The Determinants of Urban Sprawl: Theory and Estimation

Joseph S. DeSalvo
Department of Economics
University of South Florida—Tampa
4202 E. Fowler Avenue CMC342
Tampa, FL 33620-5700
E-Mail: jdesalvo@usf.edu
Phone: 813-974-6388

Qing Su
Department of Economics and Finance
Northern Kentucky University
Nunn Drive, BC 338
Highland Heights, KY 41099
E-Mail: suq1@nku.edu
Phone: 859-572-6590

January 26, 2018

(Forthcoming in the *International Journal of Urban Sciences*)

ABSTRACT. We argue that a well-articulated theory, by which we mean a set of structural equations equal in number to the endogenous variables and from which testable hypotheses may be drawn, should be the basis for any effort to estimate the determinants of urban sprawl. Without such a theory, it is not possible to know why a particular determinant "works" to explain a particular definition of urban sprawl, nor is it possible to know whether any particular policy to combat sprawl, however defined, will be successful in achieving that objective without also creating other, possibly adverse, effects. To illustrate our argument, we contrast Burchfield, et al. (2006), which is not based on a well-articulated theory, with the urban monocentric model (Brueckner, 1987), which is a well-articulated theory.

The Determinants of Urban Sprawl: Theory and Estimation

I. Introduction

Nechyba and Walsh (2004, p. 296) conclude their survey of urban sprawl as follows: "Cities and suburbs are complicated economies, and most policies are likely to give rise to similarly complicated tradeoffs. Nevertheless, it is difficult to see how appropriate policy responses to growing concerns about the sprawl of U.S. cities can be formulated without a clearer understanding of these underlying tradeoffs." This paper argues that empirical work drawn from a well-articulated theory contributes to such a clearer understanding of underlying tradeoffs.

Various definitions of sprawl have been offered. Glaster, et al. (2001, p. 681), propose "eight distinct dimensions of land-use patterns: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity." Their definition of sprawl is a "condition of land use that is represented by low values on one or more of these dimensions." They do not provide empirical analysis of the determinants of these eight dimensions of sprawl, for their goal is, as their subtitle suggests, to define and measure an elusive concept.

Malpezzi and Guo (2001) and Wassmer (2008) have regressed various measures of sprawl on a consistent set of regressors, while Burchfield, et al. (2006), among others, have dealt with only a single measure. These authors do not provide a theory of the factors that determine their measures of sprawl. Instead, they draw their explanatory variables from various theories, empirical analyses, and plausible conjectures.

We argue that any effort to estimate the determinants of urban sprawl should be based on a well-articulated theory, by which we mean a set of structural equations equal in number to the endogenous variables and from which testable hypotheses may be drawn. Such a theory determines which variables are endogenous and which are exogenous as well as the relationship among the endogenous variables and the exogenous variables. From a theoretical point of view, these relationships provide an "explanation" of how any given exogenous variable affects the endogenous variables. From an empirical point of view, if sufficient data are available, one or more of the statistically identifiable structural equations can be estimated. Alternatively, one can estimate one or more of the reduced form equations of the model.

Without such a theory, it is not possible to know, either theoretically and empirically, why a particular determinant "works" to explain a particular definition of urban sprawl, nor is it possible to know how any particular policy to combat sprawl, however defined, will achieve that objective without creating unintended consequences. To illustrate our argument, we contrast Burchfield, et al. (2006), which is not based on a well-articulated theory, with the urban monocentric model (Brueckner, 1987), which is a well-articulated theory. It is our hope that this contrast encourages future researchers to base their empirical work on urban sprawl on well-articulated theories of their various measures of sprawl. If our hope is realized, we think we will have made an important contribution of urban science.[1]

We begin with an exposition of the urban monocentric model, which concludes with the comparative static effects of the exogenous variables on the endogenous variables, from which we draw the determinants of urban sprawl, as measured by the spatial size of the urban area. This is followed by an exposition of the reasons offered by Burchfield, et al. (2006), for their choice of determinants of urban sprawl, which they define as an index of the amount of undeveloped land around an average dwelling.[2] Although, as noted earlier, there exists research on several different definitions and determinants of urban sprawl, we choose Burchfield, et al. (2006), because the authors have made their data set available (http://diegopuga.org/data/sprawl).

We proceed next to the empirical analysis. To provide a baseline, we start by replicating column 4 in Table IV of Burchfield, et al. (2006, p. 616), which is a cross-section regression of their sprawl index on their explanatory variables. What we find is consistent with their results. Next, we regress their sprawl index on explanatory variables of the urban monocentric model. The results are poor. When we combine these variables with those of Burchfield, et al. (2006), the results are only moderately better. We conclude that the urban monocentric model's variables contribute little to the explanation of sprawl as defined by Burchfield, et al. (2006).

The next step is to see if the Burchfield, et al. (2006), variables explain the spatial size of the urban area. As a baseline, we regress the spatial size of the urban area on the urban monocentric model's variables. The results are good and consistent with those of other researchers. When we regress urban spatial size on the Burchfield, et al. (2006), variables, however, we get poor results.[3]

It is no surprise that different measures of sprawl have different determinants. Without a theory, however, there is no way to determine why a researcher's choice of determinants works with that researcher's sprawl measure, much less why they might or might not work for a different measure. In our case, we cannot know why the Burchfield, et al. (2006), explanatory variables work with their index of sprawl, especially since they claim to draw at least some of their explanatory variables from the urban monocentric model. It is clear, however, why the exogenous variables of the urban monocentric model work with its explanatory variables because there is a well-articulated theory relating the endogenous to the exogenous variables. Although neither Burchfield, et al. (2006), nor Brueckner (1987) discuss anti-sprawl policies, without a well-articulated theory, it is unclear whether such policies would achieve the presumably desired result of retarding or reversing sprawl, while avoiding unintended consequences. We have some additional comments on this last point in our conclusion.

