Determining the Relationship Between Urban Form and the Costs of Public Services

by

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Abstract

Documentation of the need for the evaluation of the influence of urban form on the provision of local government services dates back to the 1950s. The literature indicates low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. Areas diverge from optimal patterns of land use because of information asymmetries and the ability to pass the costs of growth on to the general public. Inefficiencies occur due to average cost user charges which undercharge outlying low-density areas while overcharging interior or high-density areas. There are two potential corrective actions: 1) incorporating information on the fiscal consequences of development, including the spatial component of public service costs, in planning and decision making; and 2) charging each location the full marginal costs of providing services to that location. With the latter action, a subsidy is then eliminated, and efficient development follows. Both approaches require actionable information on the spatial component of public services costs. In order to develop this information, this thesis extends emerging methods in fiscal modeling where government service provision may be modeled with a production function. In this framework the level of service outputs are determined by local government expenditures on inputs and neighborhood (socioeconomic and demographic) characteristics. A corresponding allocation function may be developed where local government expenditures on inputs are determined by socioeconomic and demographic traits, often referred to as neighborhood characteristics. The allocation function is built on a hedonic framework where expenditures are determined by production attributes and neighborhood characteristics may be incorporated as amenity attributes. The research presented here extends previous econometric modeling of public service provision to include a spatial index representing urban form as an explanatory variable in the allocation function. The inclusion of urban form in the allocation function offers the opportunity to determine the spatial component of development costs, enabling more informed decision making.
Declaration of Originality

The work presented in this dissertation, to the best of my knowledge, is the original work of the author and no material published or written by any person except as acknowledged in the text. It has not been submitted previously, either in whole or in part, for a degree at the University of the Sunshine Coast or any other university.

Scott N. Lieske
October 14, 2010

Contributions to Jointly-Authored Publications and this Dissertation

The contents of chapters four and five have been developed into a jointly-authored publication. It is necessary and appropriate to acknowledge the contributions of the respective authors and the relationship of these contributions to other portions of this dissertation. Roger H. Coupal and Donald M. McLeod provided guidance in the development and editing of the economic theory presented in chapters three and five. Sanjeev K. Srivastava provided guidance as well as assistance in editing the spatial theory presented in chapters three and four.

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Chapter One
Introduction and Overview of Urban Form and the Costs of Public services

1.1 The Title of the Research Project
At the leading edge of international research in geography and land planning are efforts
to leverage geospatial technologies to foster the most desirable characteristics of
human habitation: environmental sustainability, economic opportunity, social well-
being, historic preservation, participation in civic processes, and human health. A key
issue touching on sustainability, equity and overall quality of life is fiscally sound
governmental planning. In making development decisions, typically on a per parcel
basis, the income and expenditure implications to the deciding body (government) are
almost never taken into account. There are two reasons. Firstly, local governments,
more often than not, do not incorporate the limited information available on the fiscal
impacts of development into their planning and decision making at any scale. Secondly,
the mechanisms to evaluate the spatial component of development costs do not yet
exist.

Inspired by these broad goals, the purpose of this research is to advance the discussion
of how differences in urban form affect the costs of local government provision of
service. The approach taken is to investigate the relationship between urban form and
the cost of public services using quantitative geography, spatial modeling and
econometric modeling. In order to highlight the general relationship under study, the
title of this research is, Determining the Relationship Between Urban Form and the Costs
of Public Services.

1.2 The Research Puzzle
At the cornerstone of this research are the ideas of fiscal impact analysis and urban
form. Heikkila and Kantiotou (1992) provide a concise definition of fiscal impact analysis:
The evaluation of the impacts of changing land use on local government provision of
service. Paul Tischler provides additional clarification, “A fiscal impact analysis projects the net cash flow to the public sector ... resulting from new development -- residential, commercial, industrial, or other” (Tischler, 2002a, p. 2).

Urban form is defined by Gleeson (2006) as the density, extent and appearance of the urban environment (p. 11). The term urban form as used in this thesis primarily indicates the pattern, including both land use and density, of the built environment. As such the use of the term here de-emphasizes the appearance aspect of Gleeson’s definition. Inherent in the use of the term urban form in this research is the element of the spatial heterogeneity, or lack of spatial uniformity per Anselin and Getis (1992), of the built environment.

