Costs of sprawl in the metropolitan West: census block group evaluation of public service expenditures

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Introduction

The multifaceted impacts of built form on both communities and individuals are a national issue (Banzhaf and Lavey 2010). Built form, sometimes referred to as urban form, is simply the spatial structure of cities and towns (Lowry and Lowry 2014) as established by the buildings, roads and open spaces in our communities and how we use them. Built form is a continuum where on one side there is clustered, dense, development and the other side there is dispersed, low-density development, agricultural lands and open spaces. Typical characterizations of the built environment such as urban, rural, village, traditional neighborhood, smart growth, sprawl, etc. fall at different points along this continuum.

Among the numerous impacts of built form (e.g. Ewing and Hamidi 2015) the relationship between the built environment and public service costs is extremely relevant as municipalities and counties face fiscal stress due to rising costs and recession (Reuters 2013). The preponderance of research suggests low density developments distant from nodes of service provision are more expensive to service than proximate, high-density developments (e.g. Carruthers and Ulfarsson 2008). Local governments, in turn, largely acknowledge these realities. The negative impacts of dispersed development are frequently mentioned and policies to mitigate these problems are often put forward in community plans. However, the impacts of programs meant to address problems with dispersed built environments are limited (Ewing and Hamidi 2015). Government’s inability to mitigate the fiscal and other stresses of differing urban forms is due in part to the lack of actionable information available at the scale of land-use change, the land parcel. With continuing population and second home growth (Taylor and Lanning 2012a, b) these issues are particularly important in the West. While the West is not necessarily more sprawling than other regions of the country, the interface of urban and natural areas in western cities (Travis 2007) makes informed policy and decision making especially critical.

This paper seeks to extend research on the relationship between built form and public service costs in order to develop methods and information useful to planners and decision makers in the metro West. The analysis looks at changes in built form and land use over time in a western metropolitan area. Change in built form over time is measured with an index that when incorporated in an econometric model enables linking change in the built environment with change in spending on policing services. Impacts are made spatially explicit and actionable through census block group and grid cell mapping of both expenditure and fiscal efficiency of public service provision. Fiscal efficiency is defined as whether an area pays its way for a public service or not. Results of the econometric model show the pattern of residential development is a significant determinant of police expenditures. Outputs of the spatial model show dispersed development incurs slightly lower per unit area expenditures when compared with highly clustered development. However, more dispersed development does not generate the revenue needed to pay for services. Spatial results also show limited uncertainty found primarily in transition areas between highly clustered urban and more dispersed development types.

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**Study Area, Methods and Data**

This paper presents a case study investigation of Natrona County, Wyoming. Like many communities in the West, Natrona County is an example of a community growing at a moderate rate with considerable development occurring beyond the urban fringe. Over the time period of this study, 1990 – 2011, population in the unincorporated portion of Natrona County changed by 22.9% from 9,131 to 11,219. The City of Casper, one of two metropolitan areas in Wyoming, is the seat of government and the geographic source of most public service provision Natrona County. Casper grew by 20% from its 1990 population of 46,756 to a 2011 population of 56,104 (WDEA 2011a, c).

The Natrona County Comprehensive Plan (1998), still current in January 2016, outlines major policies concerning future physical development including limiting sprawl and the complementary issue of maintaining culturally traditional uses such as agriculture, mineral development and ranching. The plan encourages compact growth and infill development within the City of Casper Metropolitan Planning Organization (MPO) boundary with the aim of maximizing efficiency in public service provision and preserving environmental quality. The document presents the benefits of compact development as reduced need for new infrastructure, land savings, improved efficiency, reduced cost of public services, reduced sprawl and conservation of open space (Natrona County 1998). The City of Casper Comprehensive Plan is similar. The City plan calls for compact development, encouraging infill and redevelopment; directing development toward vacant or underutilized parcels where city services and infrastructure already exist, separation of urban and rural uses, centralizing government, commercial and residential uses and increasing land-use intensity and employment in urban areas (Balloffet 2000).