II. The Urban Monocentric Model

To illustrate what we mean by a "well-articulated" theory, we present the urban monocentric model and summarize its comparative static results, drawing on Brueckner (1987). This analysis provides the exogenous variables of the model and their expected qualitative effects on the endogenous variables.

The Household Sector

The urban monocentric model has a predetermined center, the central business district (CBD), to which all travel is made for work and other activities. Travel is along radial and dense transportation routes between the household's residential location and the CBD. A household's quasi-concave utility function, $v(c,q)$, is defined over housing consumption, q, which is a normal good, and non-housing, non-transportation expenditures, c. The household spends its exogenous income, y, on housing; non-housing, non-transportation goods; and transportation. Round-trip transportation cost is determined by distance between home and CBD, x, and the round-trip cost per mile of travel, t. Thus, the problem of the household is to maximize $v(c,q)$ subject to $y = c +$

$pq + tx$, where p is the price per unit of housing. Upon eliminating c, this problem gives rise to the first-order condition

$$\frac{v_q(y - tx - pq, q)}{v_c(y - tx - pq, q)} = p\,, \tag{1}$$

where the price of the numéraire good, c, is normalized to unity, and subscripts indicate partial differentiation with respect to the subscripted variable. Equation (1) says that at the constrained maximum, the marginal rate of substitution of housing for money is equal to the price of housing. All urban households are assumed identical with respect to utility function and income. Consequently, for them to be in spatial equilibrium in which no one wants to move, it is necessary for the following condition to hold:

$$u = v(y - tx - pq, q)\,, \tag{2}$$

where u is the urban-area-wide spatial equilibrium utility level. The numéraire good plays no role in the analysis and is therefore ignored.

The Housing-Production Sector

Housing, H, is produced via a constant-returns-to-scale concave production function defined over land, L, and non-land inputs, N, as follows:

$$H = H(L, N)\,,$$

but because of constant returns to scale, this may be rewritten as

$$\frac{H}{L} = H\left(\frac{N}{L}, 1\right) = H(S, 1) = h(S)\,,$$

where S is the ratio of non-land to land, called structural density. Profit per unit of land is given by

$$\pi = ph(S) - iS - r\,,$$

where p is housing price, as before; i is the rental rate of the non-land input; and r is the rental rate of the land input. The spatial equilibrium condition for housing producers is that land rent absorb profit, so all housing producers are equally well off at any location:

$$r = ph(S) - iS\,. \tag{3}$$

Maximizing rent per unit of land produces the following first-order condition:

$$ph'(S) = i\,, \tag{4}$$

which says that the marginal revenue product of structural density equals the rental rate of the non-land input at the profit-maximizing *S*.

Boundary and Population Conditions

To complete the model requires an urban area boundary condition and an urban population condition. The urban boundary condition is

$$r\left(\bar{x}\right)=r_A, \tag{5}$$

where $\bar{x}$ is the distance from the CBD at which the urban area ends and the rural area begins and r_A is rural land rent (or the opportunity cost of land). Urban households outbid rural land users between the CBD and $\bar{x}$, while rural land users outbid urban land users beyond $\bar{x}$. The urban population condition is

$$\int_0^{\bar{x}} \delta x \frac{h(S)}{q} dx = P , \tag{6}$$

where δ is the number of radians in a circular urban area available for urban residential use and *P* is the urban population, which is assumed the same as the number of urban households. The quotient is population density since it is the total quantity of housing per unit of land at any given *x* divided by per-capita consumption of housing at that *x*. Integrating population density times residential land over all urban land gives total population. This condition ensures that the population of the urban area exactly fits inside the boundary of the urban area.

Closed City and Open City Solutions of the Model

Equations (1)–(6) constitute the model, but it can be solved in two ways called the “open city” and “closed city” versions. In the open city model, utility is exogenous while population is endogenous. The idea behind this is that if utility is higher in one urban area than in another, people will migrate to the first urban area from the second. This raises population and lowers utility in the first urban area while lowering population and raising utility in the second. Eventually, the utility level is the same in both urban areas—a spatial equilibrium—and migration stops. In the closed city model, population is exogenous while the spatial equilibrium utility level is endogenous. In this model, an exogenous increase in population lowers utility in the urban area, but no out-migration occurs. Instead, households establish a spatial equilibrium by moving within the urban area until they all have the same utility level. It is sometimes said that the closed city model is a “short-run” model, while the open city model is a “long-run” model. Since all of the empirical articles we discuss below use the closed city version, we shall present comparative static results for that version only.

Comparative Static Analysis

Comparative static analysis of this model is quite complicated and has been provided by Brueckner (1987) for both the closed city and open city versions. Table 1 summarizes the results for the closed city model. Following Brueckner (and all other researchers), we suppress the variables for the radians of available residential land, δ, and the price of the non-land input, i. Equilibrium housing consumption, q, housing price, p, structural density, S, and land rent, r, are functions of distance from the CBD, x, and the latter three pivot at the distance x' due to changes in income and transportation cost, while the effect on q beyond x' is ambiguous.[4]

TABLE 1
Comparative Statics: Closed City Model, Brueckner (1987)

Exogenous variables		Endogenous variables					
		q	p	S	r	$\bar{x}$	u
x		+	–	–	–	*NC*	*NC*
P		–	+	+	+	+	–
r_A		–	+	+	+	–	–
y	$x < x'$	+	–	–	–	+	+
	$x > x'$	?	+	+	+	+	+
t	$x < x'$	?	+	+	+	–	–
	$x > x'$	+	–	–	–	–	–

Notes: Effects due to δ and i are omitted. *NC* means "no change.

