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Modeling Farmland Conversion with New GIS Data

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Abstract:
This paper uses an analytical and econometric approach to analyze the farmland conversion process, including the effects of population growth, real estate markets, the agricultural-urban edge, and farm returns. We use a unique county-level dataset on farmland conversion for California that tracks conversions between agricultural, urban and other land uses.

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Introduction

Many people seem to feel strongly about the conversion of farmland to urban uses. Recently, conversion of farmland to housing provoked terrorists on Long Island to burn construction sites to call attention to the issue, injuring some firefighters in the process (CBS news). This issue has also attracted considerable attention from federal, state and local governments. State and local farmland preservation organizations used public funds to purchase permanent conservation easements on 819,000 acres of U.S. farmland between 1974 and February 2000 (American Farmland Trust). This area is equivalent to about one tenth of one percent of all U.S. farmland. Perhaps the largest public outlays for farmland preservation come in the form of higher housing costs incurred as a result of zoning and development restrictions enacted by local governments to prevent what they believe to be "excessive" farmland conversion.

Farmland loss to urban development and farmland preservation programs have received considerable attention in economic literature (see Nickerson and Lynch), as well as in the mainstream media. A newer concern in the United States, particularly evident among the agricultural community, is the conversion of farmland to environmental habitat[1]. For example, in September 2000, the California Farm Bureau Federation, along with other parties, brought a lawsuit against the Cal-Fed Bay Delta Program on the grounds that the Program had not adequately considered the impact on agriculture of its plan to purchase and permanently convert about one million acres of farmland and hundreds of thousands of acre-feet of water for environmental purposes (California Farm Bureau Federation).

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[1] Concern about "excessive" farmland conversion to forests is an issue that is well established in Sweden and other northern European countries (Drake).

Most of the work that has been done by economists on farmland conversion has focused primarily on the effects of farmland loss. The general consensus has been that there is little or no evidence to suggest that farmland conversion will significantly decrease food security or damage the economy, and that the strongest argument for preventing conversion is an aesthetic one (see for examples, Beattie, Gardner, or Kuminoff, Sokolow and Sumner). Yet this has not decreased the extent to which people are concerned about conversion and are willing to devote resources to prevent it. If the primary motivation behind farmland preservation efforts is aesthetic, and assuming that aesthetic value of farmland is a luxury good, we would expect resources devoted to preventing conversion to continue increasing as society becomes wealthier.

Despite the continued interest in farmland conversion, there has been relatively little effort to describe what causes it. Perhaps this is because it seems obvious to most people that conversion is caused by some combination of income growth, population growth, and farm returns. But there is no consensus on how these factors interact to decrease farmland, which ones are most important, or how to model the process. A better understanding of how these forces interact to generate conversion could lead to more efficient policy and more informed decision making on the farmland conversion issue.

In this paper we use an analytical and econometric approach to analyze the farmland conversion process, taking advantage of new GIS data. We begin by describing some problems with the data that are commonly used in discussions of this issue. Then we introduce a unique data source for California that is more detailed and more appropriate for analyzing farmland conversion. A theoretical model and some empirical observations are discussed, and then we perform an econometric exercise to explain farmland conversion as a function of population growth, real estate markets, the agricultural-urban edge, and farm returns. Our analysis yields some insight into the farmland conversion process that is of general interest and particularly applicable to other states with large populations and farmland acreage.

Farmland Conversion Data

In econometric work on farmland conversion the dependent variable is usually some measure of farmland loss constructed from aggregate data on land use (see for examples Tweeten, Kahn, and Ramsey and Cortey). In addition, there is generally no treatment of spatial characteristics of different land uses. In this paper we introduce a unique GIS dataset that provides a direct measure of farmland conversion to alternative uses that we use as our dependent variable. In addition, the GIS data allows us to construct an independent variable for length of the agricultural-urban edge in each California county.

