Decomposing the growth in residential land in the United States

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First version, November 2006
This version, April 2008

Abstract: This paper decomposes the growth in land occupied by residences in the United States to give the relative contributions of changing demographics versus changes in residential land per household. Between 1976 and 1992 the amount of residential land in the United States grew 47.7% while population only grew 17.8%. At first glance, this suggest an important role for per-household increases. However, the calculations in this paper show that only 24.5% of the growth in residential land area can be attributed to state-level changes in land per household. 37.3% is due to overall population growth, 22.6% to an increase in the number of households over this period, 6% to the shift of population towards states with larger houses, and the remaining 9.6% to interactions between these changes. There are large differences across states and metropolitan areas in the relative importance of these components.

Key words: land cover, population growth
JEL classification: R14, O51

[*]We are grateful to William Fischel for comments on an earlier version of the decomposition presented here. Jacqueline Geoghegan, participants at the NARSC meetings in Toronto, the editor and three referees provided useful suggestions. Funding from the Social Sciences and Humanities Research Council of Canada (Puga and Turner) and the Comunidad de Madrid through the grant PROCIUDAD-CM (Overman and Puga), and the support of the Canadian Institute for Advanced Research and the Centre de Recerca en Economia Internacional (Puga) are gratefully acknowledged.

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1. Introduction

Between 1976 and 1992 the amount of land built up for residential use in the continental United States increased by 47.7%.[1] In contrast, population increased by 17.8%, from 216 million people to 255 million people, over this same 16-year period. At first glance, the fact that population increased by roughly one-third as much as residential land may suggest that population changes account for about one-third of the overall increase, leaving changes in the land area covered by individual houses to account for the other two-thirds.

In this paper we conduct a simple decomposition that accounts for the relative contribution of demographic changes and individual and household changes in land consumption behavior to the growth in residential land in the United States. This decomposition reveals a much more complex picture of the components of urban expansion than the back-of-the-envelope one-third two-thirds calculation would suggest. While the contribution of overall population growth, at 37.3%, is precisely the result of dividing the 17.8% increase in population by the 47.7% increase in residential land, only a small fraction of the remaining urban expansion can be attributed to larger houses (i.e. increases in residential land per individual household). Instead, our analysis demonstrates the importance of the increase in the number of households and the spatial shift in population within the United States to the spatial expansion of residential land.

2. Data

Residential Land Data

The amount of land built up for residential purposes in 1976 and 1992 is calculated from the data set developed in Burchfield *et al.* (2006). These data are constructed from two publicly-available remote-sensing data sets.

The most recent of these two remote-sensing data sets, the 1992 National Land Cover Data (Vogelmann, Howard, Yang, Larson, Wylie, and Driel, 2001), is derived mainly from 1992 Landsat 5 Thematic Mapper satellite imagery. The underlying units of observation are 8.7 billion 30×30 meter cells on a grid covering the entire conterminous United States. The Earth Resources Observation Systems (EROS) data center of the United States Geological Survey (USGS) converted the raw satellite images to land cover categories. The process involved generating first-pass boundaries of contiguous areas with similar land cover by grouping together contiguous cells with similar vectors of reflectance values recorded by satellite imagery. Aerial photographs and ancillary data were then used to refine these boundaries and to assign land cover codes. While 30×30 meter cells are much finer than the units of observation of any other data set tracking land developed across the country, they are still coarser than most building structures (over five times larger than the median single-family house and about one half of the median residential lot). Thus, most cells include a combination of covers (e.g., houses, streets, and vegetation). A cell that is

[1] This increase is almost identical to the 48% increase in overall developed land (which includes commercial land and roads in addition to residential land) reported by Burchfield, Overman, Puga, and Turner (2006). The shares of land allocated to residential uses (70%) and commercial/transportation uses (30%) remained almost unchanged between 1976 and 1992.

estimated to be more than 30% covered by constructed materials is classified as developed. If that constructed cover is used mainly for housing then the type of development is classified as residential. Only about 20% of cells classified as residential land are more than 80% covered by constructed materials. Thus, the residential land areas reported below include land occupied by houses but also substantial amounts of land covered by streets, driveways and gardens located in the immediate vicinity of the houses.[2]

An earlier data set (US Geological Survey, 1990, US Environmental Protection Agency, 1994) classifies the conterminous US land area into land use and land cover categories circa 1976.[3] This was derived mainly from high-altitude aerial photographs, also converted to land use and land cover data by the USGS. The process involved drawing boundaries of contiguous areas with similar land cover and land use on the basis of aerial photographs and then using these photographs and ancillary data to assign land cover and land use codes. The US Environmental Protection Agency (EPA) further processed the data to facilitate their use in geographic information systems, and we use their version(US Environmental Protection Agency, 1994). We filled gaps in these data to obtain complete coverage for the conterminous United States as detailed in Burchfield *et al.* (2006).

While there are many similarities between the 1976 and the 1992 data, there are some subtle, but relevant, differences in the thresholds used to classify an area as developed in the 1976 and in the 1992 data. Given this, we believe one should not compare the data directly. Instead, one can take advantage of the fact that, while land is often redeveloped, it is almost never undeveloped. At the national level, according to the U.S. Department of Agriculture's National Resource Inventory, less than 0.8% of developed land was converted from urban to non-urban uses over the 15-year period 1982–1997 (US Department of Agriculture, 2000). With virtually no undevelopment taking place, we can base our analysis on the 1992 data and use the 1976 data only to determine whether development that existed in 1992 was built before or after 1976. Thus 1992 residential land is land classified as residential in the 1992 data. However, 1976 residential land is land classified as urban in 1992 that was also classified as residential in 1976. See Burchfield *et al.* (2006) and the web page `http://diegopuga.org/data/sprawl/` for a more detailed description.

It is worth noting that the element of the residential land data that matters for our decomposition exercise is the growth rate of residential land in different parts of the United States. The growth rate of residential land area we report is calculated by counting 30×30 meter cells that were not part of an area classified as developed in 1976 but were estimated to have crossed the 30% threshold of constructed materials by 1992 and used mainly for housing, and comparing this to the number of cells already classified as residential in 1976. While there is no other data set that

[2]An additional implication of this combination of land covers within a single 30×30 meter cell is that there is room for small-scale infilling in many cells that are already classified in our data as residential development in 1976. This, combined with redevelopment and increasing building heights, allows in some areas to house substantial population increases with only moderate increases in the number of cells classified as residential land, as illustrated below by the case of Portland.