The effect of exogenous variables on the size of the urban area, $\bar{x}$, may be seen from Table 1. An increase in population increases the demand for housing, which drives up housing price and land rent. At the urban-rural boundary, urban households now outbid rural households and the urban area expands. In contrast, a rise in rural land rent allows rural households to outbid urban households for land at the urban fringe, and the urban area contracts. An increase in income causes an increase in the demand for housing, and since housing price and land rent fall with distance from the CBD, more housing is a better buy farther out. Moving farther out raises housing price, structural density, and land rent there and lowers them closer in, indicated by the pivoting of these functions at x'. The increase in land rent farther out allows urban households to outbid rural households at the urban fringe, thereby expanding the urban area. An increase in transport cost has effects opposite those of an income increase because an increase in transport cost lowers income available for all non-transportation expenditures, including housing.

To the extent that the small number of explanatory variables does a good job of empirically supporting the theory, the previous paragraph illustrates how a well-articulated theory helps explain empirical results. We reserve for later some comments on the use of theory in policy formation.

Tests of the Urban Monocentric Model's Implications for Urban Spatial Size

Brueckner and Fansler (1983) initiated empirical research on the determinants of urban spatial size in the urban monocentric model. After a long lag, additional work began to appear, starting with McGrath (2005). Since then seven additional articles have appeared (Song and Zenou, 2006; Deng, et al., 2008; Spivey, 2008; Su and DeSalvo, 2008; Geshkov and DeSalvo, 2012; Paulsen, 2012; and Oueslati, Alvanides, and Garrod, 2015). Some of these articles are essentially tests of the basic model with different data sets and additional variables, and some are extensions of the model. Table 2 provides a summary of these articles. Without going into a detailed review of the articles summarized in Table 2, we think it is clear that the urban monocentric model is robust to estimation method, estimating equation, proxies for theoretical variables, sample size, and the definition of urban area. Extensions of the basic model to include property taxes, transportation subsidies, and land-use controls have also held up well to estimation.

III. The Burchfield, et al. (2006), Explanatory Variables[5]

The authors divide their Section IV, "Urban Economic Theory and the Causes of Sprawl," into three parts: (IV.A.) the monocentric city model and its generalizations, (IV.B.) when space is not a featureless plain, and (IV.C.) political geography. Each subsection provides their rationales for the regressors they choose.

The Monocentric Model and Its Generalizations[6]

In Subsection IV.A., after a brief statement of the main assumptions of the urban monocentric model, the authors note that U.S. urban areas have become less centralized over time, and they follow this with a brief discussion of various contributions of polycentric urban models, with an emphasis on the role of agglomeration economies in determining subcenters. They conclude with a discussion of general equilibrium models of systems of cities, again with an emphasis on the role of agglomeration economies (Burchfield, et al., 2006, pp. 608–609). From this discussion, they draw the following hypotheses regarding their explanatory variables.

"...a crucial implication of the monocentric city model is that *cities specializing in sectors where employment tends to be more concentrated will be more compact*" (p. 609). Their proxy for this variable is centralized-sector employment in 1977. Their citations justifying this variable are Fujita and Thisse (2002), Glaeser and Khan (2001), and Henderson (1987). The first of these presents a series of models leading to polycentricity. There is no distinction among firms' employment concentrations. The second of these is a largely empirical work, from which Burchfield, et al. (2006), partially justify their hypothesis. Finally, they draw on Henderson (1987), saying that cities that specialize in products with stronger agglomeration economies have more expensive land, which results in substitution of capital for land, implying more compact development. It is difficult, however, to find justification for this hypothesis in Henderson (1987). First, Henderson's model is aspatial: "We will utilize a specific functional form model, without explicit spatial dimensions" (Henderson 1987, p. 930). Instead, Henderson associates population with the spatial dimension of an urban area (Henderson 1987, p. 932). Since greater population produces greater agglomeration

TABLE 2
Determinants of Urban Spatial Size

Source	Independent Variables					Data	Reported Estimation[a]	*n*	R^2
	P	*y*	r_A	*t*	*Others*				
Brueckner & Fansler (1983)	Population**	Median Household Income**	Median Agricultural Land Value/Acre**	% Using Transit % Owning Auto(s)	-	1970 Cross Section (UA)	Box-Cox OLS[b]	40	0.80
McGrath (2005)	Population***	Per-Capita Income*	Mean Agricultural Land Value/Acre**	Transport Cost Index**	Time Trend***	1950–90 Pooled (UA)	OLS	153	0.88
Song & Zenou (2006)	Population***	Median Household Income***	Median Agricultural Land Value/Acre	Government Expenditure/ Commuter***	Property Tax***	2000 Cross Section (UA)	OLS	448	0.85
Deng et al. (2008)	Population***	GDP***	Agricultural Investment***	Highway Density***	*c*	1987–2000 Pooled (County)	OLS	4,482	0.81
Spivey (2008)	Population***	Median Family Income***	Mean Agricultural Land Value/Acre*	Congestion Costs***	Subcenters** Sea Coast or Border	2000 Cross Section (UA)	Box-Cox	85	-
Su & DeSalvo (2008)	Households***	Median Household Income***	Mean Agricultural Land Value/Acre	Fare/ Passenger-Mi.*** Fuel Tax/ Vehicle-Mi.**	Bus Subsidy** Auto Subsidy*** *d*	2000 Cross Section (UA)	OLS 2SLS	93	0.84
Geshkov & DeSalvo (2010)	Households***	Mean Household Income***	Mean Agricultural Land Value/Acre**	Government Transport Expenditure/User	Dummy Variables for Land-Use Controls	2000 Cross Section (UA)	OLS	182	0.73
Paulsen (2012)	Population***	Median Household Income***	Mean Agricultural Land Value/Acre	-	-	1980–2000 Panel (MA)	OLS Fixed Effects	329	0.694
Oueslati, Alvanides & Garrod (2015)	Population***	GDP/capita***	Agricultural Value Added/ Hectare***	Highway Density***	Regional Dummies**, ***	1990, 2000, 2006 Panel (LUZ)	OLS Fixed Effects	677	0.301