The *Census of Agriculture* and the *Natural Resources Inventory* are the two sources that seem to be most frequently used to track farmland conversion in the United States (for example, Kahn uses the *Census of Agriculture*, and Heimlich and Anderson use the *Natural Resources Inventory*). Although these may be the only widely available sources of agricultural land use data their definitions and methods make the data questionable for use in tracking farmland conversion. Through comparison with aerial photography and GIS mapping we have found that they are poor and even misleading proxies for farmland conversion in California.

The *1997 California Census of Agriculture* shows a decrease in "Land in Farms" of 2.9 million acres since 1987. The *1997 Natural Resources Inventory* shows a decrease in farmland during the same period of about 1.3 million acres. Meanwhile, data generated through aerial photography and GIS mapping by the source we use for our analysis, the California Department of Conservation Farmland Mapping and Monitoring Program, indicate that total farmland conversion between 1988 and 1998 was only about 0.5 million acres.

The main incentives for using the *Census of Agriculture* (Census) in discussion of farmland conversion are that its data are easily accessible, go back at least a century for most states, and are available at both the state and county level. However, there are several reasons why the Census is a poor indicator of farmland conversion. First, the Census does not attempt to measure farmland conversion to any particular use and a decrease in its "Land in Farms[2]" (LIF) statistic does not necessarily imply there has been any actual conversion. The definition of LIF was frequently changed prior to 1974 to remove many of the smallest farms from Census statistics, causing the series to overstate the actual decrease in farmland. In addition, LIF includes federal grazing land leased by ranchers but not federal grazing land used by permit. This creates a particularly important definitional problem for tracking farmland conversion because trends in federal grazing land may overshadow more permanent changes in privately owned agricultural land. This happened in California as a result of the 1994 Desert Protection Act. The Act transferred about 1.3 million acres of federal grazing land that had previously been leased

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[2] "Land in Farms" is a measure estimated by the National Agricultural Statistics Service and reported in the *Census of Agriculture* and in the annual publication *Farms and Land in Farms.* The actual statistic reported in these publications differs in that the number in *Farms and Land in Farms* is adjusted to reflect an undercount, while the number published in the Census is not. See the *California Census of Agriculture,*

to ranchers by the Bureau of Land Management to the National Park Service, which continued to allow ranchers to use the land, but by permit instead of lease. According to Census definitions, this land would have been counted as LIF in 1992 but not in 1997 although there was no actual change in the land or its use.

A second source that is widely used to track land conversion is the Natural Resources Conservation Service, *Natural Resources Inventory* (NRI). Unlike the Census, the NRI does attempt to track land conversion between specific uses. However, its definitions focus more on vegetative cover than on land use. For example, it includes as "rangeland" grazing land, as well as certain types of low growth vegetation that may never have been grazed or have had any connection to agriculture. Thus its conversion statistics may overstate the true extent of land used for agriculture that is converted to another use.

California is unique among the states in that it has a state government program designed for the sole purpose of tracking and reporting agricultural land use and conversion[3]. The California Department of Conservation Farmland Mapping and Monitoring Program (FMMP) uses aerial photography, GIS mapping and field checking to biennially track changes in land use at the county level. Unlike the Census and NRI, FMMP differentiates between farmland converted to urban uses and farmland converted to "other" uses, which include idled land, wetlands and wildlife habitat. FMMP also tracks land that is converted from "other" land to agriculture.

Table 1 shows land conversion in California between agricultural and non-agricultural uses from 1988 to 1998. About 316,000 acres of crop and grazing land were

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Appendix C for more detail.

[3] Florida and Wisconsin had similar programs in the past that are now defunct (Poseley).

converted to urban use, while another 312,000 acres were converted to wetlands and wildlife habitat, or idled for at least 4 consecutive years. 190,000 acres were converted from idle farmland, wetlands and wildlife habitat to urban uses. Anecdotal information suggests that much of this land was previously farmland that was idled in anticipation of development. While 628,000 acres were taken out of agriculture between 1988 and 1998, 145,000 acres were converted to agriculture either from land that was previously idled or from wetlands and wildlife habitat. Thus, the net conversion out of agriculture during this period was about 483,000 acres. In 1998 California had about 26.7 million acres of privately owned agricultural land. Thus, the development of 483,000 acres between 1988 and 1998 resulted in conversion of about 1.8 percent of the developable agricultural land base.