[3]The 1976 data actually corresponds to different dates circa 1976. We correct for data not from 1976 by first determining the portions of each county with data collected in each given year, then estimating the percentage of urban land in each of these county portions by assuming a constant local annual growth rate over the period, then splitting urban land into residential and commercial according to the proportions recorded in the data for each county portion, and finally aggregating up to the county level. The metropolitan area, state and national figures used in our calculations are computed as aggregates of the county numbers.

allows tracking residential development with comparable spatial detail during this period, the American Housing Survey reports an annual growth rate of the number of housing units of 1.64% between 1976 and 1993 (US Bureau of the Census, 1978, 1995). To translate this into an annual growth rate of the total residential land area, we would need to know the annual growth rate of the average surface area of housing units during this period, and this is not available. Using as an approximation the 0.69% annual growth rate of the square footage of the median single-family house between 1985 and 1993 (US Bureau of the Census, 1988, 1995) yields an approximate annual growth rate of residential land of 2.34%, which is close to the 2.47% annual growth rate we obtain from our data.

Demographic data

Population data corresponds to intercensal county-level population estimates for 1976 and 1992 from the US Bureau of the Census.[4] Household data were obtained by interpolating the total number of households in each county in Census years 1970, 1980, 1990 and 2000 to calculate a county-level average number of people per household in 1976 and 1992, and then combining this with the intercensal county-level population estimates to obtain the number of households in each county in 1976 and 1992.

3. Decomposing changes in US residential land use

There is a large and growing literature that seeks to explain the causes of the United States' ongoing urban expansion (often pejoratively referred to as 'sprawl'). This literature is concerned with two main questions. First, what has caused changing spatial patterns of development? Or as Glaeser and Kahn (2004) put it: Why have cities started to grow outward rather than upward? Second, and obviously related, what can explain increasing per-person consumption of land? Such increases in per-person urban land may reflect the fact that, on average, people are building larger houses than they used to. Alternatively, the number of dwellings used to house a given population may have increased as a result of changes in the number of individuals living in each house or of some houses being left empty as, for example, 'flight from blight' sees people abandon housing downtown and relocate to new houses in the suburbs. Of course, these possibilities are not mutually exclusive. Our aim is precisely to assess the relative importance of various factors contributing to the growth in residential land in the United States.

Implicit in this discussion, and in much of the literature, is the assumption that increasing average residential land per household is the key factor driving urban expansion in the United States. This section is concerned with assessing that implicit assumption. We do not aim to explain what may have caused houses to become larger on average. Instead we quantify the importance of rising house sizes relative to various demographic factors for the growth in the amount of residential land in the United States. As a first step, we decompose the increase in residential land to find the relative contributions of population growth and increasing land use per person.

[4] These were obtained from `http://www.census.gov/popest/archives/pre-1980/co-asr-1976.xls` and `http://www.census.gov/popest/archives/EST90INTERCENSAL/STCH-Intercensal/STCH-icen1992.txt`.

Some notation will be helpful, so let us define the following variables:

$$L_i^t \equiv \text{Residential land in location } i \text{ at time } t\ ,$$
$$P_i^t \equiv \text{Population in location } i \text{ at time } t\ ,$$
$$l_i^t \equiv \frac{L_i^t}{P_i^t} = \text{Average residential land per person in location } i \text{ at time } t\ .$$

The change in the total amount of residential land in the United States between 1976 and 1992 can then be decomposed into three distinct components:[5]

$$\begin{aligned}
L_{\text{US}}^{92} - L_{\text{US}}^{76} &= P_{\text{US}}^{92}\, l_{\text{US}}^{92} - P_{\text{US}}^{76}\, l_{\text{US}}^{76} \\
&= \left.(P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{76}\right\} \text{Contribution of changes in US } \textit{population}\text{: } 37.3\% \\
&+ \left.P_{\text{US}}^{76}\,(l_{\text{US}}^{92} - l_{\text{US}}^{76})\right\} \text{Contribution of changes in US } \textit{residential land per person}\text{: } 53.2\% \\
&+ \left.(P_{\text{US}}^{92} - P_{\text{US}}^{76})(l_{\text{US}}^{92} - l_{\text{US}}^{76})\right\} \text{Contribution of } \textit{interactions}\text{: } 9.5\%\ .
\end{aligned}$$

Note that this decomposition is an identity: the sum of the three individual components exactly equals the total change. Thus, it is not an expression one needs to estimate, but instead it is computed simply by substituting in the actual values of population and land per person in 1976 and 1992.

The first component of this decomposition, $(P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{76}$, represents the contribution of changes in US population. This is how much the total amount of residential land in the US would have increased in the hypothetical case that US population had grown as it did over the period 1976–92, $(P_{\text{US}}^{92} - P_{\text{US}}^{76})$, but that US residential land per person had remained constant at its 1976 level, l_{US}^{76}. Plugging in the actual values, the contribution of changes in US population turns out to be 37.3% of the increase in the total amount of residential land. A little algebra will show that this is equivalent to our earlier back-of-the-envelope calculation, which divided the 17.8% increase in population by the 47.7% increase in residential land to obtain the same 37.3% contribution of changes in US population.

The second component of the decomposition, $P_{\text{US}}^{76}\,(l_{\text{US}}^{92} - l_{\text{US}}^{76})$, represents the contribution of changes in US residential land per person. This is how much the total amount of residential land in the United States would have increased in the hypothetical case that US residential land per person had grown as it did over the period 1976–92, $(l_{\text{US}}^{92} - l_{\text{US}}^{76})$, but that US population had remained constant at its 1976 level, P_{US}^{76}. Again, plugging in the actual values, we find that the contribution of changes in US residential land per person is 53.2% of the actual increase in the total amount of residential land.

The third component of the decomposition, $(P_{\text{US}}^{92} - P_{\text{US}}^{76})(l_{\text{US}}^{92} - l_{\text{US}}^{76})$, represents the contribution of the interaction between changes in US population and changes in US residential land per person. It accounts for the fact that the increased population is being housed at the new higher average amount of residential land per person. The contribution of this interaction term is 9.5% of the actual increase in the total amount of residential land.

[5] A discussion of technical issues concerning the exact form of the decomposition can be found in Appendix A.