[a]If more than one estimation technique is used, we report the one giving the best results. [b]Same results for each. [c]GDP shares in industry and services, urban area in 1988, terrain ruggedness variables, rainfall, temperature, distance to a seaport, distance from provincial capital. [d] % using transit, various auto fees, income tax, intergovernmental transfers, and various IVs.
Notes: In all but one case (McGrath 2005), *k** is proxied by land area. McGrath imputes the urban area radius from land area. UA = Urbanized Area, MA = Metropolitan Area, LUZ = Large Urban Zone, OLS = Ordinary Least Squares, 2SLS = Two-Stage Least Squares. ***Significant at 1-percent level. **Significant at 5-percent level. *Significant at 10-percent level.

economies, then cities with stronger agglomeration economies should be larger (Henderson, 1987, p. 932), i.e., less compact. It seems that Burchfield, et al. (2006), have combined logic from the monocentric model with that of Henderson (1987) to reach their conclusion.

"A second prediction arising from the monocentric city model is that *lower transport costs within a city will result in more dispersed development*" (p. 609). Their proxy for this variable is streetcar passengers per capita. Although not previously used, this proxy follows directly from the monocentric model of Section II.

"...c*ities that have been growing faster will tend to experience less sprawl*" (p. 610). Their proxy for this variable is mean decennial percentage population growth from 1920 to 1970. "...when leapfrogging occurs, *leapfrogging is greater the greater the uncertainty about future urban growth*" (p. 610). Their proxy for this variable is the standard deviation of decennial population growth from 1920 to 1970. Both of these variables are attempts to capture the effects of leapfrogging development, which they claim correctly is not part of the urban monocentric model. For the first of these, they cite Turner (2005), who postulates an amenity value for open space. Households prefer open space but worry that development might diminish it. Thus faster growth retards sprawl. The second of these is concerned with the uncertainty associated with long lags between the decision to build and the completion of construction. An increase in this uncertainty may lead to greater leapfrogging development. The main citation is Bar-Ilan and Strange (1996). Neither of these conjectures has yet been incorporated into a fully articulated model of urban structure.

When Space Is Not a Featureless Plain

Subsection IV.B. recognizes the reality that space is not a featureless plain, which the authors claim is contrary to the assumption of the monocentric model. They specifically note that the presence of aquifers may allow households to sink their own water wells, thereby avoiding the necessity of connecting to a public water system, which may induce sprawl. "*...wherever aquifers underlie the urban fringe, household water can be obtained without the large increasing returns associated with public water systems and this facilitates scattered development*" (p. 612). Their proxy for this variable is the percentage of urban fringe area that overlies aquifers. They also discuss physical barriers, such as mountains and hilly terrain, concluding, "*...we would expect rugged terrain to naturally encourage scattered development*" (pp. 612–613). Their proxy for this variable is the range in elevation at the urban fringe. "In contrast, *high mountains in the urban fringe are likely to make development more compact*" (p. 613). Their proxy for this variable is a terrain ruggedness index in the urban fringe. Finally, they introduce climatic factors affecting location, concluding "...that *cities with a pleasant temperate climate experience more sprawl*" (p. 613). They provide two proxies for this variable: mean cooling degree-days and mean heating degree-days.

The final variable under this category is suggested by Glaeser, Kolko, and Saiz (2001), bars and restaurants per capita. "Peoples' choice of residence might be driven by their leisure activities as well as by their employment. If employment centralization tends to limit the amount of sprawl, perhaps centralized amenities could play a similar role" (p. 617).

Choice of these variables is not suggested by any theory. Nevertheless, Burchfield, et al. (2006), provide plausible conjectures for their variables in an effort to counteract the urban monocentric model's featureless-plain assumption. Although they do not note it, the urban monocentric model can deal with aspects of urban areas that do not fit the assumption of a featureless plain.

The variable δ, the radians of a circular urban area available for residential development, accounts for the reduction in supply of developable land due to the kinds of topographical features noted by Burchfield, et al. (2006). No one, however, has used that variable in empirical work.

Political Geography

Subsection IV.C. introduces political geography, from which the authors draw two hypotheses: "*To the extent that there are unincorporated areas on the urban fringe, developers can escape municipal regulations by building outside municipal boundaries, and this facilitates sprawl*" (p. 614). Their proxy for this variable is the percentage of urban fringe land that was incorporated in 1980. Although Burchfield, et al. (2006), cite academic work on zoning, their hypothesis is drawn from their empirical analysis of St. Louis' incorporated and unincorporated land, in which a disproportionate share of development occurs on unincorporated land.

Their final hypothesis is that "*...sprawl should be more prevalent where local taxpayers pay a smaller share of local government expenses*" (p. 614). Their proxy for this variable is the amount of intergovernmental transfers as a percentage of local revenues in 1967. The authors cite Tiebout (1956) in this context, but their hypothesis is not drawn directly from Tiebout's work. Instead, they note that if local public services are more costly to provide in areas with scattered development, then aversion to sprawl should be lessened the more the cost of such services is financed by intergovernmental transfers.

In summary, the choice of explanatory variables made by Burchfield, et al. (2006), is based on a combination of theories, empirical analyses, and plausible conjectures. Their choice of explanatory variables is not drawn from a theory of sprawl that generates empirically testable hypotheses about the theory's exogenous variables, such as the urban monocentric model does.

