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Beyond density: municipal expenditures and the shape and location of development

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ABSTRACT
A clear understanding of the relationship between development patterns and municipal expenditures is complicated by how one chooses to quantify these patterns. Extant literature often employs a single density measure to capture the low-density nature of sprawl. While density provides an intuitive link to economies of scale and congestion costs, it fails to capture other spatial characteristics of sprawl related to centrality, connectedness, and mixed use that may influence municipal expenditures according to Smart Growth and New Urbanism advocates. This study uses Massachusetts orthoimagery data to construct multidimensional measures of residential and commercial land use patterns. Municipal expenditures associated with public works, fire, and police are regressed on multidimensional measures of land use as well as a number of demand controls. Findings indicate that economies and diseconomies do exist with respect to the multidimensional metrics considered. Support is mixed for development patterns emphasized by Smart Growth and New Urbanism advocates.

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1. Introduction

How municipalities are developed matters. The way in which various forms of development are oriented in space has the potential to impact the environment, the economy, as well as societal and public health. In particular, expanding, disconnected, low-density development patterns are associated with numerous ills: increased air pollution; decreased employment accessibility and decreased labor productivity as housing and employment locations become scattered (Brueckner, 2000, 2001; Fallah, Partridge, & Olfert, 2011; Glaeser & Kahn, 2004); increased social isolation and racial segregation (Brueckner, 2000, 2001; Downs, 1999; Galster & Cutsinger, 2007; Glaeser & Kahn, 2004); and excessive conversion of farmland and natural environments to urban use (Blais, 2011; Ewing, 2008). Most recently, as seen in the aftermath of Hurricane Harvey in Houston, Texas, the abundance of impervious surfaces resulting

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Supplemental data for this article can be accessed here.

from sprawling developments may be increasing the severity of hurricane and flood damage (Fleming, 2017; Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). There is some evidence that sprawling land use patterns are also associated with increasing the per capita cost to deliver municipal services as road, water, and sewer networks become more expansive (see, for example, Carruthers & Ulfarsson, 2008). The relationship between development patterns and municipal expenditures may not be of the greatest importance in terms of social and economic equity or the health of residents, but it is immediate and tangible with respect to municipal budgets and thus to taxpayers. Unfortunately, how development patterns ultimately impact municipal budgets has received limited academic attention.

"The Costs of Sprawl" report, released by the Real Estate Research Corporation in 1974, was the first to argue the lack of salience regarding the relationship between various land use patterns and their development and maintenance costs may lead to increased municipal expenditures (water, sewer, roads, public transit, etc.). This increase is thought to arise as municipalities fail to exploit economies associated with more compact and connected development patterns as they grow. Although this report suffers from methodological and measurement flaws (Altshuler, 1993; Burchell, 1998), it highlights an important relationship between the built environment and local public finance that may be costly if ignored. In fact, more recent research by Carruthers and Ulfarsson (2008) estimates a decrease in population density by 25% would increase an average American county's total direct municipal expenditures by $1.8 million.[1] While the authors caution that this is a back-of-the-envelope estimate, the magnitude and significance indicates that this relationship has real fiscal consequences for municipalities and deserves a deeper investigation. Unfortunately, it is difficult to fully parse the complex relationship between sprawling development patterns, and municipal expenditures as sprawl is exceedingly hard to define. Furthermore, the channels through which inefficient development influences municipal costs may be opaque.

Sprawl contains a complex combination of qualities that renders single measures inadequate. Regardless, the single measure of density is often used within and across the various academic disciplines that study sprawl. There are benefits to using a density measure; it can be calculated with relative ease and is able to capture important average vertical aspects of development. However, the larger the geographic unit one examines, the less information this single measure provides. When analyzing the relationship between municipal expenditures and land use patterns, density (be it population, housing, or employment) provides an intuitive measure of economies of scale and urban congestion but is unlikely to adequately capture all possible economies (or diseconomies) associated with the shape and location of land uses.

Within the research presented here, we rely on Blais' (2011) definition of sprawl as an inefficient land use pattern. More specifically, "[Sprawl] embodies a misallocation of resources that is wasteful, consuming resources that could have been put to more productive uses" (Blais, 2011). Taking this broad definition of sprawl, we pose the following question: does the shape and location of various forms of development, not just the overall density of development, have the potential to create inefficiencies with respect to the provision of municipal services? In other words, are more compact, dense, central, mixed, and connected land use patterns more efficient with respect to providing municipal services?

In order to address this question we rely on advances in geographic information system (GIS) techniques within planning and landscape ecology. These advances allow for the shape of developed land and the spatial relationships between different land uses to be quantified via a rich set of multidimensional metrics (Allen, 2001; Clifton, Ewing, Knaap, & Song, 2008; Cutsinger & Galster, 2006; Cutsinger, Galster, Wolman, Hanson, & Towns, 2005; Ewing, Pendall, & Chen, 2002; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Sarzynski, Galster, & Stack, 2014a, 2014b; Torrens & Alberti, 2000). These metrics quantify patterns of leapfrog development (discontinous/disperse development); ribbon sprawl/retailscape; the diversity, evenness, and clustering of the distribution of land use types; and the accessibility/proximity between uses. To our knowledge, extant literature has not incorporated such metrics. Thus, this paper is the first to empirically test the magnitude and significance of the relationship between municipal expenditures and the shape and location of development.

A simple cross-sectional framework is used to explore the relationship between these metrics, total municipal expenditures, as well as three disaggregated expenditure categories within Massachusetts municipalities. Metrics describing concentration, centrality, isolation, interaction, and fragmentation of residential and commercial uses are considered. We compare more traditional measures (population density and proportion of land developed) with the set of multidimensional metrics to assess whether or not these measures are able to describe relationships not captured by density or proportion of land developed and whether or not these relationships prove to be more consequential with respect to municipal expenditures. Numerous controls are considered in order to capture variation in the demand *for* and the cost *of* delivering municipal services between Massachusetts municipalities.

Land use patterns observed within the state of Massachusetts may not represent the same variation in patterns observed across the United States; however, Massachusetts contains the fifth largest US metropolitan area made up of inner core communities, streetcar suburbs, maturing suburbs and developing suburbs. Additionally, Massachusetts contains numerous regional and sub-regional urban centers with substantial adjacent suburban populations and small towns scattered throughout much of the state.[2] Given this variation, we argue that the state of Massachusetts presents an adequate case through which to analyze the relationship of interest.

2. Municipal expenditures and land use

Smart Growth and New Urbanism development plans advocate for compactness in the form of dense, central, mixed, and connected land use patterns (Blais, 2011). These development patterns are thought to limit the negative impact of environmental, social, and economic externalities associated with more diffuse patterns. With respect to economic externalities, dense development patterns are assumed to exploit economies of scale associated with municipal services where underutilization of land is expected to translate into larger expenditures per capita. There is some empirical support for this theory; however, the relationship is complicated by the diseconomies stemming from the “harshness” of denser built environments. It is posited by the local public finance literature that denser land use patterns may require larger expenditures for traffic safety and flow, waste management, and police services due to a greater intensity of use (Bradbury, Ladd, Perrault, Reschovsky, & Yinger, 1984; Ladd, 1992, 1994).

Extant literature is limited by the rigidity of the land use metrics used but still succeeds in highlighting the complexities of the relationship between land use patterns and municipal expenditures. Ladd (1992) is one of the first articles to apply rigorous analysis of land use patterns and municipal costs using U.S. county level data. Ladd finds a nonlinear relationship between population density and municipal costs; initial decline in spending as density increases at very low levels but an overall increase in the cost as density increases. However, these results must be taken cautiously as the county unit of analysis does not reflect the true spatial level of municipal expenditures.