The FMMP-based estimate for farmland conversion during 1988-98 (483,000 acres) is less than half the amount of conversion reported by the NRI during 1987-97 (1,289,000 acres), and less than one fifth the decrease in "Land in Farms" reported by the Census between 1987 and 1997 (2,899,000 acres). Because the differences between these three measures are largely a result of the way that public and private grazing land is defined, states with a higher ratio of grazing land to cropland will be more likely to have large amounts of conversion reported by the NRI and large decreases in "Land in Farms" relative to actual farmland conversion. Thus any national analysis of farmland conversion trends should be extremely cautious in using Census and NRI statistics, as should any analysis of a state with significant grazing land.

A Model of Farmland Conversion

The first theoretical effort to model farmland conversion to urban uses was done by Muth in 1961. He constructed a model showing how two industries (agriculture and housing in his example) compete for land in a von Thünen plain, where land is homogenous as distance from the city center increases. Thus, city borders expand and contract in concentric circles. Muth noted that the principal implication of his analysis is that the price elasticity of demand for the agricultural commodity is crucial in determining the direction of conversion between agricultural and urban land[4].

Muth's equation 19 (shown as (1) below) predicts conversion between agricultural and urban land in the case where an increase in per capita income or population increases demand for both the agricultural product and housing. In the equation, $\bar{k}$ is the location of the agricultural-urban edge, a's are parameters of the production function, c's are parameters describing the rate of fall in land rental price with distance from the city center, A_0's are the parameters determining the positions of the demand schedules, D is the determinant of the coefficient matrix of price changes, ${}_iA_y$ is the income elasticity of demand, P is population, the subscripts refer to markets for the agricultural product and housing, and the *'s refer to terms expressed as natural logarithms.

$$(1) \qquad \partial\bar{k}^* = \frac{\left({}_2a\partial\,{}_1A_0^* - {}_1a\partial\,{}_2A_0^*\right)}{\left(\frac{{}_1c}{{}_1a_2} - \frac{{}_2c}{{}_2a_2}\right)\bar{k}D},$$

where $\partial\,{}_iA_0^* = {}_iA_y\,\partial y^* + \partial P^*$, and $i = \{1, 2\}$.

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[4] Muth also used the model to show the change in rental price of land.

Suppose commodity 1 is houses and commodity 2 is the agricultural product. According to (1), if the demand elasticity facing local farms is relatively low, an increase in per capita income or population could cause the city boundary to contract as agricultural land expands toward the city center. A more realistic scenario is that the farms bordering any U.S. city produce only a tiny share of agricultural product that could be shipped to the city and, thus, the demand elasticity facing those farms tends toward infinity. In this case an increase in population or income would lead to farmland conversion to urban uses at the city boundary.

Muth's model is rigorous and provides some intuitive results. However, the model does not account for a non-uniform agricultural-urban border that could result from heterogeneous land or zoning and development restrictions, both of which we believe to be important in our empirical example. It would take considerable space to formally revise and extend his model to reflect our empirical example, and little would be gained over an analytical approach. Therefore, although we proceed with a reasoning that is similar to Muth's we do not attempt to apply his theoretical model directly. Still, some aspects of Muth's model have empirical counterparts in our work.

We envision a landowner choosing between using land for farming in the current period, and retaining the option to convert in the future, versus a sale to one of two non-farm uses, environmental open space or urbanization, where conversion to urban land is irreversible. Given the choice to sell, the landowner will consider the expected future agricultural value of the land for its productive lifetime, its value for conversion to urban or environmental use in the current time period, and its option value for conversion to urban or environmental use in the future. In other words, this is a dynamic optimization problem with the landowner maximizing expected net present value across use and sales of land, and across time. Other factors that might affect the decision to sell are relocation costs if the landowner lives on the land that is to be converted, emotional attachment to the land, environmental ethics, and other difficult-to-measure personal factors.

