A major shift in U.S. land development avoids significant losses in forest and agricultural land

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Abstract: Land development, which typically results from the conversion of lands previously in agricultural and forest uses, is one of the most fundamental ways in which humans impact the natural environment. We study the remarkable decline in land development rates across the conterminous United States over the period 2000-2015, which occurred after development rates had grown rapidly over the last two decades of the 20th century. Despite relatively constant population growth since 1980, we find that the current annual rate of land development has declined consistently across several stratifications of the U.S. land base and amounts to less than 25% of the peak rate observed in the mid-late 1990s, implying that the developed land base of the U.S. has become increasingly dense in recent years. We show that the widespread shift in land development rates resulted in 7 million acres of avoided land development, roughly half of which would have come from conversions of previously forested lands. Panel data econometric estimation indicates that growth in development over the last two decades of the 20th century was driven by falling gas prices and, to a lesser extent, rising income levels. Since 2000, however, income growth has been stagnant while gas prices have risen sharply, and we find that the latter has played a larger role than population or income in shaping the recent shift towards denser development. Results illustrate an often overlooked effect of how rising gas prices can indirectly avoid losses in forest and agricultural land by reducing developed land-use change.

Introduction

The conversion of agricultural and forested lands to urban and rural land development has been a defining feature of the United States landscape over many decades. For example, two-thirds of the global forest loss to urban development between 2001 and 2015 occurred in the eastern U.S. (Curtis et al. 2018). Excessive land development that expands the size of urban areas is often referred to as urban sprawl, and a widespread policy debate has occurred around whether current development patterns lead to excessive loss of forest and agricultural lands given the number of damaging impacts that arise from irreversible land-use change (Glaeser and Kahn 2004; Burchfield et al. 2006; Irwin and Bockstael 2007; Seto et al. 2012; Sorensen et al. 2018). In particular, land development has been linked to a number of challenges for the food system, such as a loss of productive farmland (Bren d'Amour et al. 2017; Sorensen et al. 2018; Zuo et al. 2018), net primary productivity in soils (Imhoff et al. 2004), and pollinators (Wilson and Jamieson 2019). Research has also found that land development reduces the provision of numerous ecosystem services, including carbon sequestration and oxygen production (Wang et al. 2019), water quality (Cumming et al. 2014), and habitat for wildlife (Lawler et al. 2014). Finally, low-density development has been associated with other social challenges such as higher obesity rates (Zhao and Kaestner 2010; Ewing et al. 2014), reduced air quality (McCarty and Kaza 2015), increased vehicle usage and fuel consumption (Bento et al. 2005; Kim and Brownstone 2013), and reduced upward mobility (Ewing et al. 2016). Since the potential damages from urban sprawl are increasing in the area of converted land, understanding the trajectory of damages ultimately depends on the rate of change in land development and its trend over time.

Land-use policy can lower damages from land-use change by altering the amount and configuration of landscapes. While policy design has traditionally been informed by retrospective analyses of past land-use policy impacts on land-use change (e.g. Andam et al. 2008; Heilmayr et al. 2020) and by forward-looking projections of land-use change under alternative scenarios (e.g. Lawler et al. 2014), retrospective analyses of the roles played by the fundamental drivers of land development can also inform policy for at least three reasons. First, sudden changes in land development rates indicate changes in the demand for developed land, which influences the effect that both regulatory policies (e.g. zoning) and incentive policies (e.g. payment-for-ecosystem service programs) would have on the density of the developed landscape and the stock of natural and undeveloped lands. Second, since conversion of land to developed use tends to be irreversible, low-density developed areas with low-connectivity roads will have little ability to adapt to policies that have indirect effects on land use, such as a carbon price that would alter gas prices (Barrington-Leigh and Millard-Ball 2015). Third, analyses that quantify the effects of specific drivers of land development can shed light on which margins and mechanisms policymakers should focus on when designing land-use and environmental policy.

This paper fills two key gaps in the existing literature on land-use change involving the conversion of forest and agricultural lands to developed uses. First, using a longitudinal federal land-use database that follows a large sample of private land plots over 1982-2015, we provide a complete empirical description of a large-scale shift in land-use change that has numerous social and environmental implications – the reduction in the land development rate that occurred across the conterminous United States (U.S.) during the first 15 years of the 21st century. While the rate of land development steadily increased in the 1980s and peaked in the mid-to-late 1990s, the annual area of land converted to a developed use began a steady decline starting around the year 2000 and plateaued around 2010 at a level that amounts to less than one-quarter of the peak conversion rate. The same general trend in recent land development has been documented or suggested in passing in several prior studies (Barrington-Leigh and Millard-Ball 2015; Homer et al. 2020; Leyk et al. 2020; Cuberes et al. 2021), but the potential causes and consequences of the change in U.S. development patterns have not been explored in any depth. Beyond describing this aggregate trend, our analysis further contributes to the land-use change literature by assessing trends in U.S. land development across multiple strata, including geographical region, pre-existing undeveloped land use, population density, household income, and commuting cost. We extend this descriptive analysis by conducting a simple landscape simulation based on plot-level land-use transition probabilities that allows us to quantify how the relative stock of forest and agricultural land has been affected by the land development slowdown.