Carruthers and Ulfarsson (2008) also perform a county-level analysis. Two measures of sprawl are used: density of developed land and the percentage of county land area that is developed. A variety of expenditure variables are considered, including per capita education, fire, housing, libraries, parks and recreation, police, roadways, sewerage, and solid waste. Density of developed land is found to have a negative effect on education, parks and recreation, police protection, and roadway expenditures. Percentage of county land area that is developed has an overall significant and positive effect on all expenditure categories except for housing and solid waste where the effect is positive but not significant.

Hortas-Rico and Sole-Olle (2010) paper uses municipal level data from 2500 Spanish municipalities. A public spending equation is estimated for aggregate expenditures as well as six disaggregated categories that are grouped as community facilities, basic infrastructure and transport, local police, culture and sports, housing and community development, and general administration. Four different variables are used to measure sprawl with the main variable being urbanized land per capita. Residential houses, percentage of scattered population, and number of population centers all measured in per capita terms are also considered. These measures of sprawl are an improvement over the typical density measure. In general, the authors find that low-density development patterns lead to greater local expenditures and consequently higher levels of taxation for public services with the exception of housing and basic infrastructure and transport.

A panel approach is taken by Goodman (2015) using the same expenditure categories as Carruthers and Ulfarsson (2008) with the addition of natural resources. U.S. county level data from 1982 to 2012 are employed within a county and year fixed effects regression framework that allows for the land use variables of residents per acre and percentage of developed land within the county to enter cubically. Density is significant only within the education and natural resources specifications. In both cases, low levels of density are associated with lower expenditure levels. Increasing density then increases expenditures but at very high-density levels the relationship becomes negative. The percentage of developed land is inversely related to all expenditures except housing, roadways, and sewerage. The relationship is initially positive for low levels of developed land, then negative, and eventually positive for high levels of developed land. Percentage of developed land demonstrates a positive linear relationship with roadway expenditures but negative and linear with respect to waste management. No effect is found on housing expenditures. Based on the strength of the associations, Goodman's findings suggest the percentage of developed land is a far more influential factor than density.

Overall, the argument in favor of the economies of scale theory does have some support; however, Goodman's findings show virtually no impact of density on numerous expenditure categories. Allowing density to enter nonlinearly improves the ability to assess the complexity of the relationship but it does not ameliorate the intrinsic problem with density, it is a blackbox. An entire urbanized area's (or county's) built environment is reduced to a one-dimensional average measure that omits possibly influential patterns of clustering, centrality, and accessibility between uses. On average, residential density within an urbanized area may be high but the shape and location of residential developments may be inefficient with respect to providing particular municipal services. In effect, any economies associated with shape and location not correlated with density are empirically unaccounted for.

Literature cited in support of the economies of scale and harshness arguments provide limited detail regarding the potential channels through which land use patterns may influence efficiencies or inefficiencies with respect to delivering municipal services. While not an exhaustive review of engineering systems or fire and police operations, the potential built environment related cost sources with respect to select municipal services within the state of Massachusetts are summarized below.

2.1. Water and sewer

The majority of the expenditures associated with water and sewer infrastructure stem from the high cost of water distribution and sewer collection mains. These outlays dominate transmission main and pump costs (Blais, 2011). Larger distribution and collection mains are required for larger lots. Additionally, pumping costs increase with lot size as larger lengths of pipe tend to exhibit pressure losses. Larger lots also tend to have higher levels of water usage (Blais, 2011). This relationship between lot size and water and sewer costs is confirmed empirically by Speir and Stephenson (2002); doubling lot size increases costs by 30%.

While the connection between density and water/sewer provision is fairly clear, how water and sewer expenditures may relate to other land use patterns remains unclear. Specifically, mixed-use may require inefficient levels of water or sewer service, as they must accommodate the highest capacity requirement – i.e. larger distribution and collection infrastructure than needed for lower capacity uses within a mixed development that contain uses with high capacity requirements. Efficiencies may exist with respect to supplying services to residential land that is not fragmented, leapfrogging, or winding as less infrastructure would be required to service more contiguous development.

2.2. Roadways

Unlike many other states, Massachusetts legally does not allow municipalities to charge property developers impact fees to cover costs associated with new road construction (MassDOT, 2017). However, under Chapter 90, Massachusetts municipalities are reimbursed by the state for a portion of expenditures relating to road construction and maintenance (MassDOT, 2017). Therefore, the impact of road construction and maintenance on expenditures may be slightly dampened. Without access to state aid, a positive relationship between fragmented, low-density development would be expected as more infrastructure per resident would be required. However, the infrastructure requirements for many low-density residential developments are minimal (e.g. no sidewalks, no curbs, gravel roads in some instances).

More mixed-use development patterns may also produce ambiguous effects with respect to construction and maintenance expenditures. Less infrastructure may be required to link residential uses to commercial uses; however, the wear and tear on roads may increase if roads are used consistently throughout the day as opposed to in the morning and evening (residential) or during business hours (commercial).

2.3. Fire

Massachusetts communities create service zone plans for emergency services based on the following: available resources, geography, population density, and community expectations (MA Dept. of Fire Services, 2011). In addition to the requirements in service zone plans, the National Fire Protection Association stipulates that every ladder and engine be staffed by a minimum of four firefighters with more services to be made available depending on the hazard level associated with the buildings within a community (NFPA, 2015). High-hazard occupancies consist of schools, hospitals, and nursing homes. Medium-hazard occupancies include apartments, offices, and industrial uses. Low-hazard occupancies include one to three family residential units, as well as scattered small business and industrial buildings. Response capacities are based on the number and location of these various occupancies (NFPA, 2015). Thus, density increases the number of structures accessible within a service zone; however, density may increase the fire hazard especially with high densities of high-hazard occupancies. More fragmented, irregular development patterns may hinder accessibility within a service zone, but it is unclear if these development patterns have a measurable impact on service costs.

2.4. Police

Labor costs are the most substantial outlay associated with police expenditures (Spence, Webster, & Conners, 2016). In general, larger populations require larger police forces as economies of scale with respect to population are likely nonexistent or negative given the intense labor requirements and associated costs (Gyimah-Brempong, 1987; Walzer, 1972).

An additional influence on police expenditures is crime where increasing crime levels lead to increases in police services (Marvell & Moody, 1996). Following Jacobs' (1961) emphasis on land use diversity and high levels of pedestrian activity as methods to reduce potential criminal activities, a substantial literature linking the built environment to crime levels has developed.[3] Jacobs posited that dense, mixed-use neighborhoods increased pedestrian traffic throughout the day. The increased number of "eyes on the street" are thought to provide passive monitoring of potential criminal activity. However, the effectiveness of increased monitoring seems limited to certain crime types. Browning et al. (2010) find reductions in violent crimes such as homicide and aggravated assault but increases in robberies, which may rely on the density of people and traffic. It remains unclear whether the increase in non-violent crime in mixed-use areas translates into increases in police expenditures per capita.

3. Methodology

Multidimensional land use measurements of concentration, centrality, and local proximity between land uses are adapted from Galster et al. (2001), Cutsinger and Galster (2006), and Sarzynski et al. (2014b). To capture the fragmented characteristics of diffuse land use, two common landscape ecology metrics are used: mean patch area and mean perimeter-to-area ratio (O'Neill, Riitters, Wickham, & Jones, 1999; Pickett & Cadenasso, 1995; Wiens, Crawford, & Gosz, 1985). A land use GIS datalayer produced from a high resolution orthoimagery dataset spanning the entire state of Massachusetts is used to construct the multidimensional land use metrics. Land use types within the datalayer are categorized into one of 33 land use categories that represent developed, potentially developable, and undevelopable land. Developed land includes residential use at four density levels, commercial, industrial, recreational, and institutional uses.[4] Potentially developable land includes agricultural, forest, and shrub cover. Undevelopable land includes wetlands, beaches, cemeteries, land used for waste disposal infrastructure, mining, and transportation infrastructure. In addition to these categories of undevelopable land, we utilize elevation data to reclassify potentially developable land as undevelopable if the land is sloped greater than 15%. A datalayer consisting of protected lands within Massachusetts is further used to reclassify potentially developable land as undevelopable. Figure 1 depicts the various land uses within the town of Needham.