At the regional level zoning and development restrictions are important factors in the pattern of urban development. From the perspective of a social planner faced with the static problem of allocating land across various uses in a region during one time period, zoning and development restrictions would be modeled as a constraint. But over time these restrictions may depend on conversion and be determined endogenously. This could be reflected in a theoretical model by a simultaneous equation system of dynamic optimization equations that estimated conversion as a function of development restrictions and other factors, and development restrictions as a function of conversion and other factors. This exogenous-endogenous issue may also apply to population and income growth, as changes in these variables may lead to farmland being converted to urban uses, as well as depend on it. In an empirical application the variables that are actually modeled as endogenous may depend largely on the time frame.

Empirical Considerations

In the past there have only been brief attempts to construct econometric models of farmland conversion. For example, in a short section and appendix of a recent paper on food security and farmland preservation Tweeten outlined an econometric exercise that used state-level Census data from 1949-1992 to estimate changes in cropland as a function of the ratio of gross farm income per capita to overall per capita income, farm population per square mile, and urban population per square mile. To estimate the impact of farm factors on conversion, Tweeten expressed the predicted change in cropland due to farm factors (farm population and the ratio of farm income per capita to overall per capita income) as a percentage of total change in predicted cropland. He found that, overall, farm factors accounted for 74 percent of U.S. farmland conversion, concluding that "the implication of this modest statistical analysis is that lack of farm economic viability rather than urban encroachment is the principal reason for cropland loss." Although he did not show results for specific states in his paper, Tweeten notes that farm influences were lowest relative to urban influences in the Mountain and West Coast regions, and also in New England, Arkansas and Florida. The lowest quartile, which included California, was estimated to have had between 0 and 71 percent of its change in cropland due to farm related sources. Other examples of brief econometric analyses on this topic include Ramsey and Cortey, and Kahn.

We expect that in California, and other states with large urban populations, conversion out of farmland is due mainly to urban factors, not farm income. Much of the state's recent urban expansion has been in areas that were previously farmed. The price offered for conversion to urbanization on any agricultural parcel of land is typically much larger, generally by an order of magnitude, than its agricultural or environmental price. For example, bare ground sold for development in California's urbanizing areas regularly exceeds $40,000 per acre, considerably more if urban improvements are in place. The average agricultural land prices in the state are much smaller—$1,050 for grazing land and $5500 for fruit, tree-nut and vegetable areas (NASS, 2000). In extreme cases farmland can be much more expensive. Napa County vineyards, for example, have sold for as much as $90,000 per acre. But, even this extremely high price of agricultural land is dwarfed by the price of Napa land for homesite development, as much as $1.5 million per acre (California Chapter of the American Society of Farm Managers and Rural Appraisers (CCASFMRA)).

Given these land sale prices, we hypothesize that most agricultural landowners who have the opportunity to sell to urban development, do. Relocation cost and personal attachment to the land may be extremely important to a few landowners, but it seems unlikely that these effects would have a significant impact overall. Relocation cost is likely to be small in comparison with the difference between the land's value for urban use and for agriculture. Similarly, a landowner who simply likes to farm and enjoys being part of the agricultural landscape could take advantage of profits from an urban land sale by purchasing a larger parcel in another agricultural location.

The price of land for conversion to environmental uses seems to be much closer to the price of agricultural land. Because statewide data on agricultural land sold for conversion to environmental use were not readily available, we compared the price per acre for 49 parcels of land (17,829 acres total) purchased in the Sacramento Valley by the Wildlife Conservation Board between 1965 and 1999 (Northern California Water Association). Converting to 2000 dollars using the GDP deflator, the average price was $1393 per acre, with prices ranging from $112/acre to $7354/acre. These prices are far below the price of land for urban development but well within the price range for agricultural use. For example, in 1999 agricultural land sale prices in the Sacramento

Valley ranged from $300 to $1100 for rangeland, from $1400 to $3100 for field crops, and from $2500 to $8000 for fruits, tree-nuts and vegetables (CCASFMRA).