The shift in population within the United States

The 53.2% contribution of changes in US residential land per person seems large. One possible explanation for this large increase in per-person land use is that new houses are much bigger than older houses. We can certainly observe this trend in the average size of newly constructed houses. For example, in 1992, the average floor area in new one-family houses was 2,095 square feet (195 square meters), up from 1,700 square feet in 1976 (156 square meters) — the increase in the average lot size between 1976 and 1992 was much smaller, from 0.37 to 0.41 acres.[6]

A fact that has received far less attention than changing house sizes, is the shift of population towards areas where houses have traditionally been larger. This shift means that, even if people moving into an area built houses that were similar in size to those of their new neighbors, they still would tend to be larger than the houses they left behind.[7] Table 1 shows levels and changes in land use and population for individual states.[8] We can see that, for example, the three states experiencing the largest percentage increases in population, Nevada, Arizona and Florida (108.9%, 66.8% and 57.0% respectively) all had above average levels of residential land per person in 1976. The case of Florida is particularly striking. Residential land use per person was over one and a half times the US average in 1976 and its population grew at a rate more than three times that of the United States as a whole.[9]

To check whether these examples are representative of a general trend, we start by repeating our original decomposition, but now at the level of individual states and separating US-level population changes from the differential population changes experienced by each state as follows:

$$P_s^{92} - P_s^{76} = \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} P_s^{76} + \left(\frac{P_s^{92} - P_s^{76}}{P_s^{76}} - \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} \right) P_s^{76} \ .$$

The first term on the right-hand side, $(P_{\text{US}}^{92} - P_{\text{US}}^{76}) P_s^{76} / P_{\text{US}}^{76}$, represents how much population in the state would have increased if its population had grown at the same rate as total US population. The second term is the difference with respect to the state's actual population change (positive if it grew at a higher rate than total US population, negative otherwise). We then sum over all states to

[6] These data refer to new single-family homes (completed) and are taken from the U.S Bureau of the Census Survey of Construction, C25 Annual. See `http://www.census.gov/const/C25Ann/sftotalmedavgsqft.pdf` and `http://www.census.gov/const/C25Ann/malotsizesold.pdf`

[7] Of course, the pattern of moves is likely to be much more complicated than 'in-movers' building and occupying new homes while existing residents live in the established housing stock.

[8] While our decompositions could in principle be performed at the level of any spatial unit, when picking the appropriate spatial scale we face a tradeoff. Smaller spatial scales clearly give more detail. But at smaller spatial scales, moves between areas may largely be driven by differences between the size of houses (and other characteristics of the housing stock). For example, as couples have children they often move from downtown to the suburbs of the same metropolitan area explicitly to increase the size of their house. In this case, it seems odd to attribute the resulting increase in residential land to population shifts between downtown and the suburbs when that shift is essentially driven by a desire to increase land consumption per person. Instead, we want a spatial scale at which population movements are largely exogenous to the differences in the per-person residential land consumption in different areas. We would argue that US states and metropolitan areas are suitable candidates. Thus, we perform our decomposition first for states and then (in section 5) for metropolitan areas.

[9] In an earlier draft of this paper, tables 1 and 3 reported residential land per person in acres that, due to a coding error, were 9 times larger than the correct magnitudes. This error only affected this particular column of these tables. It did not affect the decompositions we perform or any other results. The relative magnitudes of land per person were also correct. We are very grateful to a referee for pointing this out.

Table 1: State-level land use and demographic changes 1976–92

State	% growth residential land 1976–92	% growth residential land per person 1976–92	% growth population 1976–92	% growth household size 1976–92	residential land per person 1976 (sq. meters)	population 1976 (millions)	household size 1976 (people)
Alabama	26.8	14.1	11.2	−13.5	246.31	3.74	3.07
Arizona	56.1	−6.4	66.8	−11.3	389.09	2.35	3.02
Arkansas	87.3	68.1	11.4	−10.5	290.47	2.17	2.93
California	47.5	4.4	41.2	0.5	262.47	21.93	2.86
Colorado	78.2	34.2	32.8	−12.0	337.79	2.63	2.92
Connecticut	71.1	59.9	7.0	−11.5	301.86	3.09	3.01
Delaware	20.5	2.8	17.2	−12.2	367.03	0.59	3.05
DC	18.8	38.4	−14.2	−9.6	93.39	0.70	2.67
Florida	116.1	37.6	57.0	−8.3	555.79	8.70	2.75
Georgia	54.7	16.3	33.0	−11.6	333.79	5.13	3.09
Idaho	40.7	12.5	25.0	−8.9	318.43	0.86	3.05
Illinois	41.1	37.0	2.9	−8.3	243.92	11.36	2.97
Indiana	39.0	31.6	5.6	−11.0	300.75	5.37	3.00
Iowa	76.1	81.5	−2.9	−11.2	294.04	2.90	2.92
Kansas	33.7	21.4	10.2	−8.8	419.92	2.30	2.87
Kentucky	36.9	28.4	6.6	−13.3	264.39	3.53	3.05
Louisiana	50.1	38.2	8.6	−11.9	342.61	3.95	3.17
Maine	32.4	16.5	13.6	−13.8	497.34	1.09	3.02
Maryland	21.7	3.1	18.0	−11.4	297.98	4.17	3.07
Massachusetts	45.0	38.3	4.9	−10.8	338.78	5.75	2.99
Michigan	33.0	27.9	4.0	−12.4	271.22	9.12	3.08
Minnesota	69.7	49.4	13.6	−12.3	296.24	3.96	3.01
Mississippi	62.1	50.2	8.0	−13.0	275.58	2.43	3.22
Missouri	40.4	29.8	8.2	−9.7	315.31	4.82	2.88
Montana	42.1	30.5	8.9	−12.1	291.02	0.76	2.94
Nebraska	9.7	5.4	4.0	−10.2	337.67	1.55	2.91
Nevada	130.5	10.4	108.9	−7.6	330.37	0.65	2.80
N. Hampshire	64.6	24.7	32.0	−11.3	432.41	0.85	3.02
New Jersey	35.5	26.3	7.3	−8.7	337.36	7.34	3.03
New Mexico	13.9	−14.7	33.5	−13.0	372.01	1.20	3.18
New York	37.0	35.0	1.5	−6.6	219.24	17.97	2.90
N. Carolina	38.4	12.2	23.3	−14.8	499.59	5.59	3.08
N. Dakota	106.2	108.6	−1.1	−15.2	244.47	0.65	3.08
Ohio	26.7	23.5	2.6	−11.8	306.11	10.75	2.99
Oklahoma	42.0	24.5	14.1	−8.1	480.65	2.82	2.83
Oregon	13.1	−10.3	26.1	−8.4	389.52	2.37	2.81
Pennsylvania	37.5	35.6	1.4	−11.2	212.55	11.89	2.96
Rhode Island	33.0	24.8	6.6	−11.1	314.17	0.95	2.97
S. Carolina	47.2	19.6	23.1	−15.2	448.62	2.94	3.23
S. Dakota	90.9	83.9	3.8	−12.4	251.67	0.69	3.04
Tennessee	39.5	19.6	16.6	−12.7	360.63	4.33	3.00
Texas	55.6	13.0	37.6	−7.9	392.31	12.90	3.04
Utah	28.1	−11.3	44.4	−5.2	353.85	1.27	3.38
Vermont	77.4	50.3	18.1	−13.8	305.01	0.49	3.07
Virginia	20.3	−3.7	25.0	−12.4	399.22	5.13	3.06
Washington	26.5	−9.5	39.8	−8.7	523.38	3.69	2.84
West Virginia	33.0	38.3	−3.8	−13.7	214.14	1.88	2.98
Wisconsin	48.2	35.2	9.6	−12.5	258.49	4.58	3.04
Wyoming	93.7	64.3	17.9	−10.6	389.03	0.40	2.97
United States	47.7	25.4	17.8	−9.3	319.86	216.27	2.97