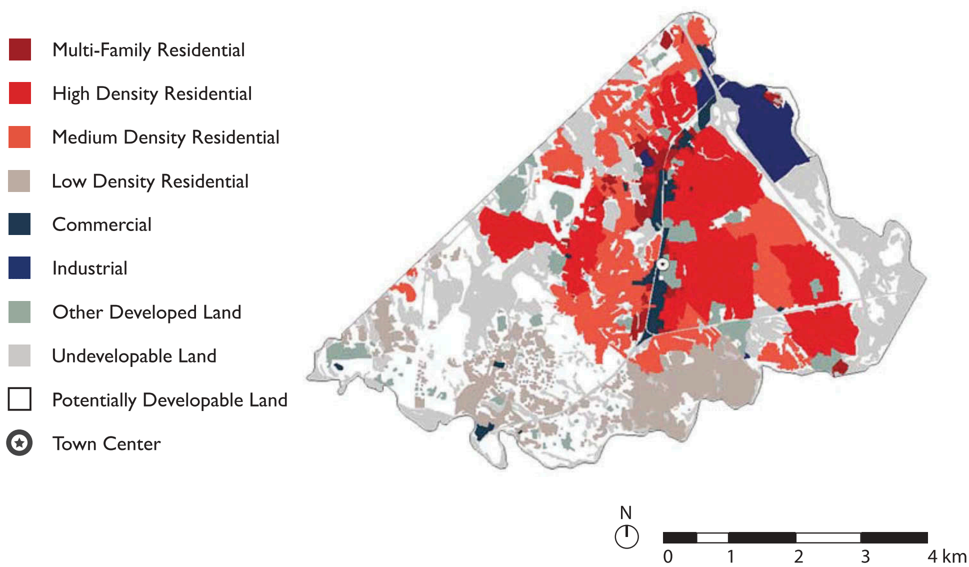

Figure 1. Town of Needham. MassGIS land use datalayer.

For analysis, low and medium-density residential land use are grouped, as are high-density residential and multi-family. Commercial land use is also considered but industrial land use is omitted as many municipalities do not contain industrial land.

To construct the metrics pertaining to concentration, centrality, and local proximity, a uniform unit of analysis within each municipality is required. Similar to Galster et al. (2001), a grid comprised of 1.29 km square (1/2 mile square) cells overlaying the entire Massachusetts land use datalayer is constructed. The total area of the two residential groupings, and commercial use, along with totals for all developable, potentially developable, and undevelopable land within each cell for each municipality are calculated. There is no unincorporated land in Massachussetts; thus, all land falls within municipal boundaries.

The disaggregated expenditures considered are limited to public works,[5] fire, and police in the subsequent regression analysis in order to focus on municipal services that may have a more intuitive connection to economies or diseconomies of shape and location. Specifications using total expenditures are also constructed. Total expenditures include general government,[6] police, fire, other public safety,[7] education, public works, human services,[8] culture and recreation,[9] intergovernmental assessments, fixed cost,[10] debt service,[11] other expenditures,[12] transfers to other funds, and other financing uses.

The density metric used is based on developed land within a given municipality's borders. Specifically, it is calculated as the number of residents per square kilometer of developed land. In addition to density, we consider another commonly used metric: proportion of land developed. This metric provides a general description of the spatial extent of developed land. The proportion of land developed within a municipality is constructed as the ratio of developed land over the sum of developed and potentially developable land within a municipality. Multidimensional metrics are described in detail below.

When constructing metrics based on spatial phenomena, it is import to consider how the Modifiable Areal Unit Problem (MAUP) may affect subsequent analysis (Fotheringham & Rogerson, 2009). MAUP can arise either through the scale or zone of analysis. Scale MAUP is related to the appropriateness of the geographic unit at which analysis is carried out. Because this study is strictly interested in municipal expenditures, municipal level land use metrics are appropriate. Thus, this study does not contain an imposition of artificial units. Zone MAUP may arise due to the zonal unit one uses to construct a spatial measure. In this study 1/2 square mile grid cells are used to construct the various land use metrics. The use of 500 m, 1/2 mile, and 1 mile square grid cells are commonly used in the land use metric literature. Metrics based on 1 mile square cells were considered for the present analysis but were deemed too coarse given the numerous geographically small municipalities within Massachusetts.

3.1. Concentration

Concentration measures the degree to which a land use type is disproportionately located in relatively few areas or spread evenly across a municipality. It is akin to Massey and Denton (1988) dissimilarity index for racial segregation. Here, the value indicates the share of land use that would need to be redistributed in order to achieve a uniform distribution across the developable land within a municipality. Larger values indicate higher levels of concentration. Concentration of land use type i is calculated as follows:

$$Conc_i = \frac{1}{2}\sum_{m=1}^{N}\left(\frac{i_m}{I} - \frac{t_m}{T}\right) \tag{1}$$

where m refers to a cell within the municipality with N being the total number of cells, i_m is the area of land use type i within cell m, I is total area of land use type i within a given municipality, t_m is total developed and potentially developable area within cell m, and T is total developed and potentially developable area within a given municipality. Galster et al. (2001) associate lower levels of concentration with more sprawling development patterns.

3.2. Centrality

Centrality measures the weighted average distance of a given land use type to the municipality center measured by the town hall location. Given the variation in municipality total area, the weighted average distance is standardized with respect to the average distance from all cells to the center:

$$Ctr_i = \frac{\sum_{m=1}^{N} d(m, center)/N}{\sum_{m=1}^{N} (i_m/I) \cdot d(m, center)} - 1 \tag{2}$$

where $d(m, center)$ is the distance from the centroid of cell m to the town/city center and i_m/I is the weight assigned to cell m based on the proportion of land use type i with respect to the total area of land use type i within the municipality. A number larger than zero indicates a land use type is more centrally located than would be expected on average.

Centrality represents a general notion of compactness where decentralization implies increasing sprawl. A more centralized residential pattern may allow for quicker access by fire and police services. A less centralized municipality may likely need additional stations in order to service residents in a required amount of time. Based on the notion that centrality measures an aspect of compactness, Smart Growth literature anticipates a negative relationship between public works expenditures and low and medium-density residential centrality. More road, water, and sewer infrastructure is assumed to be needed to access less central locations.

3.3. Local proximity

Local proximity measures the extent to which land use type i is exposed to land use type j (interaction index) or the extent to which type i is exposed to only type i (isolation index). These indexes have a long history within the racial segregation literature (Massey & Denton, 1988; Sørensen, Taeuber, & Jr, 1975; White, 1986) and were adapted to be used within the land use context by Galster et al. (2001).

The isolation and interaction indexes are calculated as follows:

$$p_{ij} = \frac{\sum_{m=1}^{N} (i_m/I)(j_m/J)}{J/(I+J)} \tag{3}$$

$$p_{ii} = \frac{\sum_{m=1}^{N} (i_m/I)^2 - I/T}{1 - I/T} \tag{4}$$

where, again, I and J are the total areas of land use type i and j within a given municipality. T is the total area of developed and developable land in a given municipality. These metrics are symmetric, bounded by 0 and 1, and are analogous to the probability that two use types exist within the same cell or a use type exists on its own within a cell.

Isolation of residential uses from commercial uses may result from restrictive zoning practices such as minimum lot size zoning within different zoning categories (Galster et al., 2001). As the distance between residences and employment/retail areas increases, so does travel time. Larger amounts of infrastructure may be required to connect the uses.