The fiscal implications of differing urban forms are important considerations for local government financial health and as evaluation criteria in planning processes. The need for accurate assessments and projections of the fiscal consequences of development is well established and persistent. Burchell and Listokin (1978) articulate the need for fiscal impacts analysis stating that municipalities, “...must be aware of the public costs associated with private development, major rezonings, annexations, or alternative land use plans” (p. 1). Tischler (2002a) augments Burchell and Listokin’s (1978) assessment of the need for fiscal impact analyses by further articulating their benefits. A fiscal impact analysis may be used to predict local government budget deficits. They allow local governments to quantitatively consider land-use policy decisions, levels of service, capital improvement plans and long term financing needs including current and future revenue streams. Fiscal impact analyses are helpful in short and long-term land-use policy and financial planning (Tischler, 2002a). For comprehensive planning, Tischler recommends evaluation of different plan alternatives early in the planning process--prior to making the plan. This allows planners, “...to determine if land use ... and location assumptions generate net revenues or net costs to the jurisdiction” (Tischler, 2002b, p. 4). Gibson (2006) highlights the relevance of this research from an Australian context,
pointing out that the Queensland Integrated Planning Act of 1997 (now replaced by the Sustainable Planning Act of 2009) failed to achieve a number of reforms including equitable and efficient charges for infrastructure. Goetz (2007) further emphasizes the importance of the issue when he juxtaposes the need for the fiscal evaluation of planning alternatives with the idea of planning as a non-repeatable experiment:

State and local governments across the U.S. must weigh carefully the benefits and costs of alternative land use patterns associated with residential construction because they are largely irreversible (Goetz, 2007, p. 20).

Even with numerous and well-reasoned calls for the incorporation of fiscal analysis in planning, and Tischler’s putting forth that location assumptions should be incorporated in fiscal analyses, the influence of urban form on the costs of public services has yet to be quantified. In the late 1940s and 1950s researchers began to note changes in the pattern of the built environment and began to speculate on the social and economic impacts of those changes (e.g. Isard and Whitney 1949; Branch 1951; Isard 1951; Berry 1959; and Carol 1960). Isard and Whitney (1949) mention how changing transportation technologies, from horse to steam to private automobile, all affected the built environment and altered community interactions. Branch (1951) furthers the arguments of Isard and Whitney and specifically mentions the critical influence of urban form:

... from the founding of the city throughout its life, there is a disposition of foci for prime activities, established by a combination of physical factors (necessary or desirable spatial characteristics, proximities, or interrelationships), and socio-economic considerations (such as land and operation costs, taxes, or some aspect of human welfare). The arrangement of these main functional elements—the pattern formed by their location on the ground—exerts a directive influence throughout the community. ... Some of the outstanding urban problems in the United States today relate to the formation of new foci and the modification of the urban-wide pattern of centralization and spatial emphasis, brought about by the decentralization movement toward the suburbs. In planning for any municipality, the location and efficient functioning of these concentrations of activity, the spatial pattern which they form ... are prime considerations (Branch, 1951, p. 274-275).

More recently the term ‘sprawl’ is invoked to indicate far-flung, low-density development and its association with a number of negative externalities. Stone (2008) links sprawl with increased costs of service provision, increased vehicle travel and
congestion, loss of agricultural lands, and increased obesity. Clifton et al. (2008) note similar links between sprawl and a number of negative externalities, including high public service costs. They suggest the negative externalities associated with sprawl have resulted in widespread interest in the topic as well as increased interest in urban form.

Carruthers and Ulfarsson in their 2003 paper, “Urban sprawl and the cost of public services” express the continuing uncertainty in the relationship between urban form and the cost of service provision as they pose two questions, “How does the character of urban development affect the cost of services...?” and, “...what does this imply for land-use planning and growth management efforts administered in the name of economic efficiency?” (Carruthers and Ulfarsson, 2003, p. 503). Discussing the idea that sprawl may result in higher public service costs, they add the evidence supporting this assertion is thin and, “... little is known about the actual relationship between urban form and the cost of services--if any exists at all.”(Carruthers and Ulfarsson, 2003, p. 505)