The second key contribution of our paper is an econometric analysis of the three fundamental drivers of land development cited in previous literature, namely population growth, income, and commuting cost (Brueckner 2000; Glaeser and Khan 2004; and Nechyba and Walsh 2004). Existing analyses suggest that population growth and income should spur additional development, while increases in commuting costs should slow development. We construct a panel-data econometric model to estimate the effects of population, income, and gas prices on county-level land development rates, thereby allowing us to analyze the relative impact of observed changes in these three variables on the land development rate slowdown. Our econometric estimates complement recent studies that show how increases in gas prices can lower housing construction (Molloy and Shan 2013; Ortuno-Padilla and Fernandez-Aracil 2013), urban sprawl (Young et al. 2016), and the value of homes far from urban centers (Wu et al. 2019) by estimating how gas price increases also can also lower the rate of change in the amount of land used for urban development in areas with high commuting costs. The econometric estimates also highlight a potentially significant connection between land development patterns and climate mitigation policy. Specifically, since gas prices would rise in response to adoption of a carbon price proposal, our results highlight how carbon pricing would indirectly conserve forest and agricultural lands by reducing developed land-use change.

Data and methods

Data

Analysis is primarily conducted with the National Resources Inventory (NRI), a plot-level longitudinal land-use database compiled by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service covering the 1982-2015 period and comprising a sample of over 800,000 points (USDA 2018). A key feature of the NRI database is that it tracks changes between all major land-use categories. Our main focus is on trends in urban and built-up (or "developed") land, including conversion from the four major undeveloped NRI land classes: forest, cropland, pasture, and range. Additional detail on the land-use classes contained in the NRI data are provided in the Supplemental Materials (SM) Appendix A. The NRI data have been used in a number of previous empirical studies of land-use change (e.g., Lewis and Plantinga 2007; Lubowski et al. 2008; Lawler et al. 2014; Bigelow and Kuethe 2020). We aggregate the plot-level NRI data to the county level (the finest geographic resolution possible) to generate our main findings concerning the spatial and temporal pattern of land development across the U.S. Data on other variables that enter the analysis come from well-known publicly available sources, such as the U.S. Census Bureau and Energy Information Administration, and are described in greater detail in SM Appendix A. Our county-level dataset includes the 3,024 counties in the conterminous U.S. accounted for in all datasets used in the analysis.

Descriptive trend analysis

We begin by presenting a set of descriptive trends that depict how the rate of land development has changed over the 1982-2015 study period. In doing so, we draw comparisons with concurrent trends in large-scale socioeconomic drivers (population, income, and gasoline prices). To study the spatial distribution of the land development trend, we decompose the National trend into strata based on the 1980 quartiles of population density, household income, and commuting cost, and provide further breakdowns by U.S. state, region, starting land use, and urban classification as measured by the USDA Economic Research Service's (ERS) 2013 Urban Influence Codes (USDA, ERS 2013). We also consider the changes in the spatial distribution of the ratio of population to developed area, a metric we term the "developed area population density", between 1982-2000 and 2000-2015. Calculation of the developed area population density is described in detail in SM Appendix A.

Landscape simulation

The second section of results uses the plot-level NRI land-use transition probabilities to simulate what the 2015 landscape would have looked like if the pre-2000 land development rate had continued through the first 15 years of the 21st century. To compute the cumulative avoided land development, we adopt an approach used in prior land-use simulation studies (Lewis and Plantinga 2007) that accounts for the fact that any avoided land development must alter the composition of undeveloped uses in a way that the total landscape size remains fixed. This process generates transition probabilities $P_{c,t,j,k}$ defining the probability that an acre of land in county c in use j converts to use k in time t, which we use to describe the likelihood that an acre of land in a county either stays in its starting use or converts to an alternative over a 15-year (1982-1997) time step. SM Table B1 presents these conversion probabilities relative to urban conversions in both the pre- and post-2000 periods. We omit the 1997-2000 period in calculating $P_{c,t,j,k}$ so that our 15-year conversion probability is applied to a consistent time step. A simulated U.S. landscape in 2015 is generated by fixing the transition probabilities $P_{c,t,j,k}$ at these initial levels and using them to project how the landscape would have evolved from 2000 to 2015. We then compare our simulated 2015 landscape with the 2015 observed landscape to illustrate how changes in the probability of land development have affected the amounts of land remaining in forest, crop, pasture, and range uses, which account for 95% of all new land developed over our study period (SM Fig. B1).

Drivers of land development

The final section of results uses an econometric model to decompose county-level land development trends into constituent components stemming from population growth, income, and gasoline prices, which are the major drivers of land development cited in the urban economics literature (e.g., Brueckner 2000; Nechyba and Walsh 2004). The model we estimate is a linear two-way fixed effect regression model of the following form:

$$\widetilde{Dev}_{c,t} = \beta_0 + \beta_1 PG_{c,t-j} + \beta_2 I_{c,t-j} + \beta_3 P^G_{c(s),t-j} + \beta_4 P^G_{c(s),t-j} \times TT_c$$
$$+\gamma 1\{State_c = s\}t + \tau_t + \alpha_c + \varepsilon_{c,t} \tag{1}$$

