+1)}{(1+r)}$, decreases and, thus, the net gain of postponement increases. As the inflation rate increases, the risk premia that lenders charge developers for loans to finance land development might increase as well. If so, the discounted cost of conversion in the future will decrease and the net gain of postponing land development will increase. Also, the demand for land increases and, thus, the price of land increases as the inflation rate increases (Just and Miranowski 1993, p. 157). If the price of undeveloped land increases more than the price of developed land—one possible reason might be that new owners of undeveloped land can more easily self finance their purchases than would-be developers can—then some parcels would become unprofitable for development.

In theory (e.g., Capozza and Helsey 1989, p. 297) and empirical analyses (e.g., Brueckner and Fansler 1983, pp. 481-482; Bockstael 1996, p. 1176), housing prices usually decline as residential locations get farther from the central business district, town center, or highway because commuting costs increase with distance. Commuting costs also increase with the real price of gas. Although prices of land for developed and undeveloped uses will decrease as transport costs increase, the decrease in the price of land for developed uses will tend to be more pronounced because commuting tends to be more time-intensive for users of developed land than users of undeveloped land. For example, people typically commute four to six days per week whereas farmers transport produce several times per year. As a result, less land is converted to developed uses as real gas prices increase. In other words, for a given population, the area of developed land decreases as the real price of gas increases because, to economize on commute costs, people choose to live and work closer together and, thereby, create denser uses of developed land. Increases in gas prices also imply increases in the cost of converting undeveloped land into developed land. The higher is the real cost of conversion, the fewer are the parcels of land that are profitably developed.

As the share of Democrats in the lower legislative house increases, local government officials might be more likely to regulate land use through zoning or other policies because these officials are more likely to be Democrats themselves or, at least, the voting public is more likely to support such regulations. In general, Democrats regulate the economy and its environmental impacts more than Republicans do (Friedman 2000). As prohibitions and inhibitions on land development increase, future real returns to developed uses of currently undeveloped land decrease and the amount of land that is converted to urban uses decreases as well.

Increases in previous five-year average conservation-reserve-program payments per hectare of enrolled land imply increases in real returns to owners of agricultural and timber land for the duration of the CRP contract. Similarly, as the previous five-year average area of land that is enrolled in the CRP increases, the subsequent supply of land for agriculture and other undeveloped uses decreases and real returns per hectare of this land increase. As real returns for uses of undeveloped land increase, some of the land that would have otherwise been developed for urban uses is not. However, increases in the previous five-year average CRP payments beyond $617 per hectare lead to net increases in the area of developed land for this possible reason: these relatively high payments enable farmers to finance development of some of the non-enrolled land.

As the area of federal land in a state increases, for a given surface area, the more environmental amenities and better access to them the residents of the state have. The more abundant and closer are environmental amenities to agricultural and residential land, the higher are rents for these properties (e.g., Bastian et al. 2002; Smith et al. 2002). If users of developed land tend to value the larger quantities and better access to environmental amenities more than the users of undeveloped land do, then the area of developed land will increase and the area of undeveloped land will decrease as the area of federal land increases. However, in addition to the amenity effect, a scale effect exists. That is, given a state's water bodies, CRP land, and constant surface area, a larger area of federal land in a state implies a smaller area of non-federal, non-CRP land. The smaller is the area of non-federal, non-CRP land in a state, the smaller are the areas of both developed and undeveloped land. In the nonlinear models, this scale effect dominates the amenity effect in western states with above-average areas of federal land.

Conclusions

Population growth induces land development. Urban land-use coefficients and marginal urban land consumption overstate the incremental effect of an additional person, however. Moreover, even if state populations do not grow, another type of economic growth—increases in real non-agricultural and non-mining output per capita up to a relatively high threshold—also engenders land development. There might be a U-shaped relationship between the environmental benefits of certain types of undeveloped land and income per capita. One type of economic growth—increases in agricultural and mining output per capita—inhibits land development. In addition to reducing emissions of greenhouse-producing gases, an increase in the real price of gas generates an additional environmental benefit to the extent that land which would have otherwise been developed provides ecosystem goods or services. Similarly, in addition to conserving soil and providing other *in-situ* environmental benefits, each additional hectare of land enrolled in the CRP creates an *ex-situ* environmental benefit to the extent that the extra 0.1 hectare not developed as a result also provides ecosystem goods and services.