While we suspect that urban factors are generally more important than farm returns in determining farmland conversion, it also seems likely that farm returns may affect the timing of conversion, particularly for conversion to environmental uses. For example, if an agricultural landowner expects extraordinary profits from agriculture in the following year or two with no change in the urban or environmental land markets, he may delay sale of the land to maximize profits. However, with the large difference in urban and agricultural land prices it would also seem likely that small percentage changes in the expected sale price for development could outweigh large percentage changes in expected farm returns.

One challenge in modeling farmland conversion empirically is to account for the fact that relatively few landowners have the option to sell their agricultural land for urban or environmental use at any one time. This is because their land is not located close to the urbanizing fringes of existing cities where most new development occurs, is not targeted by environmental groups that can afford permanent land acquisitions, or because conversion in that area is prevented by zoning or development restrictions. One way to address this issue is to incorporate a variable in the econometric model that accounts for spatial relationships between different land uses. (See Bockstael for discussion of the importance of a spatial perspective in modeling land conversion and economics.)

We used FMMP data and GIS software[5] to create a proxy variable for the amount of farmland that would be subject to conversion pressure at the beginning of each time

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[5] We used *Arcview GIS 3.2* to work with the FMMP GIS data, and the *X-Tools* extension to recalculate polygon perimeters, which were not given.

period. For each county we generated a variable for the length of the border (or "edge") that urban areas shared with agriculture and other land uses. We found that there was considerable variation across counties. For example, according to FMMP data Tulare County had about 49,000 acres of urban land in 1998, while Solano County had about 53,000 acres. Yet, the total perimeter of Tulare's urban land was 875,000 meters, while Solano's urban perimeter was 525,000 meters. Moreover, in Tulare 79% of the urban perimeter (697,000 meters) was adjacent to farmland, while in Solano 67% of the urban perimeter (352,000 meters) bordered farmland, while the rest bordered other land and water. So although these two counties had similar amounts of urban land in 1988, the length of the agricultural-urban edge was almost twice as large in Tulare because of the geometric shape of its urban areas and location of other lands. Generally, we would expect more farmland conversion in counties with larger agricultural-urban edges, holding development restrictions and other factors constant.

Econometric Specification

In our econometric model we use data on land use, urban factors and farm income to explain three different types of land conversion: agriculture-to-urban conversion, all conversion out of agriculture (conversion from agricultural land to urban land, idled farmland, wetlands and wildlife habitat), and all conversion to urban land (conversion from agriculture and "other" land to urban land). Our dataset is a pooled time-series cross section. For each type of land conversion we use FMMP data for 42 California counties. As noted above, FMMP reports its conversion data for 2-year periods. However, the development process is often time-consuming and it can take many years between the point that agricultural land stops being farmed and the point that construction actually starts (Kuminoff, Sokolow and Sumner). For example, an agricultural parcel that was sold for development in 1988 may not actually have been developed until 1991. In this case, although the land was sold in 1988 it would have been recorded as a conversion by FMMP in 1991 when aerial photographs first revealed the new development. To reflect the fact that the conversion process often takes more than two years we aggregated the FMMP conversion data into two periods, 1988-1992 and 1992-1998[6]. There appears to be a natural division between these two periods in the sense that annual conversion was much higher in the first period (see Table 1). In our regressions, conversion is measured on a per year basis.

We attempted to create independent variables that would capture the effects of conversion pressure along the urban edge, changes in farm income, changes in the price of agricultural land for development, population growth, the stock of agricultural land in each county, zoning and development restrictions, and time period. Equation 2 shows our econometric specification in a linear form, Table 2 shows summary statistics for each variable, and each variable is explained in detail below.

$$(2)\ C_{i,t} = \beta_0 + \beta_1 EDGE_{i,t} + \beta_2\, \Delta FARMINC_{i,t} + \beta_3 \Delta HOUSEP_{i,t} + \beta_4\, \Delta POP_{i,t} + \\ \beta_5 STOCK_{i,t} + \beta_6\, RESTRICT_{i,t} + \beta_7 t + \mu_{i,t}$$