3.4. Mean patch area

The landscape ecology term “patch” is analogous to contiguous land use polygons observed within the land use data. Mean patch area of land use type i within a given municipality is calculated as follows:

$$MPA_i = \frac{\sum_{l=1}^{n_i} a_{il}}{n_i} \tag{5}$$

where n_i is the total number of patches of land use i within a given municipality, a_{il} is the area of patch l with land use i. Smaller values indicate higher degrees of fragmentation where fragmentation is associated with sprawling, leapfrogging development patterns. Based on issues of accessibility and connectedness, Smart Growth advocates expect fragmented development to be more costly to service.

3.5. Mean perimeter-to-area ratio

This metric captures the degree to which a patch is compact versus long, winding, or irregularly shaped in general:

$$MPAR_i = \frac{\sum_{l=1}^{n_i} r_{il}/a_{il}}{n_i} \tag{6}$$

where r_{il} is the perimeter of patch l of land use i. A larger ratio indicates a more complex patch shape. In general, more winding, non-convex developments are thought to be associated with inefficient delivery of municipal services. A more compact patch may require less infrastructure to service a similar amount of people. Accessibility is also diminished which in turn may affect police and fire response times as well as garbage pick-up and snow removal.

See Figures A to F in the supplemental materials for visual representations of the multidimensional metrics presented in this section.

3.5.1. Regression model

In order to identify the relationship between land use patterns and municipal expenditures, factors contributing to the demand and costs of municipal services must be considered. The costs associated with delivering municipal services include environmental as well as input costs (Bradford, Malt, & Oates, 1969; Hortas-Rico & Sole-Olle, 2010; Ladd, 1992, 1994). Land use patterns can be viewed as a source of environmental costs through the potential inefficiencies they impose on the delivery of municipal services. Other environmental costs include factors that affect the cost of providing municipal services but are beyond the control of local public officials (Ladd, 1992). Demand for municipal services cover demographic and socioeconomic characteristics that closely follow those outlined by Bergstrom and Goodman (1973) and Borcherding and Deacon (1972). Fiscal and political characteristics capture cross-sectional variation in sources of revenue and political ideology.

Municipal expenditures may be influenced by space and place-based characteristics given the contiguous spatial organization of municipalities in Massachusetts. To capture these potential relationships, county fixed effects are considered. These fixed effects control for broad spatial relationships without imposing a specific spatial decay structure on the data. In preliminary testing of county fixed effects, only Duke county (the island of Martha's Vineyard) and Barnstable County (the curved peninsula portion of Cape Cod) were significantly different from the baseline of Suffolk County which contains Boston. Given the unique geography of these significant counties, an island and a narrow curved peninsula, respectively, these differences are not surprising. For consistency and parsimony across specifications, we include dummy variables in all specifications for only these two counties in order to capture this variation. In addition to the general spatial organization of municipalities within Massachusetts, there may be a "Boston effect" wherein municipalities proximate to Boston use land more intensely. This implies a possible correlation of land use patterns in municipalities surrounding Boston. An investigation of the correlation between land use metrics and distance to Boston (central business district of Boston to town hall of municipality) produces low correlations with the exception of mid-level correlations for the proportion of land developed and concentration metrics. These correlations range from 0.44 to 0.60. We opt not to control for the Boston effect through a distance variable for two reasons. First, it may absorb relevant correlations between municipal expenditures and the proportion of land developed and concentration metrics given the somewhat limited spatial variation in these metrics. Second, over 70% of the variation in distance to Boston is accounted for by the regression controls discussed below and inclusion poses collinearity issues.

The following general form for per capita municipal expenditures is proposed:

$$Exp = f(\mathit{land\ use\ patterns},\ \mathit{other\ environmental\ costs},\ \mathit{demand\ for\ municipal\ services},\ \mathit{fiscal\ characteristics},\ \mathit{county\ fixed\ effects},\ \mathit{unobserved\ factors})$$

Within other environmental costs, total employment per capita and proportion of homes built before 1940 are controlled for. Municipalities with a large workforce relative to residential population (commuters) may have different demands for municipal services which are likely to increase the total required level of services. With a large proportion of older homes, a municipality is likely to have aging infrastructure requiring higher levels of expenditures related to maintenance. Demand for municipal services may be influenced by total population, population growth, per capita income, age distribution of the population, racial and ethnic composition, educational attainment, the homeownership rate, and political ideology. Fiscal controls include per capita state revenue, where increases in state revenue may coincide with increases in expenditures as municipalities fund larger projects.

Analysis begins with a comparison of baseline regressions (no land use metrics) to regressions that contain both linear and quadratic forms of the traditional density measure and the proportion of land developed. Similar to previous literature using these metrics, quadratic forms are considered to test nonlinear relationships. All models are cross-sectional ordinary least squares specifications. Density and proportion of land developed are not combined within the same specification due to their high collinearity. Logged per capita municipal expenditures are regressed on the environmental, demographic/socioeconomic, and fiscal controls.[13]

The linear and quadratic specifications are as follows:

$$Log\ Exp_i = \alpha + \beta D_i + \gamma X_i + \epsilon_i \tag{7}$$

$$LogExp_i = \alpha + \beta D_i + \theta D_i^2 + \gamma X_i + \epsilon_i \tag{8}$$

where $LogExp_i$ is the log per capita expenditure for municipality i, D_i is density or proportion of land developed, X_i represents the vector of controls which include the additional environmental costs, demand for municipal services, fiscal/political characteristics, and the two county dummy variables.

The main regression model contains all multidimensional metrics (not including density and proportion of land developed) and is as follows:

$$LogExp_i = \alpha + \sum_j \sum_k \phi_{jk} Z_{ijk} + \gamma X_i + \epsilon_i \tag{9}$$

where j = {low and medium-density residential, multi-family and high-density residential, commercial} and k = {concentration, centrality, isolation, interaction, mean patch area, mean perimeter-to-area ratio}. Z_{ijk} is the land use metric k for land use type j within municipality i.

Given that the research presented here is the first to attempt to identify the relationship between complex land use patterns and municipal expenditures, a functional form for these relationships is not known a priori. Similar to the literature exploring the impact of density and proportion of developed land on municipal expenditures, quadratic forms of the metrics are considered in order to model possible nonlinearities. With a limited sample size and the increase in independent variables the addition of quadratic terms would require, a Lasso (least absolute shrinkage operator) method is used to identify relevant quadratic terms. Lasso is a variable selection methodology that improves prediction error by choosing a subset of covariates such that the sum of coefficients remains below a threshold. This methodology is an improvement on stepwise regression and ridge regression techniques.[14] The traditional Lasso model selects over all variables including controls; in this setting we wish to retain the set of controls and linear land use metrics; thus, a Lasso variation is used. The dependent variable is first regressed only on the set of controls and linear land use metrics. The residuals from this regression enter the Lasso model that includes the quadratic land use metric terms. The inclusion of the residuals accounts for the variation attributable to the controls and the linear terms (Efron, Hastie, Johnstone, & Tibshirani, 2004).

Reverse causality may be a concern in the above regressions, i.e. are municipal expenditures influenced by land use patterns or are land use patterns the result of the cost associated with servicing particular forms of development. For example, a municipality may choose particular development patterns based on perceived costs to service. To minimize this issue, land use metrics are constructed using 2005 data whereas expenditure and control data are from 2010. The lag in expenditure and control data may be sufficient to ameliorate possible reverse causality. Instrumental variable techniques were also initially considered but instruments proved to be weak.[15]

4. Data

Land use data are collected from MassGIS, a state government office tasked with providing a "comprehensive, statewide database of spatial information for mapping and analysis supporting emergency response, environmental planning and management, transportation planning, economic development, and transparency in state government operation" (MassGIS, 2011; MassGIS Land Use, 2015). The Land Use datalayer is a digital dataset of land cover/land use and was constructed using semi-automated methods based on 0.5 meter resolution digital orthoimagery for the year 2005. The Protected Lands datalayer used to identify undevelopable land is also retrieved from (MassGIS Protected Lands, 2015). Digital Elevation Model (DEM) data are provided by the United States Geological Survey (USGS) with a resolution of 30 meters (USGS, 2015).