obtain the following richer decomposition of the change in the total amount of residential land in the United States:

$$
\begin{aligned}
L_{\text{US}}^{92} - L_{\text{US}}^{76} &= \sum_{s \in \text{US}} P_s^{92}\, l_s^{92} - P_s^{76}\, l_s^{76} \\
&= \sum_{s \in \text{US}} P_s^{76}\,(l_s^{92} - l_s^{76}) + \sum_{s \in \text{US}} (P_s^{92} - P_s^{76})\, l_s^{76} + \sum_{s \in \text{USn}} (P_s^{92} - P_s^{76})(l_s^{92} - l_s^{76}) \\
&= \sum_{s \in \text{US}} \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} P_s^{76}\, l_s^{76} \Big\} \text{ Contribution of changes in US } \textit{population}\text{: } 37.3\% \\
&+ \sum_{s \in \text{US}} \left(\frac{P_s^{92} - P_s^{76}}{P_s^{76}} - \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} \right) P_s^{76}\, l_s^{76} \Big\} \text{ Contrib. of differential changes in states' } \textit{population}\text{: } 6\% \\
&+ \sum_{s \in \text{US}} P_s^{76}\,(l_s^{92} - l_s^{76}) \Big\} \text{ Contribution of changes in states' } \textit{residential land per person}\text{: } 49.7\% \\
&+ \sum_{s \in \text{US}} (P_s^{92} - P_s^{76})(l_s^{92} - l_s^{76}) \Big\} \text{ Contribution of } \textit{interactions}\text{: } 7\% \,.
\end{aligned}
$$

The first component of this decomposition represents the contribution of changes in US population. The figure is 37.3% and is identical to the contribution attributed to US population calculated from the first decomposition we performed above. This reflects the fact that, once again, this is an accounting identity, so the numbers are identical by definition. To see this, we can take the first component in the richer decomposition and rearrange it to get the first component in our original decomposition. Specifically:

$$
\sum_{s \in \text{US}} \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} P_s^{76}\, l_s^{76} = \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{US}}^{76}} \sum_{s \in \text{US}} P_s^{76}\, l_s^{76} = (P_{\text{US}}^{92} - P_{\text{US}}^{76}) \frac{L_{\text{US}}^{76}}{P_{\text{US}}^{76}} = (P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{76} \,.
$$

Thus, the difference between our first decomposition and this one is not how we account for the contribution of the change in US population but instead is reflected in the fact that we now split what is left after accounting for this change into three components. The contribution of differential changes in states' population captures the consequences of states with different per-person amounts of residential land experiencing different population growth rates relative to the US average. This component accounts for 6% of the actual increase in the total amount of residential land. The contribution of changes in residential land per person at the level of individual states accounts for 49.7% of the total change. The remaining 7% corresponds to interactions between changes in population and changes in residential land per person at the level of individual states.

It is interesting to note two facts. First, the contribution of differential changes in states' population is positive (6%). This indicates that, as suggested by the examples picked from Table 1 and discussed above, population growth has been biased towards states with historically high levels of residential land per person (l_s^{76}). That is, $[(P_s^{92} - P_s^{76})/P_s^{76} - (P_{\text{US}}^{92} - P_{\text{US}}^{76})/P_{\text{US}}^{76}]P_s^{76}$, the difference between the state's actual population change and how much population in the state would have increased if its population had grown at the same rate as total US population, is larger for such states. This makes the contribution of differential changes in states' population positive.

The second fact that emerges from this more detailed decomposition is that the contribution of changes in residential land per person at the level of individual states is smaller than the contribution of nationwide changes in land per person we found in the first decomposition (49.7%

versus 53.2%). This decreased contribution reflects two factors. First, some of this increase is now attributed to the higher than average rates of population growth in states with higher than average residential land per person. Second, states with historically high population levels (P_s^{76}) have tended to have relatively small increases in residential land per person ($l_s^{92} - l_s^{76}$). This tends to make the contribution of changes in residential land per person at the state level smaller. The most prominent example of this is California, the most populous state, which experienced almost no increase in the amount of residential land per person between 1976 and 1992.

Falling household sizes

As a final step we look in more detail at the determinants of changes in residential land per person. One of the most significant demographic changes between 1976 and 1992 has been a fall in the average household size from 2.97 to 2.69 people. See, for example, Jiang and O'Neill (2007) for an overview of recent US evidence. This has had important consequences for land use because, as the average household size falls, the number of housing units occupied by a given population increases. In fact, the 1.6% annual growth rate of the number of households between 1976 and 1992 is identical to the 1.6% annual growth rate of total housing units recorded in the American Housing Survey between 1976 and 1993 (US Bureau of the Census, 1978, 1995).

As documented in, for example, Kobrin (1976), this fall in the average household size is the continuation of an extremely long term trend for the US and part of a more general trend for many countries. See, for example, Kuijsten (1995). This decline is the result of several changes to both family and household formation patterns. For families, there has been a sharp decline in the percentage of households headed by married couples with children (from 40.4% in 1970 to 27.9% in 1985), while the number of households headed by single parents has increased (from 5.1% to 7.9% over the same time period).[10] These changes are driven by a variety of factors. Santi (1988) identifies the most important as the rising age of first marriage, the increasing rates of marital disruption and nonmarital fertility. The proportion of households headed by married couples with children has also decreased as a result of the falling propensity of young adults to live with their parents. At the same time as these changes to family formation patterns, the proportions of single and other nonfamily households have also increased (from 18.7% in 1970 to 27.7% in 1985), partly due to an increase in the proportion of the population that is unmarried and childless (as the baby boom cohort moves through the age distribution) and partly due to this group's increased propensity to live alone. The resulting decline in average household size suggests an interesting question: How much of the growth in land per person is due to individual households using more land on average and how much to the increase in the total number of households?[11]

To answer this question note first that residential land per person is equal to the product of residential land per household and the ratio of households to people:

$$l_i^t \equiv \frac{L_i^t}{P_i^t} = \frac{L_i^t}{H_i^t}\frac{H_i^t}{P_i^t} = h_i^t r_i^t \ ,$$

[10] All figures on the changing distribution of households by type are taken from table 7 of Santi (1988).