In equation (1), the dependent variable, $\widetilde{Dev}_{c,t}$, is measured as the inverse hyperbolic sine (IHS) of the change in developed acres in county c over the year leading up to year t (i.e., the net change in total developed area between t and $t-1$). Using the IHS transformation allows us to include county-year observations with zero land developed and yields a similar interpretation to a model with a logged dependent variable (Bellemare and Wichman 2020). Explanatory variables enter the model in lagged form, where j denotes the number of years prior to year t at which the variable is measured. Included in the model are population growth over the previous year in county c ($PG_{c,t-j}$), median household income in county c ($I_{c,t-j}$), the price of gasoline the state, s, where county c is located ($P^G_{s(c),t-j}$), and an interaction term between the price of gasoline and average commuting travel time ($P^G_{c(s),t-j} \times TT_c$). For the interaction term, TT_c is fixed in each county at its baseline 1980 level to avoid confounding changes in unobserved factors affecting commuting time with changes in development (as in, e.g., Molloy and Shan 2013). The purpose of the interaction is to allow for the possibility that gasoline prices have a bigger effect on development in areas with higher average commuting costs.

An important element of our econometric modeling strategy is how we use the panel structure of the data to include county fixed effects (α_c), year fixed effects (τ_t), and state-specific linear time trends ($\gamma 1\{State_c = s\}t$), where $1\{State_c = s\}$ is an indicator variable for the state, s, in which county c is located. County fixed effects absorb features of each county that affect land development and do not change over the time period of our analysis (e.g., climate and geographic amenities that draw migrants such as coastlines, mountains, and other outdoor amenities). Year fixed effects absorb land development drivers that are spatially-invariant but time-varying (e.g., interest rates and macroeconomic shocks, such as the Great Recession). State time trends absorb land development drivers that are specific to each state and alter the trajectory of development over the time period of our analysis (e.g., state government policies that affect land-use, changing regional attractiveness for migration). To account for spatial correlation in the model error term, $\varepsilon_{c,t}$, standard errors are clustered by state.

To depict results from the econometric estimation, we first compute the average change in each explanatory variable over two periods: (a) the last two decades of the 20th century (1980-2000) and (b) the first 15 years of the 21st century (2001-2015). For income and gasoline price, which enter the model in level form, we use the average annual growth in each variable for each of the two periods. For population growth, which already enters the model in change form, we compute the average value in each of the two periods (as opposed to the change in population growth). We then use the estimated model parameters to estimate the percentage effect on land development stemming from the observed average annual change in each explanatory factor over the early (1983-2000) and later (2001-2015) portions of the study period. To highlight the importance of the observed population, income, and commuting cost drivers, relative to other state-specific influences, we combine the county and year fixed effects, along with the state-specific trends, to produce an annualized state-level marginal effect of unobserved land development drivers.

Results

National trends

Growth in the developed land area of the United States increased throughout the 1980s and into the 1990s before peaking and undergoing a persistent multidecade decline (Fig. 1A). As of 2015, the current rate of land conversion (0.47 million acres per year), is less than one-quarter of the peak development rate that occurred over 1992-1997 (2.04 million acres per year). The downward trajectory of land development after 1997 predates the Great Recession of 2007-2009 and contrasts with the contemporaneous trend in new housing starts, suggesting that the declining rate of land development is marked by an increase in the density of new housing built rather than a slowdown in construction (SM Fig. B2).

In the last two decades of the 20th century (1982-2000), U.S. population growth lagged behind growth in the developed land base (Fig. 1B), which is consistent with recently documented global trends (Seto et al. 2010; Angel et al. 2011). In relative terms, the population elasticity of land development, which we measure as the ratio of the annualized percentage change in developed land and the annualized percentage change in population, shows that land development has become increasingly population-inelastic, with the elasticity measure declining from 2.59 in 1982 to 0.7 in 2015 (Fig. 1C). This implies that the stock of developed land has become increasingly dense over time, which is also corroborated by the cumulative and annual change ratios of population and developed land shown in SM Fig. B3.

The observed trend in land development is in general agreement with trends in two of its major drivers: income and commuting costs. The last two decades of the 20th century were marked by a rise in real median household income, but household income growth was relatively stagnant between 2000 and 2015 (Fig. 1D). Gasoline prices, a primary component of our measure of commuting cost, declined rapidly in the early 1980s and remained low until the early 2000s, when they increased sharply, and have since generally remained higher, though more volatile, than in the later 20th century. Taken together with the trend in land development, the trends in income and gasoline prices accord with basic economic intuition, suggesting that (i) consumption of land increases with income and (ii) commuting costs impose a constraint on the geographic extent of growing urban areas.

Lastly, we find that the shift towards denser development patterns has occurred broadly across urban and rural areas that collectively contain a large majority of the US population. Specifically, 83% of the 2015 U.S. population is found in areas that got denser (as measured by the ratio of total population to total developed land area) over 2000-2015 compared to 1982-2000 (SM Table B1). Overall, 90% of counties with any developed land area during our study period (SM Table B2), and all but one state (Nevada; SM Fig. B4), have developed areas that became more densely populated over 2000-2015. We further decompose the spatial distribution of development using a county-level federal urban influence classification system. At least 84% of counties assigned to each of the 12 urban influence classes are associated with developed areas that got more densely populated over 2000-2015 relative to 1982-2000 (SM Table B2).