The Massachusetts Department of Revenue provides detailed annual expenditure and revenue data for all 351 municipalities (MA DOR, 2015). Annual population estimates are also provided. The 2010 Census provides demographic and socioeconomic data at the municipality level.

Not all land use types considered in the analysis exist within each of the 351 Massachusetts municipalities. A sample size of 298 remains when selecting municipalities that contain the low and high-density residential groupings along with commercial use. The municipality of Nantucket, an island, is removed from the analysis as it proves to be an extreme outlier for a number of the variables considered. Fire expenditure data are missing for 11 municipalities which lowers the number to 287 within the fire expenditure regressions. Missing data are likely due to a town being serviced by two or more neighboring communities and not by its own fire department. The number of

Table 1. Summary statistics.

Variable	Mean	Std. Dev.	Min.	Max.
Public works exp. per capita ($)	169	118	28	1,047
Fire exp. per capita ($)	109	70	6	392
Polic exp. per capita ($)	168	83	10	721
Total exp. per capita ($)	2,669	879	1,029	6,824
Residents (1000s) per km^2 of developed land	1.295	1.010	0.269	7.091
Proportion of land developed	0.267	0.180	0.019	0.826
Low/med. resid. cnc.	0.125	0.105	0.000	0.444
Multi/high resid. cnc.	0.287	0.138	0.000	0.494
Comm. cnc.	0.303	0.109	0.000	0.489
Low/med. resid. ctr.	0.156	0.225	−0.435	1.180
Multi/high resid. ctr.	0.707	1.206	−0.499	10.993
Comm. ctr.	0.554	0.745	−0.398	7.321
Low/med. resid. iso.	0.277	0.075	0.099	0.497
Multi/high resid. iso.	0.219	0.123	0.005	0.549
Comm. iso.	0.120	0.069	0.004	0.376
Low/med. to multi/high resid. inter.	0.305	0.111	0.009	0.629
Comm. to low/med. resid. inter.	0.246	0.113	0.014	0.595
Comm. to multi/high resid. inter.	0.177	0.141	0.000	0.690
Low/Mmd. resid. patch	0.033	0.029	0.004	0.193
Multi/high resid. patch	0.047	0.087	0.000	0.972
Comm. patch	0.017	0.010	0.002	0.076
Low/med. resid. peri./area	0.111	0.278	0.049	4.614
Multi/high resid. peri./area	0.194	1.269	0.015	20.791
Comm. peri./area	0.149	0.698	0.033	11.086
Population (1000s)	20.730	41.352	0.327	617.594
Pop. growth 2000 to 2010	0.090	0.112	−0.515	0.642
Prop. under 5 yrs old	0.051	0.010	0.018	0.084
Prop. over 65 yrs old	0.151	0.046	0.074	0.398
Prop. white	0.910	0.091	0.416	0.988
Prop. with Bachelor's degree or higher	0.388	0.160	0.110	0.793
Homeownership rate	0.779	0.125	0.362	0.975
Prop. Republican vote	0.442	0.123	0.106	0.661
Prop. independent vote	0.100	0.035	0.029	0.258
Prop. homes built before 1940	0.026	0.012	0.005	0.077
Number of jobs per capita	0.380	0.240	0.053	1.611
Income per capita ($)	35,365	25,574	5,440	289,184
State revenue per capita ($)	505	381	43	2,103

N = 298 for all variables except fire expenditure per capita where N = 287 and police expenditure per capita where N = 297.

municipalities drops to 297 with respect to police expenditure data as the value for the Town of Hancock is anomalously low and is dropped from the analysis. Tests for additional outliers were carried out post-estimation using leverage versus residual squared plots. No influential municipalities were found.

Summary statistics are presented in Table 1 and are discussed within the supplementary materials. Correlations between the land use metrics are presented in Table A within the supplementary materials. Correlations amongst controls are also presented in Table B within the supplementary materials. High positive correlation exists between multifamily/high-density residential concentration and commercial concentration (0.81); high correlation also exists for proportion of residents with a Bachelor's degree or higher and log per capita income (0.82). Preliminary regression analysis also produced high variance inflation factors nearing 6 for these variables. Subsequent regression specifications do not include multifamily/high-density residential concentration or proportion of residents with a Bachelor's degree or higher. Removal of these variables has no substantive impact on fit or the coefficients of interest.

5. Results

5.1. Density and proportion of land developed

Table 2 presents baseline OLS regressions that contain no land use metrics. A fair amount of the variation in the expenditure categories considered is explained by the collection of control variables with signs and significance of the coefficients in line with expectations. Population and population growth have limited effect on expenditures aside from the significant positive association between population growth and total expenditures per capita. The presence of older populations is associated with increased expenditures per capita especially with respect to public work expenditures. Increases in white proportions are associated with declines in fire and total expenditures. As the homeownership rate increases, both public works and total expenditures increase whereas fire and police expenditures decline. Higher proportions of Republican voters in the 2010 Gubernatorial election are associated with higher expenditures on fire and police but lower public works and total expenditures. Proportion of homes built before 1940 has a large positive and significant association with public works and total expenditures per capita but is highly negatively associated with fire expenditures. Per

Table 2. Baseline, No land use variables.

	Public Works	Fire	Police	Total
Population (1000s)	6.975e4	−0.304e4	7.282e4**	0.719e4
	(6.480e4)	(4.637e4)	(2.914e4)	(2.641e4)
2000 to 2010 population growth	0.254	−0.131	−0.315	0.329***
	(0.278)	(0.346)	(0.240)	(0.125)
Proportion under 5 years old	7.950*	10.445**	−5.394*	0.621
	(4.482)	(4.771)	(3.234)	(1.520)
Proportion over 65 years old	3.498***	2.225*	1.034	1.403***
	(1.221)	(1.194)	(0.900)	(0.474)
Proportion white	0.115	−1.284***	−0.465	−0.375**
	(0.458)	(0.463)	(0.302)	(0.180)
Homeownership rate	1.379***	−1.207**	−1.347***	0.348**
	(0.333)	(0.466)	(0.318)	(0.145)
Proportion Republican Vote	−1.485***	0.887**	1.354***	−0.480***
	(0.289)	(0.407)	(0.281)	(0.144)
Proportion Independent Vote	0.393	1.222	−2.409**	−0.811**
	(0.889)	(1.389)	(1.179)	(0.408)
Proportion of homes built before 1940	10.069***	−17.422***	−0.944	4.040***
	(3.019)	(3.590)	(2.544)	(1.155)
Log per capita number of jobs	0.116*	0.319***	0.180***	0.103***
	(0.062)	(0.074)	(0.049)	(0.025)
Log per capita income	0.146**	0.436***	0.202***	0.365***
	(0.068)	(0.097)	(0.074)	(0.033)
Log per capita state revenue	−0.086**	−0.065	−0.011	0.160***
	(0.041)	(0.057)	(0.036)	(0.017)
Barnstable County	0.113	0.877***	0.500**	0.337***
	(0.228)	(0.225)	(0.224)	(0.115)
Duke County	0.584***	−0.564***	1.136***	0.540***
	(0.202)	(0.117)	(0.142)	(0.091)
Constant	2.302**	1.818	4.428***	3.201***
	(1.020)	(1.201)	(0.912)	(0.439)
Observations	298	287	297	298
R-squared	0.383	0.573	0.499	0.671
Adjusted R-squared	0.352	0.551	0.474	0.655

Note: Dependent variables public works, fire, police, and total expenditures are logged.
Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

capita number of jobs and per capita income are positively associated with all expenditure categories. Total expenditures per capita are significantly increasing in per capita state revenue but disaggregate expenditure categories are decreasing in per capita state revenue. In comparison to all other counties except Duke County, Barnstable County (Cape Cod) has significantly higher fire, police, and total expenditures per capita. Duke County, exhibits significantly higher expenditures with the exception of fire.