[11] The importance of differences across countries in the evolution of average household size have been emphasized by Liu, Dally, Ehrlich, and Luck (2003) in the context of resource consumption and biodiversity.

where

$$H_i^t \equiv \text{Households in location } i \text{ at time } t \,,$$
$$h_i^t \equiv \frac{L_i^t}{H_i^t} = \text{Average residential land per household in location } i \text{ at time } t \,,$$
$$r_i^t \equiv \frac{H_i^t}{P_i^t} = \text{Ratio of households to population in location } i \text{ at time } t \,.$$

Taking this in to account, we can split the component of our decomposition that captures the contribution of changes in states' residential land per person into three parts:

$$\begin{aligned}\sum_{s\in\text{US}} P_s^{76}\,(l_s^{92} - l_s^{76}) &= \sum_{s\in\text{US}} P_s^{76}\,(h_s^{92} r_s^{92} - h_s^{76} r_s^{76}) \\ &= \sum_{s\in\text{US}} P_s^{76}\,(h_s^{92} - h_s^{76})\,r_s^{76} + \sum_{s\in\text{US}} P_s^{76}\,h_s^{76}\,(r_s^{92} - r_s^{76}) + \sum_{s\in\text{US}} P_s^{76}\,(h_s^{92} - h_s^{76})(r_s^{92} - r_s^{76}) \,.\end{aligned}$$

The first term on the right hand side, represents how much residential land per person would have increased if the average residential land per household increased as it did between 1976 and 1992, but the ratio of households to population had stayed fixed at its 1976 level. The second term, in contrast, represents how much residential land per person in the state would have increased if the land per household had remained fixed, but the ratio of households to population grew as it did. Finally, the third term represents the interaction between changing land per household and the changing ratio of households to population. Thus, these three terms capture the partial contributions of changes in residential land per household, of changes in the ratio of households to population, and of interactions between these two changes.

Substituting this back into our decomposition, we get our final and most detailed state-level decomposition of changes in residential land in the United States:

$$\begin{aligned}L_{\text{US}}^{92} - L_{\text{US}}^{76} = &\left.\sum_{s\in\text{US}} \frac{P_{\text{US}}^{92} - P_{\text{US}}^{76}}{P_{\text{USn}}^{76}} P_s^{76}\,l_s^{76}\right\} \text{Contribution of changes in US } \textit{population}\text{: } 37.3\% \\ &\left.+ \sum_{s\in\text{US}} \left(\frac{P_s^{92} - P_s^{76}}{P_s^{76}} - \frac{P_{\text{US}}^{92} - P_{\text{USn}}^{76}}{P_{\text{US}}^{76}}\right) P_s^{76}\,l_s^{76}\right\} \text{Contrib. of differential changes in states' } \textit{population}\text{: } 6\% \\ &\left.+ \sum_{s\in\text{USn}} P_s^{76}\,(h_s^{92} - h_s^{76})\,r_s^{76}\right\} \text{Contrib. of changes in states' } \textit{residential land per household}\text{: } 24.5\% \\ &\left.+ \sum_{s\in\text{US}} P_s^{76}\,h_s^{76}\,(r_s^{92} - r_s^{76})\right\} \text{Contrib. of changes in states' } \textit{household sizes}\text{: } 22.6\% \\ &\left.+ \sum_{s\in\text{US}} P_s^{76}\,(h_s^{92} - h_s^{76})(r_s^{92} - r_s^{76}) + \sum_{s\in\text{US}} (P_s^{92} - P_s^{76})(l_s^{92} - l_s^{76})\right\} \text{Contrib. of } \textit{interactions}\text{: } 9.6\% \,.\end{aligned}$$

Note that changes in residential land per household and changes in household sizes contribute almost equally to changes in residential land per person and, consequently, to the growth of total US residential land between 1976 and 1992. To summarize our findings, the most important component in increasing residential land uses has been overall population growth, but larger houses and the increasing number of households also play an important role.

Table 2: State-level decomposition of the growth in residential land 1976–92

State	% of the growth in residential land 1976–92 accounted for by				
	changes in US population	differential changes in states' population	changes in states' residential land per household	changes in states' household sizes	interactions
Alabama	66.4	−24.8	−4.9	58.2	5.1
Arizona	31.8	87.4	−30.4	22.8	−11.5
Arkansas	20.4	−7.3	57.9	13.4	15.7
California	37.5	49.3	10.4	−1.0	3.8
Colorado	22.8	19.2	23.1	17.4	17.5
Connecticut	25.0	−15.3	58.5	18.2	13.5
Delaware	86.9	−2.8	−47.5	67.6	−4.2
DC	94.7	−170.2	133.8	56.5	−14.8
Florida	15.3	33.8	22.6	7.8	20.5
Georgia	32.5	27.8	5.2	24.0	10.5
Idaho	43.7	17.8	6.1	24.1	8.3
Illinois	43.3	−36.2	62.4	22.1	8.3
Indiana	45.6	−31.2	43.7	31.8	10.0
Iowa	23.4	−27.2	80.3	16.6	7.0
Kansas	52.9	−22.7	31.7	28.6	9.5
Kentucky	48.2	−30.2	30.8	41.4	9.8
Louisiana	35.5	−18.3	43.3	27.0	12.4
Maine	55.0	−12.9	1.3	49.5	7.2
Maryland	82.0	0.9	−39.7	59.3	−2.5
Massachusetts	39.5	−28.7	52.0	26.8	10.4
Michigan	53.9	−41.9	36.5	42.9	8.5
Minnesota	25.5	−6.0	44.4	20.2	15.9
Mississippi	28.7	−15.8	49.4	24.0	13.8
Missouri	44.0	−23.9	42.6	26.6	10.6
Montana	42.3	−21.2	34.9	32.8	11.2
Nebraska	183.4	−141.8	−54.9	117.3	−4.0
Nevada	13.6	69.8	1.5	6.3	8.8
N. Hampshire	27.6	21.9	16.5	19.7	14.3
New Jersey	50.2	−29.6	42.9	27.0	9.5
New Mexico	128.5	113.2	−185.9	107.5	−63.2
New York	48.0	−44.0	70.4	19.1	6.4
N. Carolina	46.4	14.4	−11.5	45.3	5.4
N. Dakota	16.8	−17.8	72.3	16.9	11.8
Ohio	66.7	−57.1	33.4	50.2	6.7
Oklahoma	42.4	−8.9	34.3	21.0	11.2
Oregon	135.4	63.3	−135.6	69.8	−32.9
Pennsylvania	47.5	−43.9	54.5	33.7	8.2
Rhode Island	54.0	−34.1	33.3	37.7	9.1
S. Carolina	37.7	11.2	3.0	38.0	10.1
S. Dakota	19.6	−15.4	67.3	15.6	13.0
Tennessee	45.1	−2.9	11.0	37.0	9.9
Texas	32.0	35.7	7.4	15.4	9.5
Utah	63.3	94.5	−56.3	19.4	−20.8
Vermont	23.0	0.3	38.2	20.7	17.8
Virginia	87.5	35.3	−77.1	69.9	−15.5
Washington	67.2	83.2	−65.8	36.1	−20.6
West Virginia	53.9	−65.3	58.7	47.9	4.9
Wisconsin	36.9	−17.0	38.1	29.6	12.4
Wyoming	19.0	0.1	50.0	12.7	18.2
United States	37.3	6.0	24.5	22.6	9.6