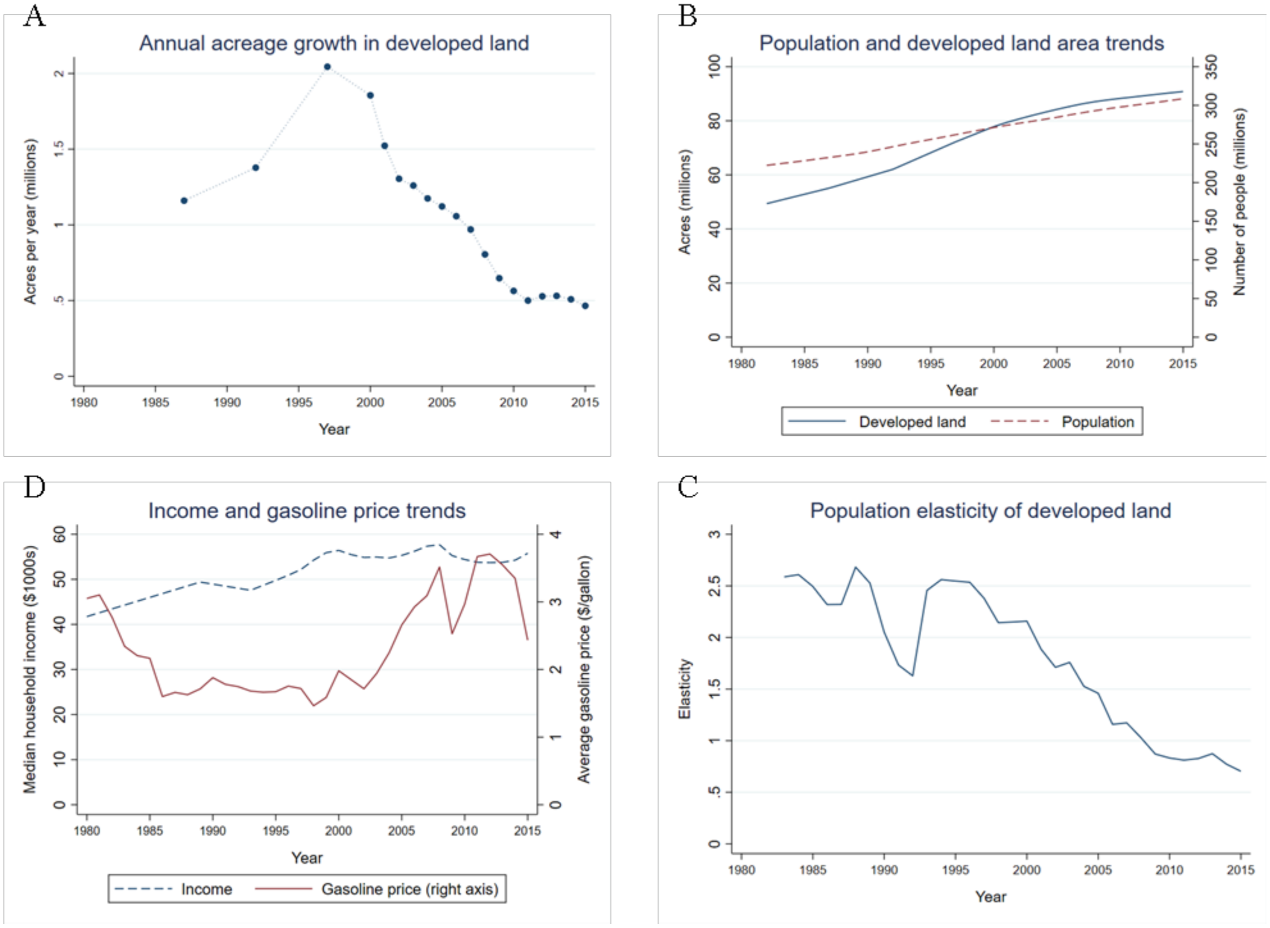


Fig. 1. The last two decades of the 20th century were characterized by rising land development, a trend that reversed course during the start of the 21st century (A); development outpaced population growth until the end of the 20th century, when population began to grow at a relatively faster pace (B); in relative terms, these trends imply that development has become inelastic with respect to population growth (C); these trends are also consistent with those of two main drivers of development, namely income and commuting costs (as measured by gasoline prices) (D).

Stratification of land development trend

In general, we find a remarkably consistent decline in land development over 2000-2015 across various stratifications of the U.S. land base. The development rate peaked in the mid-late 1990s across the quartiles of 1980 county-level population density distribution (Fig. 2A). The densest counties experienced the most dramatic reduction in land development, falling from a peak of 1.29 million acres per year over 1992-1997 to a 2015 level of just 0.23 million acres per year (an 82% reduction). As of 2015, over 80 percent of land in the highest density quartile and over 95 percent of land in the bottom three quartiles remains undeveloped (SM Fig. B5), suggesting that the decline in new land development is not entirely driven by a lack of remaining physical land onto which existing developed areas may expand. A similar pattern of land development has also taken place across the distribution of median household income in 1980 (Fig. 2B). Intuitively, total land development is positively correlated with median household income. Across all quartiles, current levels of annual development represent 73-79% percent decreases from their peaks.