IV. Empirical Analysis

The empirical analysis proceeds in two steps, the results of which are shown in Table 4 for the Burchfield, et al. (2006), sprawl index and Table 5 for sprawl as measured by the spatial size of the urban area. In each step, as a baseline, we first regress each sprawl measure on the preferred choice of explanatory variables. Next, we run a regression with only the alternative set of explanatory variables to see if they are able to explain the measure of sprawl. Finally, we include both sets of explanatory variables to see if that makes any improvement. This is an attempt to see if there is a single underlying theory to explain both sprawl measures. We conclude there is not. This conclusion buttresses our contention that any measure of sprawl should be drawn from an explicit theory developed for that measure. We have discussed the explanatory variables of Burchfield, et al. (2006), because the justification for these variables essentially constitutes the authors' "theory." We have not yet done so for the urban monocentric model's endogenous and exogenous variables, to which we now turn.

The "Standard" Urban Monocentric Model Variables

What we call the "standard" urban monocentric model variables are those variables meant to proxy the four exogenous variables of that model, P, y, r_A, and t, as well as the endogenous variable, the spatial size of the urban area, for which Table 3 gives descriptive statics.[7]

TABLE 3
Descriptive Statistics for the Urban Monocentric Model Variables
277 U.S. Urbanized Areas, 1990

Variable	Unit	Mean	St. Dev	Minimum	Maximum
A (Spatial size)	Sq. Mi.	85.36	137.82	8.29	1,301
P (Number of households)	Households	212,949	530,698	19,692	6,252,033
y (Median household income)	\$/yr.	27,452	4,680	15,747	48,151
r_A (Average value of farm land)	\$/acre	1,203	763	153	5,080
t (Gasoline price)	\$/gal.	1.09	0.066	0.98	1.30

The variable A proxies the radius of the urban area, $\bar{x}$. The U.S. Bureau of the Census (1990) provides the spatial size of urbanized areas in square kilometers for total area, water area, and land area. We use land area, which we convert to square miles. Data on P and y are also from the U.S. Bureau of the Census (1992). For r_A, we use the average value of farmland per acre at the state level in 1990 (U.S. Department of Commerce 1991, Table E, p. 202). For transportation cost, t, we use average gasoline prices in 1990 for the state in which a sample urbanized area is located. The U.S. Energy Information Administration (2013) provides this variable.

We match urbanized areas with the Burchfield, et al. (2006), metropolitan areas (MAs) to obtain a sample of 277 observations for 1990.[8] Since the Burchfield, et al. (2006), sprawl index is for 1992, we use 1990 data to reduce the potential bias created when observations are measured at different times.

Effect of Explanatory Variables on the Burchfield, et al. (2006), Sprawl Index

Column 1 of Table 4 replicates the regression results in column 4 of Table IV in Burchfield, et al. (2006, p. 616). Bars and restaurants per thousand people and centralized sector employment 1977 were not statistically significant in their regression, while the rest were significant at the 10-percent level or better, and all had the expected signs. Our results are consistent with those of Burchfield, et al. (2006).[9]

Column 2 of Table 4 is a regression of the sprawl index on the "standard" urban monocentric model variables. The results are poor. All estimated coefficients have the "wrong" sign. Moreover, number of households and average value of farmland per acre not only have the wrong signs but also are statistically significant. This indicates a negative impact of greater population but a positive impact of higher farmland value on sprawl measured as the amount of undeveloped land around a typical dwelling unit.

TABLE 4
Regressions of Burchfield, et al. (2006), Sprawl Index on Standard Monocentric Model Variables with and without Burchfield, et al., Variables

Variable	1	2	3
Centralized-sector employment 1977	–0.484		–0.432
	(1.10)		(1.04)
Streetcar passengers per capita 1902	–0.029***		–0.0189**
	(3.93)		(2.24)
Mean decennial % population growth 1920–70	–0.218***		–0.177***
	(4.14)		(3.25)
Std. dev. decennial % population growth 1920–70	0.120***		0.087*
	(2.60)		(1.86)
% of urban fringe overlying aquifers	0.046***		0.044***
	(3.26)		(3.26)
Elevation range in urban fringe	–0.002**		–0.0003
	(2.05)		(0.30)
Terrain ruggedness index in urban fringe	0.231***		0.199**
	(2.70)		(2.43)
Mean cooling degree-days	–0.006***		–0.0034**
	(3.65)		(2.18)
Mean heating degree-days	–0.003***		–0.0019***
	(4.68)		(3.13)
% of urban fringe incorporated 1980	–0.349***		–0.179*
	(3.46)		(1.71)
Intergovernmental transfers as % of local revenues 1967	0.130**		0.132***
	(2.32)		(2.77)
Restaurants and bars	–3.026*		–2.840*
	(1.82)		(1.75)
ln(Number of households)		–3.883***	–2.351***
		(6.63)	(3.58)
ln(Median household income)		–3.725	1.038
		(0.88)	(0.24)
ln(Average value of farm land per acre)		5.769***	4.174***
		(6.13)	(4.40)
ln(Gasoline prices)		.473	–13.860
		(0.05)	(1.42)
Constant	80.744***	87.731**	58.144
	(7.43)	(2.25)	(1.38)
R^2	0.4248	0.2662	0.4901
N	277	277	277

The dependent variable in columns (1), (2), and (3) is the Burchfield et al. (2006) sprawl index for 1992. Numbers in parentheses are absolute *t*-values. ***, **, and * indicate significance at the 1-percent, 5-percent, and 10-percent level, respectively.

The third column of Table 4 reports results when the standard urban monocentric model variables are included in addition to the Burchfield, et al. (2006), explanatory variables. The findings are largely consistent with the Burchfield, et al. (2006), major findings except that the coefficient on elevation range in the urban fringe becomes statistically insignificant. Except for gasoline prices, the standard urban monocentric variables have the wrong signs, while number of households and average value of farmland per acre are statistically significantly wrong.