4. Decomposing changes in states' residential land use

The growth of total US residential land is the sum over all states of the growth in residential land in each state. Thus, the decomposition of US changes in residential land is the sum over all states of the same decomposition done at the state level. Table 2 lists the importance of the various contributing factors for each individual state. Note the large heterogeneity across states in the relative importance of each factor.

A few comments and examples may help with the interpretation of the evidence presented in table 2. First, components other than the contribution of the change in US population can be negative. A negative value for the differential change in states' population identifies states whose population grew at a slower rate than the US average. This slower rate of population growth reduced the increase in residential land compared to what it would have been if the state population had grown at the rate of the United States, hence the negative contribution. The most extreme example is DC whose population decline of -14.2% during this period would have seen the amount of residential land decrease by nearly 32% if that population decline had not been offset by other factors.[12] Negative contributions for changes in residential land per household are markedly less common, but we can still identify 11 states where decreases in the amount of residential land per household would have decreased the overall amount of residential land if, once again, those changes had not been offset by other factors. Finally, only 1 state, California, saw a negative contribution of household size to overall residential land, consistent with the fact that it was the only state to see an increase in household sizes during the time period of our study (see Table 1). As should be clear from the example of DC, the contributions of individual components can be greater than 100% provided that they are offset by changes elsewhere. The most striking example of this is New Mexico that would have seen larger increases in residential land per person than the 13.9% increase actually recorded, if its fast growing population and decreasing household size, had not been more than offset by marked decreases in the amount of residential land per household.

5. Metropolitan areas

Having studied the relative contributions of changing demographics versus changes in residential land per household for individual states, it is natural to repeat the exercise for individual metropolitan statistical areas (MSA's).[13] Table 3 shows levels and changes in land use and population for all MSA's with a 1992 population over one million, while table 4 shows the results of the decomposition.

[12] To calculate the implied decrease in the amount of residential land, one reads off the 18.8% increase in residential land for DC from table 1 and multiplies it by the -170.2% contribution of differential changes in states' population read off from table 2.

[13] Since metropolitan areas do not cover the entire land area of the United States, we cannot calculate a decomposition of US changes as the sum of MSA-level decompositions like we did for US states.

Table 3: MSA-level land use and demographic changes 1976–92

Metro area	% growth residential land 1976–92	% growth residential land per person 1976–92	% growth population 1976–92	% growth household size 1976–92	residential land per person 1976 (sq. meters)	population 1976 (millions)	household size 1976 (people)	% open space within 1 km. of 1976–92 development
Atlanta	77.1	14.8	54.2	−10.5	322.43	2.05	3.01	63.0
Boston	51.7	41.3	7.3	−10.7	312.78	5.31	3.00	67.5
Buffalo	53.4	66.8	−8.0	−13.5	202.38	1.30	2.96	64.9
Charlotte	48.5	10.7	34.1	−12.7	547.40	0.91	3.01	67.9
Chicago	40.2	33.7	4.9	−7.9	224.13	8.08	3.01	55.2
Cincinnati	30.6	18.5	10.2	−11.2	327.00	1.69	2.99	66.4
Cleveland	19.0	22.5	−2.9	−12.5	314.37	2.99	2.96	60.3
Columbus	34.1	14.8	16.9	−12.2	279.84	1.20	2.96	57.5
Dallas	44.7	−6.4	54.7	−7.9	482.75	2.75	2.92	51.0
Denver	66.7	24.8	33.6	−12.0	356.43	1.58	2.87	43.0
Detroit	24.5	24.6	−0.1	−12.6	286.11	5.28	3.07	61.0
Greensboro	31.5	9.3	20.3	−14.5	611.83	0.91	2.95	69.6
Hartford	92.1	78.9	7.4	−12.1	293.67	1.05	3.00	53.7
Houston	80.4	21.9	48.0	−6.7	350.82	2.68	3.00	48.1
Indianapolis	38.7	24.0	11.8	−12.1	346.40	1.28	2.95	62.8
Kansas City	41.5	23.8	14.3	−9.5	369.96	1.42	2.86	50.9
Los Angeles	39.1	−0.9	40.4	4.0	235.28	10.73	2.87	57.3
Memphis	77.7	55.1	14.6	−12.7	339.32	0.90	3.14	38.1
Miami	53.8	10.4	39.2	−2.6	319.73	2.40	2.70	34.1
Milwaukee	46.6	40.2	4.5	−11.2	285.82	1.57	2.99	59.5
Minneapolis-St. Paul	60.5	28.9	24.6	−11.9	345.35	2.11	2.99	47.2
Nashville	24.1	−5.4	31.2	−12.4	428.73	0.79	2.98	68.2
New Haven	47.4	39.6	5.6	−10.8	330.51	1.56	3.00	55.4
New Orleans	45.3	37.8	5.4	−11.3	266.96	1.24	3.07	49.3
New York	35.2	31.2	3.0	−5.3	225.27	17.59	2.90	52.2
Norfolk	20.9	−8.5	32.1	−13.0	363.96	1.13	3.22	48.9
Orlando	119.1	17.1	87.1	−8.9	637.07	0.70	2.88	49.2
Philadelphia	39.5	32.7	5.1	−10.1	252.62	5.68	3.02	58.3
Phoenix	65.3	−5.8	75.6	−10.4	363.54	1.37	2.97	33.3
Pittsburgh	24.7	35.3	−7.8	−14.0	243.37	2.62	2.92	79.2
Portland	2.0	−24.0	34.2	−6.7	432.52	1.43	2.78	69.0
Rochester	63.9	56.6	4.7	−11.6	223.97	1.04	3.02	68.6
Sacramento	70.0	3.7	63.9	−5.9	374.79	0.97	2.83	54.4
Salt Lake City	25.6	−11.4	41.7	−5.9	370.42	0.80	3.28	53.0
San Antonio	39.1	3.3	34.6	−11.6	401.57	1.02	3.25	49.0
San Diego	43.9	−8.8	57.8	−4.6	246.87	1.64	2.95	58.5
San Francisco	42.4	13.0	26.0	−2.8	269.30	5.12	2.77	53.2
Seattle	12.4	−23.3	46.6	−9.1	549.04	2.14	2.82	70.1
St. Louis	29.2	23.6	4.6	−11.6	271.49	2.43	2.98	64.0
Tampa	80.0	22.5	47.0	−7.2	565.70	1.45	2.56	46.9
Washington-Baltimore	23.5	1.8	21.3	−10.3	274.27	5.72	3.00	62.2