As detailed in Lieske et al. (2015) an econometric model of local government service provision may be developed as a system of equations including both an expenditure function and a production function. The expenditure function, **Equation (1)**, explains local government service expenditure as a function of built form, local government inputs, other service conditions and unobserved factors. The production function, **Equation (2)**, explains local government production of public service outputs as a function of expenditures, service conditions and unobserved factors.

\[
E = \beta_a + \beta_b M + \beta_c I + \beta_d C_E + u_1
\]

\[
S = \beta_0 + \beta_1 E + \beta_2 C_s + u_2,
\]

where,

- **E** represents total annual per service local government expenditure,
- **M** is an index of built form,
- **I** is a vector of essential inputs related to **E**,
- **S** represents a level of public service outputs, in this case a measure of public safety;
- **C_E**, **C_s** represent sets of service conditions relevant to the expenditure and production functions, respectively,
- **\( \beta \)** are estimated parameters on the relevant variables, and
- **u** are residuals.

**Equations (1) and (2)** were evaluated as a system of equations using three stage least squares (3SLS). The 3SLS approach compensates for potential endogeneity between law enforcement expenditures and public safety. Data incorporated in the econometric model are summarized in **Table 1**. Data are annual time series observations covering 22 years from 1990–2011.
Table 1: Definition of variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$LE_{EXP}$</td>
<td>Operating Expenditures of the Natrona County Sheriff's Dept.</td>
<td>$USD 2011</td>
</tr>
<tr>
<td>Res</td>
<td>Index of residential built form</td>
<td>Spatial Index</td>
</tr>
<tr>
<td>WageSalary</td>
<td>The wage and salary component of personal income for Natrona County</td>
<td>$USD 2011</td>
</tr>
<tr>
<td>PopRural</td>
<td>Population of the unincorporated areas of Natrona County</td>
<td>Individuals</td>
</tr>
<tr>
<td>Officers</td>
<td>Officers in the Natrona County Sheriff’s Department</td>
<td>Individuals</td>
</tr>
<tr>
<td>t</td>
<td>Time</td>
<td>Years</td>
</tr>
<tr>
<td>PSI</td>
<td>Public Safety Index for the unincorporated portion of Natrona County; the inverse of crime rate</td>
<td>Index</td>
</tr>
<tr>
<td>CEN</td>
<td>Central Wyoming Cost of living index, a summary of price data</td>
<td>Index</td>
</tr>
</tbody>
</table>

Police expenditure data are the operating expenditures of the Natrona County Sheriff’s department published by the Wyoming Department of Audit (2012) and earlier titles in the same series. Data on the number of county law enforcement officers are published by the Wyoming Department of Criminal Investigation (2012). Additional service conditions used in the estimation of policing services expenditures are the wage and salary component of personal income in Natrona County (Bureau of Economic Analysis 2012) and data on the population of the unincorporated portions of Natrona County (Wyoming Division of Economic Analysis 2013a, b, c). The index of built form captures annual changes in clustering and dispersion by land use for the time period of the study. The index is a single dimension spatial statistical measure based on the clustering and distribution of building value data made available by the Wyoming Department of Revenue (2013a). The index was developed following Lieske et al. (2012) using annual land-use data snapshots modeled following Lieske and Gribb (2012). The index is based on the Natrona County subset of the January 2013 State of Wyoming parcel dataset (Wyoming Department of Enterprise Technology Services 2013).

The dependent variable of the production function is a public safety index (PSI) measured as the inverse of the crime rate for the unincorporated area of Natrona County. PSI was calculated from index crime data from the Wyoming Department of Criminal Investigation (2012) and earlier editions of the same title and population data from the Wyoming Division of Economic Analysis (WDEA 2013a, b, c). The regional cost of living index for central Wyoming, including Natrona County, was also incorporated in the analysis. The index includes food, housing, apparel, transportation, medical, recreation, personal care, and “all items” (WDEA 2013d). A time-trend variable was included in the estimations in order to de-trend the data.