Our conclusion is that the standard urban monocentric model variables contribute little to the explanation of sprawl, as measured by the Burchfield, et al. (2006), index. This raises the question why the variables that Burchfield, et al. (2006), claim to draw from the monocentric model do so well (except for centralized center employment 1977) and why the standard urban monocentric model variables do so badly.

Our answer is that only one of the Burchfield, et al. (2006), variables–the transport-cost variable–follows directly from the urban monocentric model, while the rest are drawn from other theories, empirical analyses, and plausible conjectures. It is clear that the exogenous variables of the urban monocentric model are not determinants of sprawl as defined by Burchfield, et al. (2006). Since Burchfield, et al. (2006), do not provide a theory of that sprawl measure, there is no way to tell why the variables they choose work.

Effect of Explanatory Variables on the Spatial Size of the Urban Area

The first column of Table 5 reports OLS regression results with only the standard urban monocentric model variables. All variables, except agricultural land value, have the expected signs and are statistically significant. We find the impact of income to be nonlinear, but positive for areas with median household income above $22,026. This is consistent with the theoretical result that as incomes rise, households move farther from the CBD.

The second column of Table 5 reports the results of regressing the spatial size of urbanized areas on the Burchfield, et al. (2006), variables, but without the standard urban monocentric model variables. All of the estimated coefficients, except for that of bars and restaurants per thousand people, either have the wrong sign or are not statistically significant. Interestingly, in Burchfield, et al. (2006, p. 616), bars and restaurants per thousand people had both the wrong sign and statistical insignificance (the latter is our speculation, for Burchfield, et al. (2006), do not report the *t*-value for this variable).

It is clear from these results that the Burchfield, et al. (2006), variables do not perform well in explaining the spatial size of urban areas, despite the fact that the authors claim to base their choice of variables in part on the urban monocentric model. Also, the lower R^2 indicates that their twelve variables do not explain as much of the variation in urban spatial size as do the four variables (five regressors) of the urban monocentric model.

The third column reports regression results when both standard urban monocentric model variables and Burchfield, et al. (2006), variables are included. Inclusion of the latter set of variables does not much affect the results shown in column 1 of Table 5 for population and transportation cost, while raising the statistical significance of income. The coefficient on rural land rent becomes negative, as predicted by the theoretical model, but not statistically significant. As compared to column 2, seven variables have switched signs to those expected by Burchfield, et al. (2006). Two

TABLE 5
Regressions of Urbanized Area Spatial Size on Standard Urban Monocentric Model Variables with and without Burchfield, et al. (2006), Variables

Variable	1	2	3
Centralized-sector employment 1977		0.026	0.016
		(0.68)	(1.14)
Streetcar passengers per capita 1902		0.0057***	–0.0004
		(8.74)	(1.29)
Mean decennial % population growth 1920–70		0.019***	–0.005***
		(4.12)	(2.92)
Std. dev. decennial % population growth 1920–70		–0.0135***	0.004***
		(3.33)	(2.70)
% of urban fringe overlying aquifers		0.0012	0.0005
		(0.97)	(1.23)
Elevation range in urban fringe		0.0002**	-8.61e-6
		(2.06)	(0.24)
Terrain ruggedness index in urban fringe		–0.007	0.002
		(0.97)	(0.68)
Mean cooling degree-days		0.00005	–0.00002
		(0.37)	(0.43)
Mean heating degree-days		–0.00003	–0.00004**
		(0.63)	(2.14)
% of urban fringe incorporated 1980		0.082***	0.0235***
		(9.25)	(6.86)
Intergovernmental transfers as % of local revenues 1967		–0.002	0.005***
		(0.42)	(2.60)
Restaurants and bars		–0.454***	–0.232***
		(3.11)	(4.37)
ln(Number of households)	0.868***		0.822***
	(43.46)		(38.16)
ln(Median household income)	15.360*		22.43***
	(1.71)		(2.74)
$(\ln(\text{Median household income}))^2$	–0.765*		–1.090***
	(1.74)		(2.72)
ln(Average value of farm land per acre)	0.030		–0.042
	(0.94)		(1.34)
ln(Gasoline prices)	–1.620***		–0.959***
	(4.87)		(3.01)
Constant	–83.179*	3.091***	–120.576***
	(1.82)	(3.25)	(2.88)
R^2	0.91	0.54	0.94
N	277	277	277

The dependent variable in columns (1), (2), and (3) is ln(spatial size of urbanized area). Numbers in parentheses are absolute *t*-values. ***, **, and * indicate significance at the 1-precent, 5-percent, and 10-percent level, respectively.

variables that lost statistical significance were of the wrong sign without the standard urban monocentric model variables. Two variables have gained statistical significance.

It is clear that the Burchfield, et al. (2006), variables provide virtually no explanatory value to sprawl as measured by the spatial size of the urban area. In this case, however, we do know why the exogenous variables of the urban monocentric model work because the theory provides the reasons.

V. Conclusions

What do we learn from this exercise? First, we confirm what Burchfield, et al. (2006, p. 607), suspect: There is no reason to think that their explanatory variables, which explain well their measure of sprawl, will also explain well other measures of sprawl. Nevertheless, as already noted, some of their variables do help explain the spatial size of the urban area. We therefore conclude that urban economists should pay more attention to the types of variables used by Burchfield, et al. (2006). In fact, Deng, et al. (2008), already have, but we call for theoretical justification for their use. For example, the regression of urban spatial size on the Burchfield, et al. (2006), variables, given in column 2 of Table 5, produces a positive effect of population growth between 1920 and 1970. In contrast, the regression of urban spatial size on *both* the Burchfield, et al. (2006) variables and the standard urban monocentric model variables, given in column 3 of Table 5, produces a negative effect of population growth. Both of these conflicting results are statistically significant. This suggests to us the desirability of a dynamic extension of the urban monocentric model to incorporate population growth, which might help resolve this discrepancy. Similarly, the effect of intergovernmental transfers produces opposite signs (although the result of using only the Burchfield, et al. (2006), variables is not statistically significant). This suggests an extension of the urban monocentric model to incorporate a net-tax variable. Greater intergovernmental transfers means a lower net tax and a larger urban income, which in the urban monocentric model implies a spatially larger urban area.