Table 4: MSA-level decomposition of the growth in residential land 1976–92

Metro area	% of the growth in residential land 1976–92 accounted for by				
	changes in US population	differential changes in MSAS' population	changes in MSAS' residential land per household	changes in MSAS' household sizes	interactions
Atlanta	25.4	44.9	3.6	15.2	10.8
Boston	37.9	−23.8	50.8	23.1	11.9
Buffalo	36.7	−51.7	82.9	29.2	2.9
Charlotte	40.5	30.0	−6.9	30.0	6.5
Chicago	48.8	−36.6	57.7	21.2	9.0
Cincinnati	64.1	−30.6	16.9	41.3	8.3
Cleveland	103.5	−118.9	38.2	75.2	2.0
Columbus	57.4	−8.1	2.4	40.6	7.6
Dallas	43.8	78.5	−30.9	19.2	−10.5
Denver	29.4	20.9	14.7	20.5	14.5
Detroit	80.2	−80.7	36.5	58.8	5.1
Greensboro	62.2	2.3	−20.6	53.7	2.5
Hartford	21.3	−13.3	62.2	14.9	14.9
Houston	24.4	35.4	17.1	8.9	14.3
Indianapolis	50.7	−20.1	23.4	35.5	10.6
Kansas City	47.3	−12.9	29.2	25.2	11.2
Los Angeles	50.2	53.1	7.7	−9.8	−1.3
Memphis	25.2	−6.5	45.5	18.8	17.0
Miami	36.5	36.5	14.2	4.9	8.0
Milwaukee	42.1	−32.4	52.5	27.2	10.6
Minneapolis-St. Paul	32.4	8.2	22.4	22.2	14.7
Nashville	81.4	48.0	−70.9	58.5	−17.0
New Haven	41.3	−29.5	51.6	25.7	11.0
New Orleans	43.3	−31.3	49.3	28.0	10.8
New York	55.8	−47.2	68.8	16.0	6.6
Norfolk	93.9	59.9	−97.8	71.7	−27.7
Orlando	16.5	56.7	5.7	8.2	13.1
Philadelphia	49.6	−36.6	48.8	28.5	9.7
Phoenix	30.0	85.7	−24.0	17.8	−9.6
Pittsburgh	79.3	−110.8	66.1	65.8	−0.4
Portland	988.8	733.8	−1467.4	363.9	−519.1
Rochester	30.7	−23.4	60.1	20.6	12.0
Sacramento	28.0	63.2	−3.4	8.9	3.2
Salt Lake City	76.6	86.2	−64.7	24.4	−22.5
San Antonio	50.2	38.3	−22.1	33.6	0.0
San Diego	44.6	87.0	−29.6	10.9	−13.0
San Francisco	46.2	15.1	23.2	6.8	8.7
Seattle	157.8	217.5	−243.9	80.6	−112.0
St. Louis	67.1	−51.4	31.7	44.8	7.8
Tampa	24.5	34.2	17.0	9.8	14.5
Washington-Baltimore	83.5	7.0	−36.7	48.8	−2.5

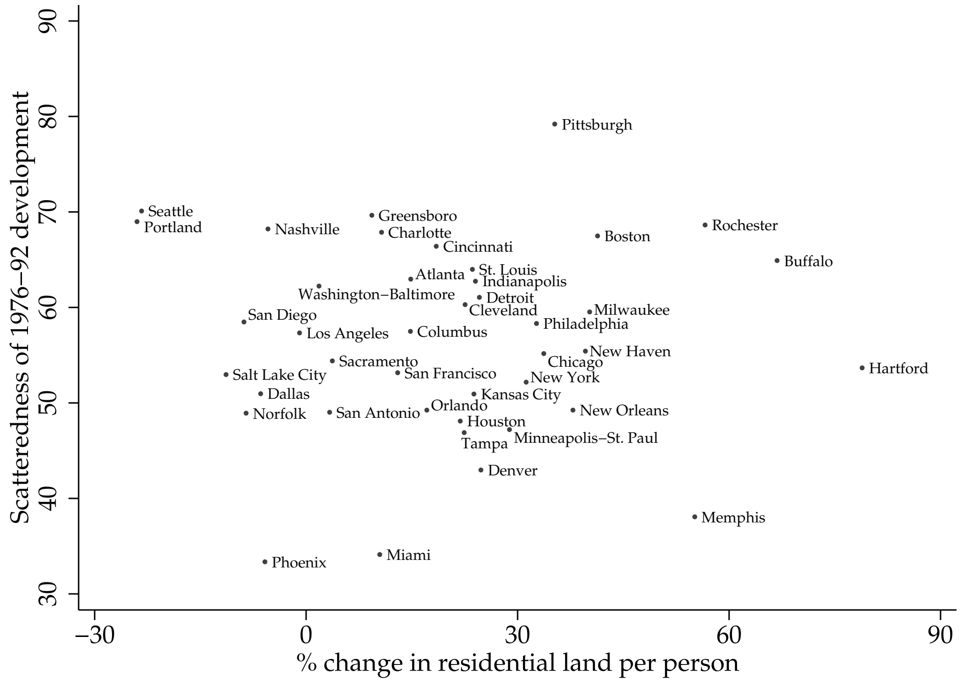

Figure 1: The scatteredness of development against the growth in residential land per person

As with the results for individual states, there is a large degree of heterogeneity across individual MSA's. The results for Portland are most striking. Table 3 shows that residential land in Portland grew at only 2% over the period, the lowest rate of all MSA's included in the table. Turning to table 4 we see that US average rates of population growth would have seen Portland residential land increase by nearly 20% (the 988.8% contribution of changes in US times the 2% increase in residential land from table 3), with its faster differential rate of population growth contributing a similar additional percentage increases. Falling household sizes would have exacerbated these population changes and contributed to a further 7 percentage point increase in the amount of residential land. That this did not happen is down to the huge offsetting change in the amount of land per household which, everything else equal, would have decreased the amount of residential land by nearly 30% over the period. Of course, everything else was not equal and the overall increase was the 2% that we mentioned at the start of this example. Other MSA's were much less unusual. Minneapolis, in particular, is the closest we get to a 'representative' city.