Counties characterized by above-median average 1980 commuting times generally saw the largest gains in developed area and, subsequently, the largest declines in the developed area growth rate after the turn of the 21st century (Fid. 2C). The pattern of declining land development in counties with the highest commuting times is consistent with prior research documenting a widespread slowdown in the decline of commuting costs around the year 2000 due to increases in congestion and the growing trend of urban renewal (Cuberes et al. 2021), as well as increases in gas prices (Fig. 1D).

Fig. 2D shows the land development rate for land being converted from each of the four major pre-development uses (forest, crop, pasture, and range). In absolute acreage terms, the current forest land development rate of 0.19 million acres per year has fallen the most off its peak of 0.87 million acres per year, amounting to a 78% rate reduction. This implies that ecosystem services from forest land, in particular, have been most affected by recent changes in the rate of land development. Qualitatively similar patterns emerge for crop, pasture, and, to a lesser extent, range. Lastly, the trend in annual land development persists across broad geographic regions of the U.S. (Fig. 2E). Most development in the conterminous U.S. takes place in the Southeast and Northeast/Midwest regions, with the two accounting for roughly 80% of total development in each year in the study period. This regional development pattern accords with the rankings by pre-developed use, as a majority of counties in the Northeast/Midwest and Southeast are associated with forest as the dominant pre-developed use (SM Fig. B6).

Simulation of avoided land development

Fig. 3 decomposes the avoided land development by state, starting land use, and RPA region. Had the land-use change trajectories from the end of the 20th century continued across 2000-2015, there would have been an additional 7 million acres of land that would have been developed. States with large amounts of avoided land development are generally located east of the Mississippi River or on the Pacific coast. The 36.6% total reduction in newly developed land implies avoided losses across all major undeveloped land-use categories. In general, there is more avoided deforestation than avoided losses in agricultural lands. Avoided deforestation amounted to 3.56 million acres, while avoided cropland loss is 2.06 million acres, most of which is concentrated in the Northeast/Midwest and Southeast regions. The 1.16 million acres of avoided pasture loss is spread more evenly throughout the conterminous U.S. Compared to the other three uses, avoided losses in rangeland are minimal. The spatial distribution of avoided development is attributable to the existing land base. Forty-one percent of avoided deforestation occurs in the Southeast region corresponding to the southeast's 39% share of all U.S. forestland. Similarly, 42% of avoided crop loss occurs in the Northeast/Midwest where approximately 54% of all U.S. cropland is located.