Panel A of Table 3 introduces linear and quadratic forms of population density to the baseline model. Only fire expenditures per capita produce a strong linear relationship with respect to population density. A one standard deviation increase in density increases fire expenditures per capita by 22.76% in the linear specification. The slight significance on the squared density term indicates the possibility of economies of scale for fire expenditures beyond densities of 6,186 people per km^2. Given the mean density of 1,295 and the maximum density of 7,091 across the municipalities, the economies of scale only occur in relatively high density municipalities. The relationship between density and total expenditures is strongly quadratic. Expenditures are initially decreasing as density increases but for densities beyond 3,207 people per km^2 congestion costs begin to accrue. Again, this inflection point occurs at relatively high densities. Fit for fire and total expenditures is somewhat improved over the baseline with the inclusion of the density measure. Density is not significant within the public works or police expenditures specifications.

Referring to Panel B of Table 3, public works, fire, and police expenditures per capita have significant quadratic associations with the proportion of land developed within a municipality's boundaries. The coefficients in the quadratic public works model

Table 3. Municipal expenditures and traditional land use measures.

	Public Works		Fire		Police		Total	
	Linear	Quad.	Linear	Quad.	Linear	Quad.	Linear	Quad.
Panel A: Density								
Residents (1000s) per km2	−0.0501	−0.131	0.203***	0.435***	0.047	0.074	0.003	−0.119**
	(0.0331)	(0.118)	(0.058)	(0.150)	(0.035)	(0.089)	(0.019)	(0.055)
Residents (1000s) per km2 sqr.		0.0124		−0.035*		−0.004		0.019***
		(0.0156)		(0.021)		(0.013)		(0.007)
Constant	2.468**	2.587**	1.145	0.824	4.287***	4.240***	3.189***	3.370***
	(1.047)	(1.020)	(1.201)	(1.249)	(0.924)	(0.938)	(0.447)	(0.426)
Observations	298	298	287	287	297	297	298	298
R-squared	0.386	0.387	0.595	0.600	0.502	0.502	0.671	0.681
Adjusted R-squared	0.353	0.352	0.573	0.576	0.475	0.474	0.654	0.663
Panel B: Proportion of Land Developed								
Proportion land developed	−0.0428	−1.874***	1.051***	3.598***	0.093	2.186***	−0.054	−0.115
	(0.242)	(0.685)	(0.276)	(0.879)	(0.162)	(0.595)	(0.087)	(0.270)
Proportion land developed sqr.		2.343***		−3.249***		−2.680***		0.079
		(0.830)		(0.921)		(0.673)		(0.328)
Constant	2.296**	2.096**	1.944	2.255*	4.441***	4.560***	3.194***	3.187***
	(1.022)	(0.980)	(1.205)	(1.208)	(0.916)	(0.918)	(0.439)	(0.441)
Observations	298	298	287	287	297	297	298	298
R-squared	0.383	0.399	0.590	0.604	0.499	0.522	0.672	0.672
Adjusted R-squared	0.350	0.364	0.567	0.580	0.472	0.495	0.654	0.653

Controls in all specifications. Robust standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

indicate expenditures decrease at a decreasing rate; however, beyond proportions of 0.400, expenditures begin increasing at an increasing rate. This inflection point occurs within one standard deviation of the mean proportion of 0.267. Both fire and police expenditures display the opposite relationship where expenditures initially increase at decreasing rates. Savings associated with increasing proportions of land developed exist beyond proportions of 0.554 and 0.408 for fire and police expenditures respectively. These inflection points imply savings exist just within and beyond one standard deviation from the mean proportion of land developed. The inclusion of the linear and quadratic forms of proportion of land developed produce marginal improvements in the adjusted R-squared over the baseline model with the exception of the total expenditures specification where proportion of land developed is not significant.

5.2. Multidimensional metrics

Table 4 presents the main regression specifications.[16] Regressions on single metric groupings were performed for comparison to coefficients produced within the main specifications with the full set of land use metrics to assess the stability of coefficients (see Tables C – H in the supplementary appendix). Signs and magnitudes of the coefficients remain generally consistent across the single metric and main specifications. Of the quadratic variables selected by the Lasso methodology, only two are strongly significant: low/medium-density residential concentration within the public works specification and low/medium-density residential centrality within the fire expenditure specification. Specifications with these variables are included in Table 4. Discussion of the results for each municipal expenditure specification follows.

5.2.1. Public works

Within the linear model, notions of general compactness (concentration and centrality) do not produce strong support of efficiency gains. In particular, expenditures increase 8.93% with a one standard deviation increase in low/medium-density residential concentration. There appears to be no compactness benefit associated with centrality. Coefficients are positive with commercial centrality somewhat significant implying a 7.17% increase in expenditures when commercial centrality increases by one standard deviation.

Isolation of use produces consistent negative coefficients across all use types with commercial use significant at the 5% level. Here, a one standard deviation increase in commercial isolation decreases expenditures by 9.56%. The effect of mixed-use is also consistently negative across all land use types with the interaction between commercial and both residential uses significant at the 5% level. A one standard deviation increase in the commercial to low/medium or multi/high-density residential interaction decreases public expenditures per capita by 10.03% and 10.09% respectively.

More fragmented use, or smaller patch areas, are hypothesized to be more costly to service based on issues of accessibility. This relationship holds for multi/high-density residential but it is not significant. Both residential perimeter-to-area ratios are positively related to public works expenditures with multi/high-density residential highly significant. This implies some support for the hypothesis that expenditures are greater when servicing complex winding land use patterns. However, the effect is small as a one

Table 4. Municipal expenditures and multidimensional metrics.

	Public Works		Fire		Police	Total
	Linear	Quad.	Linear	Quad.	Linear	Linear
Low/med. resid. cnc.	0.815**	−3.222***	0.549	0.826*	−0.447	0.392**
	(0.408)	(1.003)	(0.449)	(0.461)	(0.352)	(0.180)
Low/med. resid. cnc. sqr.		10.891***				
		(2.559)				
Comm. cnc.	−0.327	−0.143	−2.235***	−2.483***	−0.821*	−0.544***
	(0.444)	(0.425)	(0.647)	(0.649)	(0.448)	(0.205)
Low/med. resid. ctr.	0.014	0.103	−0.172	0.525	0.050	−0.162**
	(0.161)	(0.159)	(0.271)	(0.336)	(0.187)	(0.076)
Low/med. resid. ctr. sqr.				−1.186***		
				(0.420)		
Multi/high resid. ctr.	0.005	−0.000	−0.015	−0.014	−0.017	−0.006
	(0.022)	(0.023)	(0.034)	(0.032)	(0.028)	(0.009)
Comm. ctr.	0.093**	0.110***	0.069	0.058	−0.031	0.013
	(0.044)	(0.039)	(0.070)	(0.067)	(0.048)	(0.020)
Low/med. resid. iso.	−0.301	0.193	−0.051	−0.086	−0.565	−0.093
	(0.432)	(0.431)	(0.540)	(0.554)	(0.519)	(0.176)
Multi/high resid. iso.	−0.449	−0.535*	−0.040	0.113	0.077	−0.205
	(0.307)	(0.313)	(0.436)	(0.421)	(0.310)	(0.129)
Comm. iso.	−1.457**	−1.502**	0.291	0.272	0.445	−0.476*
	(0.660)	(0.660)	(0.773)	(0.755)	(0.453)	(0.260)
Low/med. to multi/high resid. inter.	−0.098	−0.227	−0.735*	−0.551	−0.160	−0.134
	(0.296)	(0.303)	(0.444)	(0.418)	(0.282)	(0.109)
Comm. to low/med. resid. inter.	−0.935**	−1.038***	0.573	0.486	0.778**	−0.010
	(0.388)	(0.383)	(0.541)	(0.530)	(0.329)	(0.167)
Comm. to multi/high resid. inter.	−0.754**	−0.875**	0.030	0.007	−0.190	−0.294*
	(0.378)	(0.361)	(0.493)	(0.482)	(0.307)	(0.151)
Low/med. resid. patch	2.621	1.763	0.742	0.381	−0.851	−0.147
	(1.721)	(1.693)	(1.297)	(1.294)	(0.829)	(0.505)
Multi/high resid. patch	−0.319	−0.027	−0.232	−0.158	0.240	−0.138
	(0.413)	(0.412)	(0.315)	(0.311)	(0.221)	(0.154)
Comm. patch	4.419	3.155	−0.835	0.205	−2.487	0.788
	(4.362)	(4.146)	(4.406)	(4.392)	(2.821)	(1.550)
Low/med. resid. peri./area	0.076*	0.087**	0.116**	0.152***	0.024	−0.045***
	(0.045)	(0.040)	(0.055)	(0.055)	(0.032)	(0.017)
Multi/high resid. peri./area	0.018***	0.015**	0.010	0.009	0.008	0.017***
	(0.006)	(0.006)	(0.011)	(0.010)	(0.007)	(0.002)
Comm. peri./area	−0.009	−0.012	0.023	0.013	−0.013	−0.010
	(0.017)	(0.016)	(0.020)	(0.019)	(0.014)	(0.007)
Constant	1.963*	2.391**	1.706	1.488	4.840***	2.973***
	(1.056)	(1.052)	(1.305)	(1.300)	(0.993)	(0.455)
Observations	298	298	287	287	297	298
R-squared	0.452	0.494	0.615	0.626	0.552	0.722
Adjusted R-squared	0.389	0.433	0.568	0.578	0.500	0.690