The term 'urban sprawl' is commonly used to describe rapid urban expansion that outpaces population growth, but also to characterize development that is scattered over previously undeveloped areas as opposed to filling in gaps in already built-up areas. These two dimension of sprawl are completely different and should not be mixed up. To emphasize the difference, the last column of table 3 reports the index of residential sprawl or 'scatteredness' developed in Burchfield *et al.* (2006). This index reports the mean share of undeveloped land in the square kilometer surrounding any residential development in the MSA. As this number increases, houses are separated from each other by more undeveloped land.

Figure 1 shows a scatter plot of the scatteredness of 1976–92 development against the change in the amount of residential land per person for MSA's with a 1992 population over one million. The figure illustrates that there is no apparent relationship between the extent to which residential land has outpaced population growth and the scatteredness of recent residential development. Burchfield *et al.* (2006) and Glaeser and Kahn (2004) have also found that different dimensions of 'urban sprawl' tend not to be highly correlated. Our finding reinforces this conclusion.

Comparisons of scatteredness and residential land per person for particular cities are also interesting. While the decomposition of Portland's land consumption (table 4) shows clear evidence that its famous land use controls are binding, residential land per person and the scatteredness of residential development are both distinctly higher in Portland than in any of the four California MSA's listed in table 3, Los Angeles, Sacramento, San Diego and San Francisco. In addition, while development in each of Florida's major MSA's, Orlando, Tampa and Miami, is less scattered than all of the major California MSA's, residential land per person in the Florida cities is generally much higher than in the California cities.

6. Conclusions

Our decompositions reveal a much more complex picture than is often implicitly assumed in discussions about the determinants of urban expansion. In particular, increasing per-household land use, the factor that receives the most attention in discussions of this topic, only contributed about 25% of the increase in residential land in the United States during our study period. Increasing population, falling household size and the shift of population across states all made significant contributions to the increase in residential land. The latter two components in particular have not yet received the attention they deserve.

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Appendix A. A note on decompositions

A central issue concerning the use of decompositions is that there are a large number of possible decompositions that one could perform, a fact that is well known in the literature (Rose and Casler, 1996, Oosterhaven and van der Linden, 1997, Dietzenbacher and Los, 1998). For example, in the text, we decompose the change in the total amount of residential land in the United States between 1976 and 1992 into three distinct components:

$$L^{92}_{\text{US}} - L^{76}_{\text{US}} = P^{92}_{\text{US}}\, l^{92}_{\text{US}} - P^{76}_{\text{US}}\, l^{76}_{\text{US}} = (P^{92}_{\text{US}} - P^{76}_{\text{US}})\, l^{76}_{\text{US}} + P^{76}_{\text{US}}\, (l^{92}_{\text{US}} - l^{76}_{\text{US}}) + (P^{92}_{\text{US}} - P^{76}_{\text{US}})(l^{92}_{\text{US}} - l^{76}_{\text{US}})\,. \tag{A1}$$

We could, alternatively, have decomposed the change as follows:

$$L_{\text{US}}^{92} - L_{\text{US}}^{76} = P_{\text{US}}^{92}\, l_{\text{US}}^{92} - P_{\text{US}}^{76}\, l_{\text{US}}^{76} = (P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{92} + P_{\text{US}}^{92}\, (l_{\text{US}}^{92} - l_{\text{US}}^{76}) - (P_{\text{US}}^{92} - P_{\text{US}}^{76})(l_{\text{US}}^{92} - l_{\text{US}}^{76})\ . \tag{A2}$$

Mathematically, there is no reason to prefer the former over the latter. However, the decomposition that we use in the text has the desirable property that the interpretation of the terms is more intuitive. For example, in the text, the first component tells us how much the total amount of residential land in the US would have increased in the hypothetical case that US population had grown as it did over the period 1976–92, but that US residential land per person had remained constant at its 1976 level, l_{US}^{76}. The first component of the alternative decomposition tells us how much the amount of residential land in the US has increased because US population grew as it did over the period 1976–92 with US residential land per person at its 1992 level. In some sense, both these components give a measure of the contribution of population growth to developed land, but the former provides an answer to the question "what would have happened if we had prevented the increase in land use per person over the period?" which appears to be the main focus of interest in both the academic and policy debates. A similar argument applies for the second component representing the change in land use per capita.

A second issue relates to whether or not to report an interaction term. An alternative would be to use only two terms as follows:

$$L_{\text{US}}^{92} - L_{\text{US}}^{76} = P_{\text{US}}^{92}\, l_{\text{US}}^{92} - P_{\text{US}}^{76}\, l_{\text{US}}^{76} = (P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{76} + P_{\text{US}}^{92}\, (l_{\text{US}}^{92} - l_{\text{US}}^{76})\ . \tag{A3}$$

Note that, relative to equation (A1), the change in land use is multiplied by the end of period population rather than the beginning of period. As before, the first term captures the contribution of the increase in population. Now, however, the second term captures the effect of increasing land use for the original population *and* the fact that additional population also consumes land at the new higher land use per person. That is the second term absorbs the contribution of the interaction term. One could call this total the "contribution of increased land use". Alternatively, one could take (A1) and use end of period land use rather than beginning of period land use in the first term and allow that to absorb the contribution of the interaction term:

$$L_{\text{US}}^{92} - L_{\text{US}}^{76} = P_{\text{US}}^{92}\, l_{\text{US}}^{92} - P_{\text{US}}^{76}\, l_{\text{US}}^{76} = (P_{\text{US}}^{92} - P_{\text{US}}^{76})\, l_{\text{US}}^{92} + P_{\text{US}}^{76}\, (l_{\text{US}}^{92} - l_{\text{US}}^{76})\ . \tag{A4}$$

One could then call this total "the contribution of increased population". As the decision is arbitrary, and as moving from the three term decomposition (including interaction) to the two term (excluding interaction) only involves adding components, we prefer to report the decompositions including interactions.

A third issue relates to the fact that one could change the ordering of the decompositions. Again, our justification here for choosing our specific ordering over any other is that we focus on decompositions that highlight demographic and land use factors that are particularly meaningful and easy to interpret in light of current discussions about changing land use.