Revenue and fiscal efficiency mapping incorporated tax district and mill levy data assigned to each parcel based on spatial data from the Wyoming Department of Revenue (2013b, c). To address concerns about the influence of the modifiable areal unit problem, expenditure and fiscal efficiency estimations were developed for four analysis layers: 1) a grid with cells one square mile in size, 2) a grid with cells one square mile in size integrated with census block groups less than one square mile in size, 3) a grid with cells one square kilometer in size and, 4) a grid with cells one square kilometer in size integrated with census block groups less than one square kilometer in size. Census block groups are useful for research as they may be used to capture land-use change and development patterns at a “fine-grained” resolution (Theobald 2001 p. 544). Census block groups smaller than the grid cell size were integrated with the
analysis grids to refine the spatial resolution of the modeling and to explore the use of more meaningful geographic units than arbitrarily sized grid cells.

Parcel-level calculations of residential property tax were aggregated for each areal unit in each analysis layer. Property tax revenues within the areal units of the analysis layer were multiplied by the average percent of property taxes that cover Sheriff’s expenditures in the County. This was calculated by averaging the rate of Sheriff’s expenditures with overall property tax revenues for 2001 through 2011 (years where total revenue data are available). The average of this value across the time period is 8.4 percent. This value represents the amount of property tax allocated to cover policing services expenditures. When the index of built form is a significant determinant of expenditures it may be spatially disaggregated in order to estimate and map the contribution of each areal unit to expenditures (Lieske et al. 2015). By contrasting revenue with expenditure for each areal unit, fiscal efficiency may be mapped in a spatially explicit fashion.

There are number of sources of uncertainty in the modeling process including the aggregation of parcel data to the areal units of the analysis layers, the expenditure model, and the fiscal efficiency model. Uncertainty evaluation of the final model outputs, the fiscal efficiency maps, is evaluated through Monte Carlo simulation of the error term associated with the expenditure model presented in Table 2. Following Griffiths et al. (1993), the Monte Carlo simulation is specified with simulated disturbance process using a normal distribution where the mean is equal to the expenditure as influence by each $P_i$ and the variance is the standard deviation of the error term associated with the expenditure estimation, in this case for the 1 square kilometer census block groups analysis layer. The simulation is a three-step process: 1) Use a random number generator to create a sample of simulated, independent errors with a normal distribution (expenditure model residuals are normally distributed); 2) Calculate sample observations of the variable $\mathbf{E}$ (modeled expenditures) based on fixed dependent variables and the simulated errors; and 3) Estimate fiscal efficiency based on these new sample observations. For the analysis layer where one square kilometer grid cells are integrated with census block groups, preliminary results indicated 36 iterations would reduce the overall Monte Carlo Standard Error to less than five percent. Random errors were generated using a GIS scripting function that generates random numbers with a normal distribution. Stochastic disturbances were incorporated in the ceteris paribus evaluation of the change in policing services expenditures as influenced by urban form allowing expenditure and efficiency to be re-calculated for each iteration.

**Results**

The index of built form was calculated for (1) residential land use, (2) combined commercial and industrial land uses and, (3) residential land use incorporating census block groups. Greater index values suggest greater clustering and lower values suggest greater dispersion. Results for Natrona County using the 1 square mile grid are shown in Figure 1. The trends in Natrona County are a decrease in residential clustering and an increase in commercial clustering over the time period of the study.
Econometric model results (Table 2) indicate a statistically significant relationship between residential built form and law enforcement expenditures. Results are largely consistent across the four analysis layers. Regressions one and two are specified with the standard and the quadratic form of the index of built form \((\text{Res} \text{ and } \text{Res}^2)\). The sign on the standard form of the index is negative, indicating that as the built environment becomes more dispersed, expenditures on policing services increase. The positive relationship between expenditures and the square of the index demonstrates that as clustering decreases expenditures increase at an increasing rate. In regressions three and four residential development is specified as the inverse of the index. The positive sign indicates that as residential development becomes more dispersed, costs of policing services increase. The positive sign on the income variable \((\text{wagesalary})\) indicates policing services expenditures increase commensurately with the wage and salary component of personal income. The positive sign on the population variable \((\text{poprural})\) indicates expenditures increase commensurately with increases in population in the unincorporated areas of the county. The positive sign on officers and negative sign on officers squared indicates increasing the number of law enforcement officers increases expenditures at a decreasing rate. This suggests economies of scale in officer staff sizes.