Controls in all specifications.Robust standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

standard deviation increase in the low/medium- and multi/high-density residential ratios increases public expenditures by only 2.14% and 2.31% respectively. Commercial perimeter-to-area ratio is negatively associated with public expenditures but is not significant.

Comparing the linear model to the model that includes the quadratic form of low/medium-density residential concentration, the strongly significant linear and quadratic coefficients imply that expenditures initially decrease as concentration increases but increase as concentration surpasses 0.148. This inflection point is about 1/5th a standard deviation above the low/medium-density residential concentration mean of 0.125. Benefits of compactness through concentration of low/medium-density residential use exist up to a point. The magnitude, sign, and significance of remaining coefficients are qualitatively consistent with the linear model.

Overall, there appears to be suggestive relationships between the multidimensional metrics and the public works expenditures. There is some support for increasing residential concentration (up to a point) and commercial/residential mixed use along with decreasing the complexity of residential use patterns in order to provide public works services more efficiently. Coefficients may be slightly attenuated as public works contains a number of different expenditures that may not all be affected similarly by development patterns, although it is likely there are some commonalities. Further, large variations in service levels exist across the municipalities examined. Of the 351 Massachusetts municipalities, 290 do not have municipal water or sewer service, 14 have only sewer, 16 have only water, and 31 have both water and sewer (Massachusetts Water Resources Authority, 2017). With respect to waste management, low-density residential areas in smaller municipalities are serviced by transfer stations, not curbside pickup.[17] When comparing the variation in public works expenditures explained by the multidimensional metrics as compared to density and proportion of land developed, it is clear that the multidimensional metric specification with the addition of the quadratic concentration term dominates. Adjusted R-squared increases by 8% over the baseline regression (Table 2) as compared to the 1.2% increase gained in the quadratic specification for proportion of land developed.

5.2.2. Fire

The hypothesis that compact land use patterns may decrease fire expenditures possibly through the increase in accessibility has some support. Focusing on the linear fire expenditure specification, significance and sign on commercial concentration indicates there are benefits to higher levels of compactness in the form of concentration. Specifically, a one standard deviation increase in commercial concentration decreases fire expenditures by 20.92%. Low/medium-density residential concentration is positively associated with expenditures but is not significant. Compactness, as measured through centrality, is not significantly associated with fire expenditures for any land use type although both residential coefficients are negative.

Proximity to uses with high fire-hazard rates is hypothesized to increase fire expenditures. Coefficient signs support this hypothesis but significance is limited. With respect to isolation, residential uses display negative coefficients (low-hazard) whereas the commercial isolation coefficient is positive (high-hazard). When residential use is proximate to commercial use, the interaction coefficients indicate that expenditures increase although they are not significant. In contrast, expenditures decline as proximity between residential uses increases.

A strong hypothesis for the relationship between mean patch area and fire expenditures does not exist and empirically there appears to be no significant relationship for any use type. Coefficients for the perimeter-to-area ratio support the hypothesis of larger expenditures being required to service more complex, winding land use patterns. All coefficients are positive although low/medium-density residential is the only coefficient to display moderate significance. Here, a one standard deviation increase in the perimeter-to-area ratio increases expenditures by 3.28%.

The quadratic specification adds a quadratic term for low/medium-density residential centrality. The highly significant quadratic term indicates that expenditures are initially increasing as centrality increases but are decreasing as centrality increases beyond 0.221. The marginal effects at centrality values below 0.221 are not significant at the 1% level given the lack of significance on the linear term. Marginal effects at centrality levels above 0.70 are significant at the 1% level. The low/medium-density residential centrality mean is 0.156 implying that the quadratic effect is only significant for municipalities with relatively high levels of centrality. The remaining land use coefficients are qualitatively similar to the linear specification, but notably, the significance on low/medium-density residential perimeter-to-area ratio is now larger in magnitude and highly significant.

To summarize, there is some support for increasing compactness (increasing commercial concentration and residential centrality) with respect to lowering fire expenditures per capita. Further, expenditures may also be reduced if low/medium-density residential land use patterns are less complex and winding. In terms of explanatory power, the multidimensional metrics perform similarly to the quadratic population density specification where the adjusted R-squared increases over the baseline specification by about 2.5%.

5.2.3. Police

Signs on concentration and centrality coefficients indicate possible benefits of compactness with respect to low/medium-density residential and commercial concentration as well as multi/high-density residential and commercial centrality. However, only commercial concentration displays any significance. Here, a one standard deviation increase in commercial concentration decreases expenditures by 8.56% with significance at the 10% level.

Isolation shows no significant association with police expenditures although signs indicate increasing expenditures for more isolated multi/high-density residential and commercial isolation. Regarding the effect of mixed-use on police expenditures, there is a somewhat significant positive effect for increased interaction between commercial and low/medium-density residential use. A one standard deviation increase in interaction of the uses increases police expenditures by 9.19%. Whether this is suggestive support for Browning et al.'s (2010) findings of increased nonviolent crime in mixed-use areas is unclear and warrants more investigation within future research. The negative and insignificant coefficient on the interaction between commercial and higher density residential use implies that at least in the Massachusetts context, the typical lower density form of suburban mixed-use and not more higher density urban mixed-use may contribute to higher police expenditures.

Similar to public works and fire expenditures, mean patch area does not have a significant or consistent influence on police expenditures. Perimeter-to-area coefficients display the same positive relationships as public works and fire expenditures although none are significant.

In general, police expenditures have limited significant associations with multidimensional metrics. However, there is suggestive evidence that compactness in the form of commercial concentration may decrease expenditures and that commercial and lower density residential mixed-use may be associated with increased expenditures.

The improvement in fit over the baseline specification is similar to the improvement from the quadratic proportion of developed land specification; the adjusted R-squared increases by 2.6%.

5.2.4. Total

Given the various expenditures included within the aggregate category, hypotheses regarding the effect of development patterns on total expenditures are general at best. With respect to the multidimensional metrics, consistencies across expenditure categories are highlighted below.