The emphasis of this analysis is the phenomena of growth expanding beyond the urban fringe into what Theobald (2005, 2001) refers to as exurban development. This trend appears at first to contrast with the worldwide phenomena of urbanization seen in the United Nation’s database, “World Urbanization Prospects” (United Nations, 2010). Cohen (2004) documents worldwide urbanization trends using earlier versions of the same database and puts forward estimates that suggest future large increases in urban population and only modest increases in rural population. Germane to this research, Cohen notes, “...there is an on-going convergence in urban and rural lifestyles so that, to some extent, the traditional distinction between these two groups is becoming redundant” (p. 27). For this research it is noted trends in development beyond the urban fringe and urbanization are occuring simultaneously. The focus of this research is on development beyond the urban fringe.
1.3 Background

A critical question, ‘Why is the built environment constructed at low-densities and in far-flung patterns that appear not to be economically efficient?’ has largely been answered. Areas diverge from optimal urban forms because of cultural preferences, information asymmetries and the ability to pass the costs of growth on to neighbors and/or taxpayers in general. While not the main thrust of this inquiry, the cultural influences yielding dispersed development provide both background and context to the discussion. The cultural influences behind dispersed urban form help explain why we build in a dispersed fashion even though conventional wisdom suggests the pattern is not economically efficient.

The explanation for the cultural predilection in the United States for dispersed development can be traced to the ideas of the social contract theorists. Thomas Hobbes (1588 - 1679), John Locke (1632 - 1704) and Jean-Jacques Rousseau (1712 - 1778), spoke of original freedom and equality; and of basing government on agreement and the consent of the governed (Morris, 1999). Their ideas can be traced to Hobbes’s famous work *Leviathan*. The idea he expressed was that prior to living in commonwealths or states people existed in a ‘state of nature’, a metaphor for the state of perfect individual freedom. From this state people agreed to form social contracts. By joining together under contract individuals limited their freedoms, but each expected to benefit from the contract (Katz, 1995). As government is analogous to social contract, government can be thought of as being created from and the alternative to the state of nature. By entering into a social contract, or supporting a government, individuals accrue various benefits at the expense of certain freedoms.

Hobbes’ interpretation of the state of nature was the natural condition of humankind is a mutually unprofitable war of all against all. People living in Hobbes’ state of nature would value self-preservation above all else. The war of all against all leads to a life that is nasty, short, brutish and ends in violent death (Gauthier, 1999). Locke’s state of
nature is less brutish than Hobbes. He argued that people can be in the state of nature and be living under highly organized governments—provided those governments were illegitimate with respect to those individuals. A person could be in a state of nature if that person has not voluntarily agreed to join a legitimate political community. The state of nature could be quite civilized, with property in land, money, commerce and cities (Simmons, 1989).

It is Locke’s concept of the state of nature and the inherent contrast with civil society that most closely relates to many of the political and social ideas associated with urban form. He establishes the freedom of the state of nature by a person’s mere unwillingness to ascribe to a legitimate political community. By withdrawing from a community one attains freedoms. This establishes the idea of living outside of a community, be it physically or otherwise, as a good thing.

Social contract theory and the contrast between collective good and individual freedom became an ingrained part of American culture with the settlement of the West. Rugged individualism is the popular and dominant self-heralded social character of the region. It was a manifestation of the freedom resulting from a lack of a social contract brought about by the lack of physical ties to a community.

The frontier is productive of individualism. Complex society is precipitated by the wilderness into a kind of primitive organization based on the family. The tendency is anti-social. It produces antipathy to control, and particularly to any direct control (Turner, 1986, p. 30).

The juxtaposition of frontier and suburbia is not uniquely an element of the American psyche. In an article describing the development of two Australian suburbs and the cultural context in which this development happened Nichols (2007) links the concepts in his title, “Post-war suburban ‘reconstruction’ and the democratized ‘frontier’ in the civic and recreational buildings of Beaumaris and Park Orchards.” Nichols also quotes Tarrant who makes the association directly:
It may be argued that Australia’s pioneer legend should be extended to the lives of the ‘suburban pioneers’ of the post-World War II period... (Tarrant, 1984, p. i in Nichols, 2007).

The idea of the frontier has and continues to dominate the American psyche. Even outside the West the ideas of the frontier can be seen in modern development; as rugged individualism and the resulting obsession with a cabin in an idyllic natural setting. This dream of a cabin in the woods has and continues to be realized countless times over. In an argument identical to that suggested by Tarrant above, “Today’s suburban reality finds its origins in the pastoral dream of the autonomous homestead in the countryside” (Duany et al. 2000 p. 40). The cabin in the woods is the manifestation in the built environment of the state of nature whereas life in the town or city represents living under the social contract.