Where, $i = (County_1, \ldots\ldots, County_{42})$, and

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[6] The mapping done by FMMP is on a crop year basis, so the 1988-1992 conversion period, for example, includes conversion during the second part of 1988, all of 1989, 1990, and 1991, and the first part of 1992.

$$t = \text{dummy variable for second time period} = \begin{cases} 0 & \text{for } 1988\text{–}1992 \\ 1 & \text{for } 1992\text{–}1998 \end{cases}$$

The dependent variable, $C_{i,t}$, is average conversion per year in county i and period t. We estimated the model for three types of conversion: agricultural-to-urban conversion, all conversion out of agriculture, and all conversion to urban land.

EDGE is a proxy for conversion pressure along the urban edge. It is measured as the length (in 1,000 meters) of the border shared by urban land and the type of land being measured as conversion by the dependent variable. For example, when the dependent variable is all conversion out of agriculture, EDGE is the length of the agricultural-urban edge, and when the dependent variable is all conversion to urban land, EDGE is the length of the agricultural-urban edge and the length of the "other"-urban edge. We would expect EDGE to be positively correlated with farmland conversion.

ΔFARMINC, the variable for change in farm income, is measured as a deviation in the conversion period from recent trends. The idea is that if there is a spike in farm income that is expected to be temporary the landowner would have an incentive to delay conversion. We use data on gross farm income per acre from the California agricultural commissioners' annual summary reports as a proxy for actual farm income. Of course, farmers are most concerned with net farm income, and by using gross farm income we are implicitly assuming that expenditures remained relatively constant during our study period or that gross and net farm income are highly correlated. Gross farm income was converted to year 2000 dollars using the GDP deflator. Equation 3 shows how we calculated ΔFARMINC.

$$(3) \quad \Delta \mathrm{FARMINC}_{i,t} = \left[\left(\frac{\sum_{m}^{n} \mathrm{FARMINC}}{n - m + 1} \right) - \left(\frac{\sum_{m-4}^{m} \mathrm{FARMINC}}{5} \right) \right],$$

where m is the first year of period t and n is the last year of period t.

ΔHOUSEP is our independent variable for the change in price of agricultural land for development. Like the variable for farm income, ΔHOUSEP was also measured as a deviation in the conversion period from recent trends. In this case the idea is that if there is an increase in the price of agricultural land for development during the conversion period, which the landowner expects to be temporary, she will be more likely to convert. We constructed our proxy for conversion prices of farmland from data on annual median prices of single-family homes provided by the California Association of Realtors for 16 different regions in the state. We matched each of the 42 counties in our sample with the region that we judged would best reflect the real estate market in that county. Here, the implicit assumption is that higher median prices of single-family homes is an indication of greater pressure for urban development and is correlated with higher prices for agricultural and other land for urban development. Median housing price was converted to year 2000 dollars using the GDP deflator. Equation 4 shows how we calculated the change in price of agricultural land for development.

$$(4)\quad \Delta \mathrm{HOUSEP}_{i,t} = \left[\left(\frac{\sum_{m}^{n} \mathrm{HOUSEP}}{n - m + 1} \right) - \left(\frac{\sum_{m-4}^{m} \mathrm{HOUSEP}}{5} \right) \right],$$

where m is the first year of period t and n is the last year of period t.

ΔPOP measures the effect of population growth on conversion. It is calculated as the annual average increase in population for each county in each period, using data from the demographics branch of the California Department of Finance. This variable is shown in equation 5.

$$(5)\quad \Delta \mathrm{POP}_{i,t} = \frac{\left(\mathrm{POP}_n - \mathrm{POP}_m\right)}{n - m},$$

where m is the first year of period t and n is the last year of period t.

STOCK is the initial stock of land being converted. It was created to account for variation in the amount of agricultural and other land by county. We would expect STOCK to be positively correlated with farmland conversion because as the stock of agricultural land decreases pressure mounts to prevent the remaining land from being converted.