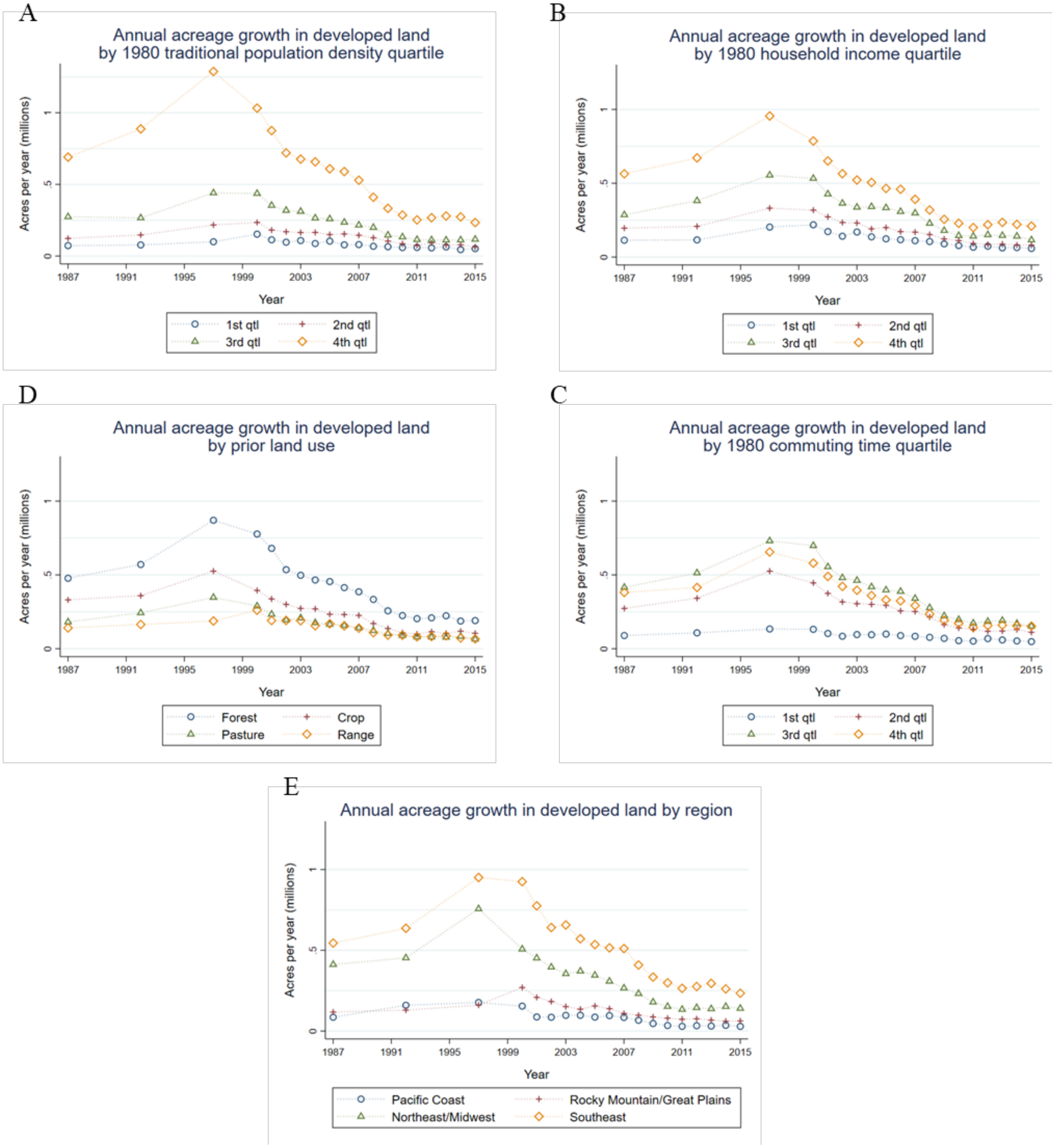
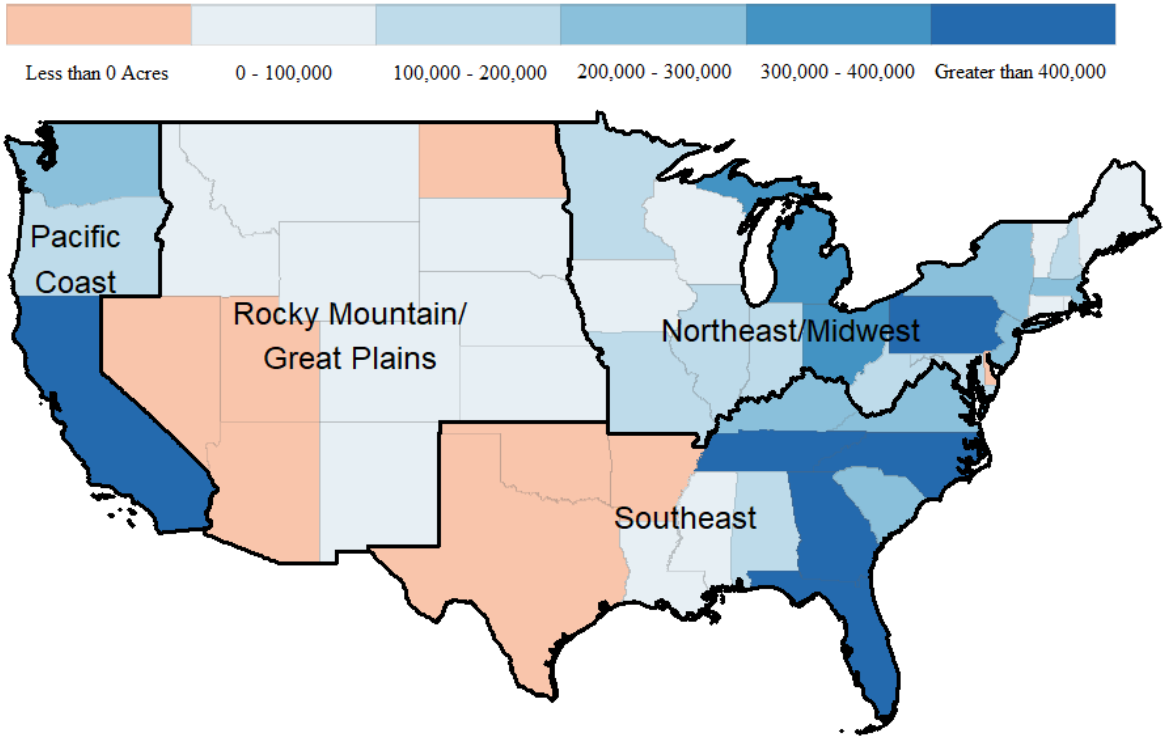


Fig. 2. The same generic pattern of land development increasing in the last two decades of the 20th century and then declining over the first 15 years of the 21st century emerges across several county level stratifications, including baseline (1980) population density (A), baseline median household income (B), baseline commuting time (C), pre-development land use (D), and broad geographic region (E). See Fig. 3 for a map of the states comprising the different regions.



	Forest to Urban	Crop to Urban	Pasture to Urban	Range to Urban	Total Urban Acres Avoided
Conterminous U.S.	3,560,887 (40.1%)	2,063,165 (39.6%)	1,166,742 (38.1%)	319,023 (14.1%)	7,109,817 (36.6%)
Northeast/Midwest	1,700,107 (49.4%)	1,214,931 (48.8%)	317,800 (38.2%)	N/A	3,232,838 (47.8%)
Southeast	1,476,018 (31.6%)	647,647 (38.2%)	599,163 (33.6%)	25,365 (3.0%)	2,748,193 (30.5%)
Pacific Coast	323,908 (57.8%)	189,871 (43.7%)	154,915 (63.7%)	289,406 (49.3%)	958,100 (52.5%)
Rocky Mountain/ Great Plains	61,854 (31.0%)	10,716 (1.8%)	93,864 (46.0%)	(4,252) (-0.5%)	162,182 (8.9%)

Fig. 3. Avoided land conversions under observed land development rates**.** The map shows the total amount of avoided development by state based on the land-use simulation described in the text. The table underneath the map decomposes the regional levels of avoided development by starting undeveloped land use. A similar table for individual states is provided in SM Table B3. Percentage changes are noted in parentheses in the table. There is no range land in the Northeast/Midwest region. SM Table B4 summarizes the transition probabilities used in the calculations.