Areas of developed land were estimated in only four different years during a sixteen-year period in 49 states of the U.S., however. Whether the results are robust for other periods of time and countries remains to be seen. Moreover, although land development is statistically reversible in the models herein, conversion of developed land into undeveloped land rarely occurs and is never observed at the scale of a state. A model of land development that incorporates irreversibility must have a structure different from the ones in this paper. One model of irreversible land development for our data is this:

$$\text{DEVAREA}_{it} = \left(e^{-\beta X_{i,t-1} + \varepsilon_{i,t-1}} + 1\right)^{-1} \left(\text{NFEDCRP - DEVAREA}\right)_{i,t-1} + \text{DEVAREA}_{i,t\text{-}1}$$

Estimation of such a model with newly released data from the NRI for 2003 is a subject for future research. Finally, the real price of gas was the only explanatory variable in the models herein that affected the undiscounted real costs of land conversion. However, forests and steep land are more costly to develop than crop land and flat land are

(Bockstael 1996, pp. 1176-1177). The NRI contains the area of forest and an erodibility index of crop land by state over time. Either variable could be included in the model of irreversible development.

In spite of its limitation, the nonlinear odds model could be used by those who forecast climate change as a function of land-use change. In this and the linear version of the odds model, the predicted share of developed land will never lie outside the 0-1 interval. A color scheme—for example, a darker color for a larger predicted share of developed land—could be used for a visual forecast.

The results also provide cautious guidance for policy making. Family-planning and other policies that reduce population growth are likely to reduce developed land area. Policies that improve the real returns to agriculture and mining are likely to prevent the conversion of some undeveloped land. Expansionary but non-inflationary monetary or fiscal policies are likely to induce land development. Changes in the Farm Bill that raise CRP payments per enrolled hectare, provided they are not too big, or expand enrollment of undeveloped land in the program will strengthen the incentives for continued use of some undeveloped land. A permanent tax on the price of gas will make the conversion of some undeveloped land unprofitable. Political campaigns that increase the shares of Republicans in lower state houses are likely to indirectly promote land urbanization.

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Table 1: Descriptive Statistics (n=196)

Variable	Mean	Std. Deviation	Minimum	Maximum
DEVAREA (1,000 hectares)	694.9	544.4	60.4	3,467.0
POP (1,000 people)	4,929	5,208	452	31,490
AGMINEPC (1996$/person)	$1,090.18	$1,372.86	$98.31	$10,028.25
NONAGMPC (1996$/person)	$22,059.55	$4,643.75	$13,618.82	$37,340.56
POPGRATE (percentage pts.)	1.09	1.12	-1.50	5.74
AMGRATE (percentage pts.)	3.20	5.01	-6.99	30.73
NAMGRATE (percentage pts.)	1.90	1.31	-2.73	5.49
INTERATE (percentage pts.)	6.40	2.15	-2.84	14.03
INFLRATE (percentage pts.)	4.59	2.68	-0.88	15.65
GASPRICE (1996$/liter)	$0.38	$0.07	$0.27	$0.59
SHAREDEM (percentage pts.)	58.99	17.62	22.00	96.82
CRPPAY (1996$s/hectare)	$78.53	$119.87	$0.00	$992.27
CRPAREA (1,000 hectares)	128.0	273.5	0.0	1,636.0
WATER (1,000 hectares)	408.6	373.5	21.2	1,637.2
FEDAREA (1,000 hectares)	3,310.1	5,714.6	1.4	24,229.6
NOFEDCRP (1,000 hectares)	12,191.0	9,923.7	265.1	66,610.1

Table 2: Models of the Log of the Share of Developed Land

VARIABLE	Parameter	S. Error	*p*-value	Parameter	S. Error	*p*-value
POPDEN	5.609E-02	1.018E-01	[.583]	2.505E-01	9.877E-02	[.012]
AGMINEPC	-2.470E-05	1.602E-05	[.125]	-2.529E-05	1.414E-05	[.076]
NONAGMPC	6.886E-06	3.681E-06	[.064]	4.430E-05	9.338E-06	[.000]
NAGMPCSQ				-7.423E-10	1.643E-10	[.000]
POPGRATE	-3.097E-03	7.534E-03	[.682]	-2.114E-03	6.938E-03	[.761]
AMGRATE	7.261E-04	8.428E-04	[.390]	6.640E-04	7.474E-04	[.376]
NAMGRATE	9.568E-03	3.316E-03	[.005]	7.908E-03	2.942E-03	[.008]
INTERATE	-2.727E-02	4.056E-03	[.000]	-2.708E-02	3.796E-03	[.000]
INFLRATE	-3.687E-02	4.812E-03	[.000]	-3.552E-02	4.379E-03	[.000]
GASPRICE	-3.842E-01	1.578E-01	[.016]	-3.415E-01	1.576E-01	[.032]
SHAREDEM	-3.363E-03	6.947E-04	[.000]	-2.543E-03	6.269E-04	[.000]
CRPPAY	-8.532E-05	4.040E-05	[.037]	-2.354E-04	1.051E-04	[.027]
CRPPAYSQ				2.005E-07	1.198E-07	[.097]
CRPDEN	-1.138E+00	4.355E-01	[.010]	-1.310E+00	3.923E-01	[.001]
WATDEN	-5.043E-01	1.515E+00	[.740]	-1.449E+00	1.369E+00	[.292]
FEDDEN	6.879E-01	4.616E-01	[.139]	3.391E+00	1.014E+00	[.001]
FEDSQDEN	-1.138E+00	4.355E-01		-1.581E-04	5.351E-05	[.004]
49 State Constants	$\overline{R}^2$, F statistic, Schwarz Information Criterion, $R^2(\hat{Y}_{it})$					
	0.9966, 187.04, -205.5, 0.99713			0.9973, 224.16, -224.4, 0.99801		