To understand why the ideas representing the state of nature still thrive, why in terms of building rugged individualism is more appealing than social contract, we need to look briefly at the alternatives to rugged individualism and the cabin in the woods. These are the cities and suburbs of twentieth and early twenty-first century which exhibit a decline in the quality of the public realm. Duany et al. (2000) define the public realm as, “...walkable public places—streets, squares and parks” (p. 60). The solution to the problem of decline in the public realm was articulated by Henry Ford in 1922:

“We shall solve the City Problem by leaving the City”
(Henry Ford, 1922, in Duany et al., 2000, p. 135).

Economists support this line of reasoning. Speaking in terms of rural comparative advantage, “We may speculate that this relative advantage may have been widened by declining amenities in many urban areas” (Galston and Baehler, 1995, p. 15). By retreating from social contract under the guise of independence and rugged individualism, Americans have created a country where we have gone from a few pioneers in the woods to a society where it is most desirable to retreat from everyone
else. Subdivisions and luxury mansions are the current manifestation within the built environment of this phenomenon.

In addition to the cultural reasons why the built environment is constructed at low-densities and in far-flung patterns that appear not to be economically efficient, there are a number of other quantifiable drivers and other enabling forces. Caruso et al. (2009) list increases in the number of households, increases in income and decreasing commuting costs as primary drivers of expanding urban areas. Enabling the expansion of urban form are information asymmetries and the ability to pass the costs of growth on to neighbors and/or taxpayers in general. Carson Bise describes information asymmetries succinctly, “Most local governments do not know the true costs of development decisions” (Bise, 2007a). Gaffney (1964) and others discuss the ability of new development to externalize the costs of growth. They argue the use of average cost pricing in both public and private utility-type services provides an incentive to develop a city in inefficiently low densities with excessive geographic area. Average cost user charges undercharge outlying low-density areas while overcharging interior or high-density areas. Thus, central city residents subsidize outlying residents. The result of the subsidy is thought to be a general tendency for development to move outward and to occur at a lower density than is economically efficient. The corrective action proposed by Gaffney is to charge each location the full marginal costs of providing services to that location. In this way, the subsidy is eliminated, and efficient development will follow. The other potential corrective action is to incorporate information on the fiscal consequences of development, including the spatial component of development costs, in planning and decision making.

1.4 The Reasons for this Research
There are a number of reasons why the proposed corrective actions to economically inefficient urban form, marginal cost pricing and informed decision making, have not been implemented. The reasons include legal institutions (Roberts, 1977), that it is not politically feasible and there would be substantial measurement problems (Bahl and
McGuire, 1977) as well as the lack of established measures of level of service outputs (Hyman, 1977). Hyman (1977) specifically states the question of imputing marginal costs of service provision is in need of empirical research. Branch (1951) notes a relationship between urban form, the physical environment, and the socio-economic characteristics of a community, including the costs of service provision and taxation. Inherent in research into the marginal costs of development is consideration of the influence of the spatial arrangement of the built environment. According to Downing and Gustely (1977), in order to develop marginal cost user charges it is necessary to understand how costs vary based on development characteristics such as land use, density, and distance from production. They suggest a need for research when they say, “…these elements in the cost function have been given little attention in the economic literature on the cost of providing local government services” (p. 63). In a similar vein, Carruthers and Ulfarsson (2003) make an explicit call for research relating costs and quality of services to urban form.

Heikkila (2000) suggests a way to link urban form with costs of services when he argues for a need to develop GIS-based production function based models that capture the spatial component of public service costs. A production function specifies production output, usually of a firm, as being a mathematical function of some set of inputs. Given an output and a set of inputs, the production function can be used to explore different combinations of inputs that yield the same output (Coelli et al. 2005). In the production modeling of local government services, the public agency is presumed to behave like a firm in that it competes in private input markets in order to provide services.