Socioeconomic drivers of land development

Population growth has a (weakly) positive effect on land development (Table 1). However, population growth was not markedly different in the early and later portions of the study period (0.89 and 0.82 1000s of persons per year, respectively). We estimate that the average annual population change over 1983-2000 increased annual development by approximately 0.63%, while the same effect in the later portion of the study period was 0.62%. Median household income increased by an average of 0.67 per year ($1000s of $USD) over 1983-2000, and our estimates indicate that this increased land development by approximately 3.29% per year. Income stagnation over 2001-2015 led to a minimal decline in land development of 0.09% per year.

Of the three drivers, changes in commuting costs play the largest relative role in driving the observed patterns of land development. Computed at the average county-level commuting time of 19 minutes, the average annual gasoline price decrease of $0.05 during the last two decades of the 20th century boosted annual land development by 6.06%, while the increase in gasoline prices in the second half of the study period ($0.03 annually) decreased land development by 2.84% per year. The interaction term between gasoline price and 1980 commuting time in the econometric model shows that the relationship between commuting costs and land development depends on the amount of time commuters spend traveling to their place of work. In the early part of the study period, the average change in gasoline price increased development by 6.11-7.12% for counties with average commuting times longer than 15 minutes, while counties with shorter commuting times were unaffected by gasoline price changes (Fig. 4). Similarly, in the second half of the study period, when gasoline prices were increasing, the estimated decrease in land development was largest for counties characterized by longer commuting times. Counties with average commuting times over 12 minutes saw a decrease in development ranging from -2.63 to -3.31%, with shorter-commute counties not seeing any impact. Compared to the average level of development over 1983-2000, the commuting cost impact estimates imply that the average annual increase in commuting costs over 2001-2015 avoided a cumulative total of 4.19 million acres of new land development ($p = 0.012$), or roughly 59% of the total avoided land development estimated with the simulation model.

A notable drawback of our estimation strategy is that we are unable to account for changes in land-use regulations, as well as inherently unobservable time-varying factors such as household locational preferences. To determine the magnitude and importance of these factors not explicitly accounted for as measurable independent variables in our model, the final column of Table 1 shows the weighted average annual effect of unobservable factors (with weights corresponding to the number of counties in each state), which we estimate by separately combining the year fixed effects and state-specific trends for the 1983-2000 and 2000-2015 periods. For the early period, our results indicate that if population, income, and commuting costs had remained fixed over this period, annual land development would have been 9.07% lower, on average. After the year 2000, however, the unobservable state trends have a positive average annual effect, but it is not statistically significant ($p<0.05$). In SM Tables C2 and C3, we present annual unobservable effects for each state, which show that the unobservable-induced decline in land development in the early period was most prominent in in several states with fairly stringent land-use regulations (e.g., New Jersey, Massachusetts, and Oregon), which is consistent with the expected effects of these policies. Moreover, the avoided increase in development in these states after 2000 was smallest, but the effects are not significant.

SM Table C1 presents the raw model coefficients and standard errors used to generate the percentage effects. SM Table C4 shows results from omitting α_c, τ_t, and $\gamma 1\{State_c = s\}t$ from (1) and provides justification for their inclusion in the final specification. The percentage effects displayed in Table 2 of the main paper are based on a two-year lag of each explanatory factor. SM Table C5 shows results from alternative lags of one and three years. See SM Appendix C for additional details on the development of the econometric model and supplemental estimation results.

Table 1. Regression model of annual land development

	Population change	Income	Gas price	Unobservable state trends
Panel A: 1983-2000	0.63	3.29	6.06	-9.07
	(0.33)*	(0.45)***	(2.90)**	(3.90)**
	[0.89]	[0.67]	[-0.05]	[1.00]
Panel B: 2001-2015	0.58	-0.09	-2.84	5.80
	(0.31)*	(0.01)***	(1.28)**	(14.62)
	[0.82]	[-0.02]	[0.03]	[1.00]

Notes: The table presents regression results for a model of county-level annual land development (in acres) over 1983 to 2015. To estimate the model, we use a balanced panel of 3,024 counties, amounting to 99,792 total observations. The outcome variable is transformed using the inverse hyperbolic sine function. The model also includes county fixed effects, year fixed effects, and state-specific linear trends. Income and gas prices are adjusted for inflation to 2015 $USD. All explanatory variables enter the model as two-year lags prior to the year over which land development takes place. Gas price enters in level form and through an interaction with 1980 average commuting time. The effects shown in the table are computed at the average observed commuting time value; see Fig. 4 for how the gas price effect varies across the distribution of commuting time. Average effects implied by the unobservable terms in the model are estimated using a combination of year fixed effects and state-specific trends. All effects represent the percentage change in annual development from increasing each regressor by the average annual change over the period delineated by each panel. For each variable-panel combination, the first entry shows the percentage effect, estimated using Kennedy's (1981) method. The second entry, in parentheses, represents the standard error, estimated using the delta method and based on an original variance-covariance matrix adjusted for clustering at the state level. The third entry, in brackets, represents the average annual change value used to compute the percentage effect. Statistical significance is denoted by the asterisks as follows: 1% (***), 5% (**), and 10% (*).