Table 3: Models of the Log of the 'Odds' of Developed Land

Variable	Parameter	S. Error	*p*-value	Parameter	S. Error	*p*-value
POPDEN	1.975E-01	1.081E-01	[.070]	3.953E-01	1.059E-01	[.000]
AGMINEPC	-2.745E-05	1.702E-05	[.109]	-2.802E-05	1.515E-05	[.067]
NONAGMPC	1.099E-05	3.910E-06	[.006]	4.801E-05	1.001E-05	[.000]
NAGMPCSQ				-7.382E-10	1.761E-10	[.000]
POPGRATE	-5.001E-03	8.004E-03	[.533]	-3.516E-03	7.438E-03	[.637]
AMGRATE	7.447E-04	8.953E-04	[.407]	6.989E-04	8.013E-04	[.385]
NAMGRATE	1.010E-02	3.523E-03	[.005]	8.386E-03	3.154E-03	[.009]
INTERATE	-2.755E-02	4.308E-03	[.000]	-2.752E-02	4.070E-03	[.000]
INFLRATE	-3.727E-02	5.112E-03	[.000]	-3.607E-02	4.694E-03	[.000]
GASPRICE	-3.442E-01	1.676E-01	[.042]	-3.082E-01	1.689E-01	[.070]
SHAREDEM	-3.748E-03	7.380E-04	[.000]	-2.906E-03	6.720E-04	[.000]
CRPPAY	-1.023E-04	4.292E-05	[.019]	-2.622E-04	1.126E-04	[.021]
CRPPAYSQ				2.126E-07	1.285E-07	[.100]
CRPDEN	-1.241E+00	4.626E-01	[.008]	-1.427E+00	4.205E-01	[.001]
WATDEN	-5.949E-01	1.610E+00	[.712]	-1.621E+00	1.468E+00	[.271]
FEDDEN	6.056E-01	4.904E-01	[.219]	3.577E+00	1.087E+00	[.001]
FEDSQDEN				-1.736E-04	5.736E-05	[.003]
49 State Constants	$\overline{R}^2$, F statistic, Schwarz Information Criterion, $R^2(\hat{Y}_{it})$					
	0.9968, 178.10, -193.7, 0.99720			0.9975, 210.95, -210.8, 0.99803		

Table 4: Marginal Effects (1000 hectares) on Developed Land Area

	Log of the Share of Developed Land		Log of the 'Odds' of Developed Land	
VARIABLE	Linear	Nonlinear	Linear	Nonlinear
POP	0.005	0.021	0.014	0.028
AGMINEPC	-0.017	-0.018	-0.017	-0.018
NONAGMPC	0.005	0.007	0.007	0.009
POPGRATE	-2.152	-1.469	-3.182	-2.237
AMGRATE	0.505	0.461	0.474	0.445
NAMGRATE	6.649	5.495	6.428	5.336
INTERATE	-18.952	-18.817	-17.526	-17.510
INFLRATE	-25.622	-24.684	-23.714	-22.949
GASPRICE	-266.946	-237.273	-219.006	-196.104
SHAREDEM	-2.337	-1.767	-2.385	-1.849
CRPPAY	-0.059	-0.141	-0.065	-0.145
CRPAREA	-0.093	-0.107	-0.087	-0.100
WATER	-0.041	-0.119	-0.042	-0.113
FEDAREA	0.056	0.235	0.042	0.206

Table 5: Elasticities of Developed Land Area

	Log of the Share of Developed Land		Log of the 'Odds' of Developed Land	
VARIABLE	Linear	Nonlinear	Linear	Nonlinear
POP	0.039	0.175	0.114	0.229
AGMINEPC	-0.027	-0.028	-0.029	-0.029
NONAGMPC	0.152	0.223	0.221	0.288
POPGRATE	-0.003	-0.002	-0.005	-0.004
AMGRATE	0.002	0.002	0.002	0.002
NAMGRATE	0.018	0.015	0.017	0.014
INTERATE	-0.175	-0.173	-0.162	-0.162
INFLRATE	-0.169	-0.163	-0.158	-0.153
GASPRICE	-0.147	-0.131	-0.121	-0.108
SHAREDEM	-0.198	-0.150	-0.202	-0.157
CRPPAY	-0.007	-0.010	-0.007	-0.011
CRPAREA	-0.009	-0.010	-0.009	-0.011
WATER	-0.026	-0.075	-0.027	-0.073
FEDAREA	0.233	-0.501	0.197	-0.585