Second, an exercise such as this raises the question as to what sprawl is and how best to measure it. This ground has been covered by Galster, et al. (2001), among others, e.g., Mills (1992) and Malpezzi and Guo (2001), and we do not wish to pursue it further here. Our results make it clear that researchers, not to mention the media, should be more careful in discussing the determinants of urban sprawl, which is a highly contentious issue, for the determinants seem to differ with the definition of sprawl. To their credit, Burchfield, et al. (2006), have carefully defined a measure of sprawl and have provided an interesting analysis of it. So have those who have used the urban monocentric model.

Third, and what motivated this paper, there is the methodological issue. As already noted several times, Burchfield, et al. (2006), do not provide a theory of sprawl. Instead, they draw their explanatory variables from various theories, empirical analyses, and plausible conjectures. The urban monocentric model, on the other hand, is a well-articulated theory that generates empirically testable hypotheses that have held up well to empirical analysis, and it is a model that has proven amenable to extension. In that model, it is clear how the exogenous variables explain the spatial size of the urban area, as discussed in Section II above. On the other hand, it is not clear how the Burchfield, et al. (2006), variables explain the amount of undeveloped land around an average dwelling. We think it unlikely to resolve that matter without a well-articulated theory that defines sprawl as the amount of undeveloped land around an average dwelling.

Finally, we close with some remarks on policy analysis. Although neither the Brueckner (1987) nor the Burchfield, et al. (2006), articles take a position on the desirability or undesirability of urban sprawl, it is nevertheless the case that many regard sprawl, however defined, as bad. We do not enter that debate here, except to note that the word *sprawl* is usually taken as pejorative, but what we (and Burchfield, et al., 2006) call sprawl is taken in a positive, not normative, sense. More is needed to move from a positive to a normative discussion, specifically what failure, either by the market or by government, produces sprawl in the pejorative sense and what should be done to about it. Brueckner (2001), for example, provides theories and recommends policies for examples of market failure, specifically failure to account for the social value of open space around urban areas, failure to account for the social cost of freeway congestion, and failure to account fully for the infrastructure costs of sprawl. Although Brueckner (2001) deals only with market failures, one could charge as government failures land-use controls, such as minimum lot sizes and maximum floor-area ratios, which tend to expand the urban area (see Geshkov and DeSalvo, 2012).

Here, however, we want to emphasize the role of theory. Hindriks and Myles (2006, p. 5) provide a succinct definition of policy analysis: "The method of policy analysis in public economics is to build a model of the economy and to find its equilibrium. Policy analysis is undertaken by determining the effect of a policy by tracing through the ways in which it changes the equilibrium of the economy relative to some *status quo*. Alternative policies are contrasted by comparing the equilibria to which they lead." These authors are essentially arguing for the kind of theory we have advocated in this paper.

The comparative static results of the urban monocentric model, summarized in Table 1 above, shed important light on the role of this kind of theory in policy analysis. Suppose, for example, that policy makers propose that to retard urban sprawl, the relevant government should impose a large and permanent tax on gasoline. The urban monocentric model, reinforced by empirical analysis, shows that doing so would increase transportation cost and, indeed, reduce the size of the urban area. Importantly, however, the model also shows what would happen to other relevant variables. Specifically, housing prices would rise near the CBD and fall farther out, structural density would behave similarly, and importantly the welfare of households would decrease. In light of these additional results, would policy makers agree that the proposed policy is a good one?

Our point is that without a well-articulated theory, we could not predict these accompanying effects of the policy. The reduced form equation that was estimated would only predict the effect on spatial size, and that would be consistent with the intended effect of the policy. The perhaps unintended consequences, which might lead policy makers not to support the gasoline tax, would not be known. In an empirical analysis, such as that of Burchfield, et al. (2006), these unintended effects would remain unknown.

Notes

1. Burchfield et al. (2006) use *sprawl* in a positive, not normative, sense, and we adopt that usage here.

2. "To measure the extent of sprawl, for each 30-meter cell of residential development, we calculate the percentage of open space in the immediate square kilometer. We then average across all residential development in each metropolitan area to compute an index of sprawl" (Burchfield, et al., 2006, p. 599).

3. Oueslati, Alvanides, and Garrod (2015, p. 1594) obtain similar results: "[T]he fundamental conclusions of the standard monocentric model are valid in the European context for both indices. Although the variables generated by the monocentric model explain a large part of the variation in artificial area [their measure of urban spatial size], their explanatory power for modelling the fragmentation index [their measure of urban fragmentation] is relatively low.

4. As implied by Brueckner (1987, p. 835) and made explicit by Anas and Kim (1993), the distance at which the quotient h/q (and therefore the population density function) pivots (if it does) is farther out than x'.

5. In this subsection, all page and subsection numbers refer to Burchfield, et al. (2006), unless otherwise stated.

6. Burchfield, et al. (2006), use the term "monocentric city model" even when they are drawing implications from polycentric and city-system models. In all of the following quotes, italics are in the original.

7. As noted earlier, the other two exogenous variables of the model, δ, the radians of a circular urban area available for residential use, and i, the rental rate of the capital input, have not been used in empirical work.

8. Two of the MAs in the Burchfield, et al. (2006), sample contain two separate urbanized areas, which makes a total of 277 observations.