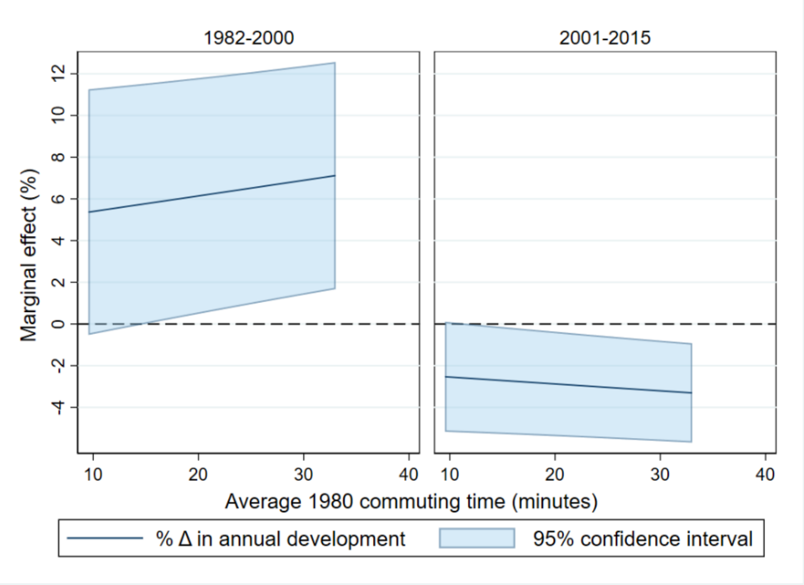


Fig. 4. Gasoline prices and land development are inversely related and the magnitude of the relationship depends on the amount of time commuters spend traveling to their place of work. Confidence intervals based on state-clustered standard errors estimated using the delta method are shown around the point estimate corresponding to the percentage effect for each commuting time percentile.

Discussion

The main takeaway of our analysis is that land development patterns have become increasingly dense in the U.S. over the first 15 years of the 21st century, which has at least three implications for environmental and land-use policy. First, while the permanent avoidance of losing agricultural and forest lands to development is the goal of conservation policies adopted across many levels of governmental and non-governmental organizations, we show that shifts in the fundamental economic drivers of land-use change can indirectly avoid significant amounts of development. While there is no guarantee that the shifts documented here will be permanent, they have, at a minimum, provided more time for land conservation policy to be adopted, which can affect conservation decision-making due to the generally irreversible nature of land development (Costello and Polasky 2004).

Second, while past literature has documented the effects that gas prices have on vehicle miles traveled (e.g. Bento et al. 2009) and housing starts (Molloy and Shan 2013), our results indicate that gas price increases also have an important indirect effect by reducing the rate of land-use change from undeveloped to developed uses in regions with high commuting costs. A direct implication of our results is that policy efforts to price carbon – which would lead to gas price increases – would lower land-use change rates to development. While many studies have documented how carbon pricing can increase forestland through sequestration payments to landowners (e.g. Lubowski et al. 2006; Bryan et al. 2014), our results show that carbon pricing can flatten the trajectory of forestland loss by reducing the incentives for development.

Third, there is a widespread push to consider the direct role of land use in the design of climate policy. Many climate policy proposals involve the preservation and replanting of forested areas to sequester carbon and mitigate the damages caused by emissions generated elsewhere. To this end, beyond avoided forestland and agricultural land loss, taking our results one step further implies that the widespread reduction in land development studied here has resulted in avoided carbon emissions. Of course, however, the extent to which these avoided emissions become permanent will be shaped by future trends in the drivers of development and land use policy.

Although our analysis presents evidence of a widespread transformation of land-use patterns across the U.S., there are several important factors our framework does not address. Perhaps most importantly, we do not model the impact of land-use regulations aimed at curbing the extent of urban land development due to a lack of consistently measured longitudinal data on land-use regulations across the conterminous U.S. To the extent that regulations have evolved in ways not captured by our model (i.e., non-linearly at localized scales), our results should be interpreted with that caveat in mind.

It also bears emphasizing that our results are specific to the United States and not necessarily representative of a similar global trend in land development. Prior research has documented how the decline in urban sprawl in the U.S. stands out when compared with trends in other countries (Barrington-Leigh and Millard-Ball 2020), where rapid low-density urban development does not appear to show any sign of abating (Seto et al. 2012). Furthermore, we use a broad definition of land development, which contrasts with other recent work considering land development and population density in large urbanized areas (e.g., Güneralp et al. 2020).

Perhaps most importantly, the patterns documented here should not be interpreted as suggesting that the recent downward trend in land development represents a permanent change. As the Covid-19 pandemic of 2020-2021 has shown, widespread changes in large-scale economic factors can occur suddenly and fundamentally alter our day-to-day lives. There has also been speculation that the pandemic will result in a shift of locational preferences from high- to lower-density areas, which would put additional pressure to develop new lands in areas already characterized by less dense development patterns. This shift in preferences would potentially be compounded by a rise in remote work, which, with continual improvement in remote-work technology, will erode the accessibility benefits of residing in dense urban areas. While the repercussions of the pandemic are still unfolding, our research lays the groundwork for future empirical analysis of the effects of large shocks like the pandemic on land-use patterns.

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