RESTRICT is the number of zoning and development restrictions per county (out of a maximum of seven). We used a unique dataset to note whether each county employed one or more of seven different zoning or development restrictions in 1998 (Sokolow). For each county RESTRICT represents the total number of the following development restrictions used in that county: agricultural element in the county general plan, growth management element in the county general plan, urban growth boundary, participation in the "Super" Williamson Act, policy to direct new urban growth to cities, Land Evaluation and Site Assessment (LESA), and the presence of a local program specializing in obtaining agricultural conservation easements. We would expect RESTRICT to be negatively correlated with conversion since these development restrictions are put in place essentially to slow or stop farmland conversion.

Finally, we included a dummy variable, t, for our second time period 1992-1998 to test for differences between the two time periods. As Table 1 shows, there was significantly less annual average conversion between 1992-1998 than between 1988-1992. (This is probably explained by the fact that California's real estate market was in a down cycle during the early and mid 1990s.) Thus, we would expect the dummy variable to be negatively correlated with conversion.

We assume that the error term is independent across counties. Our dummy variable for period should capture the effect of broad trends in the real estate market that would apply across counties. A linear functional form was the only one used for our model and we did not attempt to correct for heteroscedasticity or autocorrelation.

For each of the three types of land conversion, the econometric model was estimated using ordinary least squares estimation with 42 county observations over two time periods. The model assumes that farmers have perfect expectations of future farm income and the price of agricultural land for conversion. Thus, the empirical question we are testing is whether farm returns or urban factors are important enough as determinants of farmland conversion to appear statistically significant given our proxy independent variables, omitted variables, assumption of perfect expectations, different ols intercepts, and linear functional form.

Results

Our results (shown in Table 3) suggest that urban factors, not low farm income, have been the main cause of farmland conversion and new urban development in California. Whether we considered conversion from agriculture to urban land, all conversion out of agriculture, or all conversion to urban land, edge length and population growth were statistically significant and positively correlated with conversion. The dummy variable for the 1992-1998 conversion period was also statistically significant for each measure of conversion, but negatively correlated with conversion. It can be seen from Table 1 that annual average conversion in every category was larger during 1988-1992 than 1992-1998.

The stock of land was not statistically significant in conversion from agriculture to urban development or all conversion to urban development. FMMP data show that only a small share of the stock of agricultural and other land is converted to urban use in any period. Overall, about 2% of California's agricultural land base was converted to urban use between 1988 and 1998. Because most new urban development occurs along the edges of existing urban areas it makes sense that this development would be reflected in the econometric model by the urban edge variable, not the stock variable.

The stock variable was statistically significant for all conversion out of agriculture. Recall that this measure of conversion includes agricultural land that is idled and conversion from agriculture to environmental uses, as well as ag-to-urban conversion. The significance of the stock variable for all conversion out of agriculture is probably due to idled farmland. If a certain percentage of farmland in each county is idled as market prices drop or as part of normal farming practices, then we would expect acres left idle to increase broadly across counties with the stock of farmland in a county.

The proxy variable for temporary change in farm income was statistically significant only for conversion from agriculture to urban land. Surprisingly, it was positively correlated with conversion. Of course it does not make sense to say that farmers would be more willing to sell their land when farm returns increase temporarily. A more plausible explanation for this variable being significant is that the large difference between prices of agricultural land for crops and for urban development makes changes in farm income relatively unimportant to farmers with the opportunity to sell. Even a large percentage increase in temporary farm income could be outweighed by a small percentage increase in price of land for urban development. Another possible explanation is that farmers are acting based on longer-term trends or speculation about the future.

One unexpected result was that the proxy variable for temporary changes in price of agricultural land for urban development was not statistically significant in any of the measures of conversion. This may be an indication that our proxy measure is too rough to approximate the sale price of agricultural land for urban development.