9. The coefficients in Table IV of Burchfield, et al. (2006, p. 616), "give the impact on the index of a one-standard-deviation increase in the corresponding variable." Our coefficients give the impact of a unit change in the corresponding variable, so by "consistent" we mean in terms of sign and statistical significance.

References

Anas, Alex, and Ikki Kim. 1993. “Income Distribution and the Residential Density Gradient.” *Journal of Urban Economics* 31: 164–180.

Bar-Ilan, Aver, and William C. Strange. 1996. “Urban Development with Lags.” *Journal of Urban Economics* 39: 87–113.

Brueckner, Jan K. 1987. “The Structure of Urban Equilibrium: A Unified Treatment of the Muth-Mills Model.” In *Handbook of Regional and Urban Economics*, Vol. II, “Urban Economics,” ed. Edwin S. Mills, 821–845. Amsterdam: Elsevier.

________. 2001. "Urban Sprawl: Lessons from Urban Economics.” In William G. Gale and Janet Rothenberg Pack, eds., *Brookings-Wharton Papers on Urban Affairs 2001*, pp. 72–81. Washington, DC: Brookings Institution Press.

Brueckner, Jan K., and David A. Fansler. 1983. “The Economics of Urban Sprawl: Theory and Evidence on the Spatial Size of Cities.” *Review of Economics and Statistics* 65: 479–482.

Burchfield, Marcy, Henry G. Overman, Diego Puga, and Matthew A. Turner. 2006. “Causes of Sprawl: A Portrait from Space.” *Quarterly Journal of Economics* 121: 587–633.

Deng, Xiangzheng, Jikun Huang, Scott Rozelle, and Emi Uchida. 2008. “Growth, Population and Industrialization, and Urban Land Expansion of China.” *Journal of Urban Economics* 63: 96–115.

Fujita, Masahisa, and Jacques-François Thisse. 2002. *Economic of Agglomeration: Cities, Industrial Location, and Regional Growth*. Cambridge: Cambridge University Press.

Galster, George, Royce Hanson, Michael R. Ratcliffe, Harold Wolman, Stephen Coleman, and Jason Freihage. 2001. “Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept.” *Housing Policy Debate* 12: 681–717.

Geshkov, Marin V., and Joseph S. DeSalvo. 2012. “The Effects of Land-Use Controls on the Spatial Size of U.S. Urbanized Areas.” *Journal of Regional Science* 52: 648–675.

Glaeser, Edward L., Jed Kolko, and Albert Saiz. 2001. “Consumer City.” *Journal of Economic Geography*. 1: 27–50.

Glaeser, Edward L., and Matthew Kahn. 2001. “Decentralized Employment and the Transformation of the American City.” *Brookings-Wharton Papers on Urban Affairs*, pp. 1–47. Washington, DC: Brookings Institution Press.

Henderson, J. Vernon. 1987. “General Equilibrium Modeling of Systems of Cities.” In *Handbook of Regional and Urban Economics*, Vol. II, “Urban Economics,” ed. Edwin S. Mills, pp. 927–956. Amsterdam: Elsevier.

Hendriks, Jean, and Gareth D. Myles. 2006. *Intermediate Public Economics*. Cambridge, MA: The MIT Press.

Malpezzi, Stephen, and Wen-Kai Guo. 2001. “Measuring ‘Sprawl’: Alternative Measures of Urban Form in U.S. Metropolitan Areas.” The Center for Urban Land Economics Research Working Paper.

McGrath, Daniel. 2005. “More Evidence on the Spatial Size of Cities.” *Journal of Urban Economics* 58: 1–10.

Mills, Edwin S. 1992. “The Measurement and Determinants of Suburbanization.” *Journal of Urban Economics*. 32: 377–387.

Nechyba, Thomas J., and Randall P. Walsh. 2004. "Urban Sprawl." *Journal of Economic Perspectives* 18: 177–200.

Oueslati, Walid, Seraphim Alvanides, and Guy Garrod. 2015. "Determinants of Urban Sprawl in European Cities," *Urban Studies*, 52: 1594–1614.

Paulsen, Kurt. 2012. "Yet Even More Evidence on the Spatial Size of Cities: Urban Spatial Expansion in the U.S., 1980–2000." *Regional Science and Urban Economics*. 42: 561–568.

Song, Yan, and Yves Zenou. 2006. "Property Tax and Urban Sprawl: Theory and Implications for U.S. Cities." *Journal of Urban Economics*. 60: 519–534.

Spivey, Christy. 2008. "The Mills-Muth Model of Urban Spatial Structure: Surviving the Test of Time?" *Urban Studies* 45: 295–312.

Su, Qing, and Joseph S. DeSalvo. 2008. "The Effect of Transportation Subsidies on Urban Sprawl." *Journal of Regional Science*. 48: 567–594.

Tiebout, Charles M. 1956. "A Pure Theory of Local Expenditures." *Journal of Political Economy* 64: 416–424.

Turner, Matthew A. 2005. "Landscape Preferences and Patterns of Residential Development." *Journal of Urban Economics* 57: 19–54.

U.S. Department of Commerce. 1991. *State and Metropolitan Area Databook 1991*.

U.S. Energy Information Administration. 2013. "Motor Gasoline Sales through Retail Outlets Prices." <http://www.eia.gov/dnav/pet/pet_pri_allmg_a_epm0_ptc_dpgal_m.htm>

U.S. Bureau of the Census. 1992. *Census 1990*. <http://www.census.gov/main/www/cen1990.html>

Wassmer, Robert W. 2008. "Causes of Urban Sprawl in the United States: Auto Reliance as Compared to Natural Evolution, Flight from Blight, and Local Revenue Reliance." *Journal of Policy Analysis and Management* 27: 536–555.