Similar to the public works and fire expenditure specifications, total expenditures are positively associated with low/medium-density residential concentration. Specifically, a one standard deviation increase in the concentration increases total expenditures per capita by 4.20%. Also similar to all three disaggregate specifications, total expenditures are decreasing in commercial concentration. A one standard deviation increase in commercial concentration decreases expenditures by 5.76%. Centrality displays a somewhat significant and negative coefficient for low/medium-density residential centrality. Here, a one standard deviation increase in centrality decreases total expenditures by 3.58%. The significant effects of concentration and centrality are small but do indicate benefits to compact land use in terms of concentrated commercial use and central low/medium-density residential use.

Isolation coefficients are similar to those in the public works specification. All coefficients are negative with commercial isolation displaying some significance, the effect is small, however. A one standard deviation increase in commercial isolation decreases expenditures by 3.23%. All interaction coefficients are negative but only with minimal significance for commercial and multi/high-density residential interaction.

Mean patch area is not a significant predictor of total expenditures as is the case for the disaggregate expenditures. Multi/high-density residential perimeter-to-area is consistently positive and significant across all models with the exception of the police expenditures where it is insignificant but remains positive. With respect to total expenditures, a one standard deviation increase in the ratio increases expenditures by 2.18% – a magnitude consistent with other expenditures. Unlike the disaggregate expenditures, low/medium-density residential perimeter-to-area is negatively associated with total expenditures although the effect size is small. Here, a one standard deviation increase in the perimeter-to-area ratio decreases expenditures by 1.24%.

To summarize, total expenditures may benefit from compact land use in the form of concentrated commercial use and central low/medium-density residential use. However, consistent with fire and public works expenditures, concentrated low/medium-density residential use may increase expenditures (holds for high concentration values with respect to public works). Also consistent with the disaggregate expenditures, more complex winding multi/high-density residential land use patterns increase expenditures but the effect is small. Comparing the explanatory power of the set of multidimensional metrics to that of the quadratic density specification, which proved the most significant, the increase in adjusted R-squared over the baseline is 3.5% as compared to 0.008% from the density specification.

6. Conclusion

The results of this research highlight the complex relationship between land use patterns and municipal expenditures while providing both support for and against development patterns advocated by Smart Growth and New Urbanism literatures. While density provides an intuitive link between land use intensity, economies of scale, and congestion costs, it is ill-equipped in identifying more micro-level patterns and interactions of uses within a municipality. Similarly, proportion of land developed provides a general notion of the spatial extent of developed land but tells nothing of the interior patterns of land use. Using multidimensional metrics developed within planning and landscape ecology literature, municipal expenditures are shown to be influenced by complex characteristics of land use. Furthermore, these metrics are better predictors of public works and total expenditures than density or proportion of land developed. Explanatory power within fire and police expenditures for the multidimensional metrics is similar to the traditional metrics. In general, these results imply that alternative land use metrics capture significant relationships between land use patterns and municipal expenditures not captured by density or proportion of land developed.

The findings presented here provide mixed support for more compact, mixed, and connected development patterns with respect to municipal expenditures. In general, concentration of land use types and the perimeter to area ratio of land use types prove to be the most significant predictors of municipal expenditures. Specific relationships are as follows. Concentrated commercial use leads to decreases in fire, police, and total expenditures where higher levels of concentration are associated with less diffuse land use patterns. Public works expenditures are initially decreasing in low/medium-density residential concentration but at higher levels of concentration, costs are accrued. Fire and total expenditures are also increasing in low/medium-density residential concentration. There is conflicting evidence on the benefit of more central land use. Fire and total expenditures are decreasing in low/medium-density residential centrality (for fire expenditures, this only holds at high levels of centrality). However, increasing commercial centrality is associated with increases in public works expenditures. Significant benefits with respect to commercial and residential mixed use only exist for public works expenditures with somewhat significant costs associated with increasing proximity of commercial and low/medium-density residential use with respect to police expenditures. In support of Smart Growth hypotheses, more complex, winding residential land use patterns significantly increase public works, fire, and total expenditures.

In addition to the significant relationships we find between land use patterns and municipal expenditures, it is also worthwhile to highlight the strength of a number of controls considered. In particular, income per capita, proportion of population over 65, Republican vote proportion, and proportion of homes built before 1940 are all strong predictors of municipal expenditures.

As the first step in bringing multidimensional land use metrics into empirical analysis of the relationship between development patterns and municipal expenditures, our findings indicate the importance of incorporating more complex land use pattern measures. Policy-wise, New Urbanism and Smart Growth advocates should mollify the emphasis put on density for two reasons. First, increasing density does not necessarily translate into lower municipal expenditures per capita and may have a nonlinear relationship with particular types of expenditures. Second, attention should be paid to different land use patterns that show a more clear connection to municipal expenditures. More research is warranted on these metrics as the results presented here indicate some aspects of compact, mixed, connected developments may in fact increase municipal expenditures.

This research is foundation building and exploratory; thus, it comes with caveats and proposals for future research. For example, Sarzynski et al. (2014b) suggest that the "bundle type" of land use patterns (a typology) should be considered instead of individual measures of land use when investigating the relationship between land use patterns and economic consequences. This clustering methodology is appropriate when comparing land use of urbanized or metropolitan areas where commonalities are more likely to exist across the various land use metrics considered. However, in this study the comparison is across municipalities within Massachusetts where the variation in land use patterns is much larger than across large metro areas. Variable reduction techniques were attempted but did not produce clear typologies. With the results of the present study in mind, an important and relevant followup would entail the comparison of a national set of urban/suburban municipalities. Here, the comparison would be across similar municipality sizes/types and thus a creation of a set of typologies is likely to be successful.

In addition to focusing on a national set of municipalities, investigation into a dynamic model of the relationship between land use patterns and municipal expenditures would be worthwhile. With a panel of land use metrics and municipal data, the relationship between land use patterns and municipal expenditures can be identified through not only cross-sectional variation but also variation over time as land use patterns evolve. A large hurdle to this line of research is a lack of national data. Land use data are available for multiple years for Massachusetts municipalities; however, the construction of a consistent panel is made difficult due to changes in the measurement techniques applied to the orthoimagery data overtime, lack of municipal expenditure data for earlier decades, and limited variation in development for many Massachusetts municipalities over the decades observed. At the time of this research, a national dataset with equivalent quality and content as the Massachusetts dataset did not exist. With the optimism that such data will be available in the future, we look forward to expanding the methodologies presented here to a national set of municipalities.

Notes

1. Here, an average county is considered to have a population of 88,000 and total direct expenditures of $3,200 per capita.
2. Categorization of municipalities from the Metropolitan Area Planning Council (2017).
3. See Sohn (2016) for a summary.
4. Institutional uses include schools, churches, colleges, hospitals, museums, prisons, town halls or court houses, police and fire stations, parking lots, dormitories, university housing, and public open green spaces.
5. Highways/streets snow and ice, highway/streets other, waste collection and disposal, sewerage collection and disposal, water distribution, parking garage, street lighting and other.
6. Legislative, executive, accountant/auditor, collector, treasurer, law department, town/city counsel, public buildings/properties maintenance, assessors, operation support, license and registration, land uses, conservation commission, and others.

7. Emergency medical services, inspection, and others.
8. Health services, clinical services, special program, veteran's services, and other.
9. Library, recreation, parks, historical commission, celebrations, and others.
10. Workers' compensation, unemployment, health insurance, other employee benefits, other insurance, and retirement.
11. Retirement of debt principal, interest on long term debt, interest on short term debt, and other interest.
12. Court judgments and other unclassified expenditures.
13. Employment per capita, income per capita, and state revenue enter as natural logs. Log transformation of these variables and the dependent variables are taken to account for outliers and nonlinear relationships.
14. See Tibshirani (1996) for more details.
15. The instruments were based on 1971 land use data.
16. Control coefficients are suppressed in the main regression tables. They can be found in Table I in the supplemental materials. Signs and magnitudes are comparable to those in Table 2.
17. Dummy variables for water and sewer service levels were considered but were not significant.

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