Another surprise was that the number of zoning and development restrictions was not statistically significant in any of the regressions. The actual number of restrictions varied from 0 to 4, with a mean of 1.5 restrictions per county. One problem with this variable is that we only observed restrictions that existed in 1998, while some of them did not exist in 1988. However, because the lawmaking process can be timely, at least some planning decisions were probably made on a consistent basis before a particular restriction became law. An explanation for the lack of statistical significance is that the number of development restrictions "on the books" is less important than the way they are implemented, which is influenced by factors that are more difficult to capture with an objective variable such as political composition of county and city planning boards.

Conclusion

Our results suggest that urban factors, not low farm income, have been the primary cause of recent farmland conversion in California. The importance of edge effects as a determinant of farmland conversion and of increased urbanization may be of particular interest to city planners and farmland preservation organizations. We expect that these results would also apply to many other states that have a combination of large urban populations and large amounts of agricultural land.

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Table 1: California Land Conversion, 1988-1998*

From:	**Agriculture**	**“Other”**	**Agriculture**	**“Other”**
To:	**Urban**	**Urban**	**“Other”**	**Agriculture**
1988-90	101,915	65,767	85,232	46,301
1990-92	71,131	47,358	89,896	32,019
1992-94	37,305	21,109	30,934	12,363
1994-96	44,180	19,861	37,050	18,374
1996-98	61,622	36,150	69,153	35,958
Total	**316,154**	**190,245**	**312,265**	**145,015**

* These figures reflect small upward adjustments made to the FMMP data to reflect places where they undercount conversion according to the definition used by Kuminoff, Sokolow, and Sumner.

Table 2: Summary Statistics for Dependent and Independent Variables

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Change in House Price ($1,000)	84	20.5	33.9	-42.7	90.9
Change in Farm Income per Acre ($)	84	105.8	418.2	-1,409.0	2,123.0
Change in Population (1,000)	84	11.5	20.7	-0.2	140.2
Ag-to-Urban Conversion (acres)	84	641.9	928.8	0.0	5,315.0
Ag-to-Other Conversion (acres)	84	708.2	978.8	3.0	5,223.0
Other-to-Urban Conversion (acres)	84	419.6	790.3	0.0	3,816.0
STOCK (1,000 acres of Farmland)	84	596.4	485.9	42.3	2,799.8
STOCK (1,000 acres of "Other" land)	84	292.2	440.2	14.6	2,336.7
Ag-Urban Edge (1,000 meters)	84	334.8	245.0	32.4	1,265.7
Other-Urban Edge (1,000 meters)	84	309.1	378.0	6.4	1,966.8
Develoment Restrictions (number)	84	1.5	1.3	0.0	4.0
Dummy variable = 1 in 1992-1998	84	0.5	0.5	0.0	1.0

Table 3: Explanation of Land Converted out of Agriculture or into Urban Uses
(t-statistics in parenthesis)

	Dependent Variable (acres of land converted)*		
Independent Variable	Ag-to-Urban	Out of Agriculture	Into Urban
Edge (1,000 meters)	2.21 (6.18)	2.64 (4.53)	1.42 (4.78)
Change in Farm Income per Acre ($)	0.37 (2.10)	0.10 (0.33)	0.37 (1.39)
Change in House Price ($1,000)	-4.22 (-1.28)	-4.40 (-0.82)	-3.18 (-0.70)
Change in Population (1,000)	10.32 (2.59)	29.20 (4.49)	26.44 (3.74)
Stock of land (1,000 acres)	-0.13 (-0.85)	0.94 (3.64)	0.07 (0.52)
Development Restrictions (number)	-37.42 (-0.61)	41.72 (0.42)	1.04 (0.01)
Dummy Variable = 1 in 1992-1998	-512.30 (-2.30)	-810.75 (-2.24)	-657.46 (-2.14)
Constant	222.70 (0.97)	-8.22 (-0.02)	136.20 (0.49)
R-Square	0.58	0.62	0.71
Adjusted R-Square	0.55	0.58	0.69
N	84	84	84

* Conversion "Out of Agriculture" includes ag-to-urban conversions and ag-to-other conversions
Conversion "Into Urban" includes ag-to-urban conversions and other-to-urban conversions.