Figure 1. Change in built form over time, Natrona County, Wyoming 1990 – 2011
Table 2: Regression results

<table>
<thead>
<tr>
<th></th>
<th>1 Sq. Mile Grid</th>
<th>Sq. Mile + Block Groups</th>
<th>1 Sq. km Grid</th>
<th>Sq. km + Block Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>b/se</td>
<td>b/se</td>
<td>b/se</td>
<td>b/se</td>
</tr>
<tr>
<td>LE_EXP</td>
<td>218.370***</td>
<td>145.993**</td>
<td>(61.71)</td>
<td>(50.83)</td>
</tr>
<tr>
<td>1/res</td>
<td>7.37E-07</td>
<td>2.26E-06***</td>
<td>2.97E-07</td>
<td>(5.03E-07)</td>
</tr>
<tr>
<td>Res</td>
<td>-57.952***</td>
<td>-18.131***</td>
<td>0.0003427*</td>
<td>0.0002974</td>
</tr>
<tr>
<td></td>
<td>(15.95)</td>
<td>(4.07)</td>
<td>(0.0001611)</td>
<td>(0.0001541)</td>
</tr>
<tr>
<td>Res^2</td>
<td>4.721***</td>
<td>1.668***</td>
<td>0.0000382**</td>
<td>-0.00002787*</td>
</tr>
<tr>
<td></td>
<td>(1.38)</td>
<td>(0.38)</td>
<td>(0.00001)</td>
<td>(0.00001)</td>
</tr>
<tr>
<td>WageSalary</td>
<td>0.056*</td>
<td>0.082***</td>
<td>0.042*</td>
<td>0.046*</td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.0001)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>Officers</td>
<td>0.107</td>
<td>0.272***</td>
<td>0.040</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.06)</td>
<td>(0.04)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>constant</td>
<td>176.712***</td>
<td>37.884***</td>
<td>-19.017***</td>
<td>-12.507***</td>
</tr>
<tr>
<td></td>
<td>(45.28)</td>
<td>(10.75)</td>
<td>(3.42)</td>
<td>(2.33)</td>
</tr>
<tr>
<td>R-sqr</td>
<td>0.9559</td>
<td>0.9743</td>
<td>0.9656</td>
<td>0.9647</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PSI = dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>LE_EXP</td>
</tr>
<tr>
<td>(2.59)</td>
</tr>
<tr>
<td>CEN</td>
</tr>
<tr>
<td>(0.63)</td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>(0.37)</td>
</tr>
<tr>
<td>constant</td>
</tr>
<tr>
<td>(5.10)</td>
</tr>
<tr>
<td>R-sqr</td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001

Estimation of the public service production function is shown in the lower portion of Table 2. In regressions two, three and four, the instruments for law enforcement expenditures and the central Wyoming cost of living index are significant determinants of public safety. The positive coefficients on LE_EXP suggests as expenditures on policing services increase public safety also increases. The negative sign on the cost of living index indicates that increases in costs of living
are associated with decreases in public safety. This likely indicates that in times of rising costs police dollars have less purchasing power. Post-estimation tests showed no evidence of serial correlation or heteroskedasticity in the estimations. The similarity of results across the four analysis layers indicates the model structure and specification is robust across varying spatial units.

Revenue mapping and expenditure model results for econometric model #4 are presented in Figure 2. The revenue map shows higher revenues within the MPO boundary and lower revenues in outlying areas. Expenditure model results show higher expenditures in the central area and decreased expenditures in outlying areas.

Figure 2. Revenue model (left / green ) and expenditure model (right / red) results; 1 square kilometer grid with census block groups

Fiscal Efficiency results for econometric model 4 are presented in Figure 3. Most areas that are fiscally efficient for the provision of county policing services are within or near the MPO boundary. The small area in the southern part of the county along Wyoming Highway 220 indicated as fiscally efficient is adjacent to a recreation area, the Alcova reservoir. Taken together, Figure 2 and Figure 3 show dispersed development incurs slightly lower per unit area expenditures when compared with highly clustered development, but more dispersed development does not generate the revenue needed to pay for services. Mapped property tax revenue, expenditure and fiscal efficiency model results from the other econometric models are consistent with the results presented in Figures 2 and 3.
Figure 3. Fiscal efficiency of county policing services

Results of the Monte Carlo simulation are presented in Figure 4. Monte Carlo fiscal efficiency (left hand side of Figure 4) shows white areal units that are never fiscally efficient, black areal units that are always fiscally efficient and a blue color ramp where fiscal efficiency is presented as a percentage of model iterations. Light blue colors indicate lower percentages of simulated fiscal efficiency, dark blue colors indicate a greater percentage of simulated fiscal efficiency. Uncertainty is limited to a moderate number of grid cells located within and near the MPO planning area boundary.

Monte Carlo standard errors, representing the deviation from the percentage probability of a cell being fiscally efficient, are presented on the right hand side of Figure 4. Locations where the Monte Carlo simulation indicates cells are efficient in 100 percent of iterations or are inefficient in 100 percent of iterations have a zero standard error. Taken together, the Monte Carlo simulation (Figure 4 left) and Monte Carlo standard errors (Figure 4 right) reveal uncertainty at the edges of the fiscally efficient core of the urban environment of Natrona County. These results suggest robustness of the model where core and outlying areas are modeled with a high degree of certainty. Uncertainty is found primarily in transition areas between highly clustered urban and more dispersed development types.
Figure 4. Monte Carlo Calculation of Fiscal Efficiency (Left) and Monte Carlo Standard Error (Right)

Discussion and Conclusions

This paper presents coupled spatial and econometric models for spatially explicit public services expenditure and fiscal efficiency evaluation. The econometric model is composed of a spatially determined expenditure function and a public service production function of policing services for a county government in the metropolitan West. Results of the expenditure model show residential built form and the number of officers are significant determinants of policing services expenditures in Natrona County. Regression results also show a direct, statistically significant relationship between law enforcement expenditures and the level of public safety provided by the Natrona County Sheriff’s Department.

Mapped results indicate a core area within the MPO boundary that is fiscally efficient for the provision of policing services. More dispersed development incurs slightly lower per unit area expenditures when compared with highly clustered development, but more dispersed development does not generate the revenue needed to pay for services. Results of the Monte Carlo simulation and calculation of Monte Carlo standard errors show uncertainty in fiscal efficiency modeling in transition areas between highly clustered urban and more dispersed development types. Areas of uncertainty present an opportunity for research as these areas may be among the best locations for infill and other new development that minimizes public service costs. Integrating census block groups with the analysis grids offers an improvement, through the use of smaller areas, over other spatially explicit research relating urban form to
costs of public services and is a step toward spatially explicit expenditure evaluation at the
parcel level. Empirical evaluation of a metro area suggests the broader applicability of this
research to the other 381 metropolitan statistical areas in the USA (US Census 2013). However,
less isolated metropolitan areas may experience interaction effects with neighboring
jurisdictions. Simultaneous modeling of multiple jurisdictions and accounting for these
interaction effects is an opportunity for future research. Another potential caveat to the broader
applicability of the model is the availability of well-attributed spatially accurate cadastral data in
many western states.

These results, especially the interplay of revenues and expenditures, suggest an opportunity for
decision makers and planners to better understand the fiscal consequences of land-use
decisions. In order to be maximally useful, revenue, expenditure and efficiency information
should be available at the physical unit of decision making of land-use change, individual
parcels. Such spatially explicit knowledge of the expenditures needed to provide local
government services could enable more informed decision-making and policy and, potentially,
help ameliorate rising local government spending.

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