The application of production function modeling to local government fiscal analysis was established by Bradford et al. (1969) and overviewed most recently by Heikkila and Davis (1997) and Heikkila (2000). Heikkila seeks to correct a flaw in evaluating fiscal impacts where inputs (government expenditures) are used as a proxy measure of outputs. The recommendation is for the use of a production function where level of
service outputs are related to local government inputs, neighborhood characteristics and potentially a measure of spatial pattern. Additionally, Heikkila provides criteria for evaluation of local government inputs to a production function. One of the criteria, a service-based impact, is defined as, “the minimum cost of restoring service levels to what they were prior to the development in question” (Heikkila, 2000, p. 154). Heikkila (2000) sees strong potential for GIS and GIS-based decision support software for fiscal modeling and recommends tying GIS-based models to the output based measures of fiscal impact developed in his research. He notes a GIS-based approach is compatible with supporting economic theory.

From Clifton et al. (2008), Stone (2008) and elsewhere it is clear society is becoming aware of the negative externalities associated with low-density urban forms. The production function approach provides a promising framework for evaluation of the spatial component of public services costs. The contention in this research is the quantification of urban form and incorporation of this measure into a production model will yield a more richly specified production function and lead to quantification of the relationship between urban form and the spatial component of public services costs. With a full knowledge of the relationship between urban form and costs, local governments will be able to make more informed development decisions.

Additionally, by informing the debate on the relationship between urban form and the costs of public services provision it may eventually be possible to shift cultural values through processes of social learning and civic science. Smith et al. (2009) define social learning as, “...shared learning by decision makers, scientists, communities and institutions” (p. 1306). Lee (1993) uses the term “civic science” to describe a situation where science should be public, technical, a political activity and facilitate social learning. The term civic science describes a policy arena where issues are informed, debated and decided upon using scientific inputs as well as public values. Lee ties social learning to the action of political change by defining social learning as the combination
of adaptive management and political change (Lee 1993). Smith and Smith (2006) reiterate the political change aspect of social learning in stating social learning requires a combination of learning by doing, learning with others and learning by making change. The current state of the policy arena surrounding urban form is one of conflict where cultural values weigh against the desire to minimize negative externalities. By modeling the spatial component of public service costs it is possible, using a civic-science based approach, to inform the discussion in the policy arena surrounding urban form, enable social learning and affect positive change.

1.5 The Significance and Innovation of this Research

This research is innovative because theory based and research validated methods for modeling the spatial component of the costs of public service provision do not yet exist. While there have been numerous fiscal impact models developed in both the academic literature and in support of community planning, none have included a quantified index of urban form as a statistically significant determinant of local government expenditures on inputs for the provision of a public service.

The methods developed here for modeling the spatial component of the costs of public service provision are based on Heikkila (2000), Heikkila and Davis (1997), Heikkila and Kantiotou (1992) and Heikkila and Craig (1991). Their recommendation is for a dual production function and allocation function approach. In the production function level of service outputs are a function of local government expenditures, neighborhood characteristics and other inputs. With the allocation function local government expenditures on inputs may be determined by neighborhood characteristics and other inputs.

Urban form may be included in a production / allocation model of local government service provision by quantifying and summarizing urban form with a spatial index. By including an index of urban form in an econometric model this approach holds the potential to improve the spatial resolution of fiscal modeling techniques and to
determine the spatial component of the costs of public service provision. While the works cited immediately above and others describe methods for production function modeling of fiscal impacts and provide empirical examples, a fiscal impact model that ties urban form to local government expenditures on inputs to public services and level of service outputs has never been documented in the literature.

The primary elements of the significance of this project are that it will:

(1) Result in quantified, actionable information on the spatial component of development costs.
(2) Result in a determination of areas that are fiscally efficient for the provision of a local government service.
(3) And, broadly, advance the discussion of the relationship between urban form and the costs of local government service provision.

The significant aspects of this research relate to the two corrective actions proposed for suboptimal land-use patterns. Mapped output indicating areas that are fiscally efficient for the provision of services allows for informed planning and decision making. Information on the spatial component of public services costs may allow local governments to develop marginal cost pricing structures for the services they provide.

Modeling the spatial component of public service costs will advance the discussion of the relationship between urban form and the costs of local government service provision. These ideas are discussed throughout this dissertation. Quantification of urban form as a spatial index is detailed in chapter four, beginning on page 89. Development of the econometric model is presented in chapter five, beginning on page 115.

1.6 Broader Impacts
Among the most important elements of this research are the potential benefits to society at large. Following Clifton et al. (2008), efforts to improve development patterns
such as new urbanism and smart growth are only possible with an improved understanding of urban form. In a practical application of the argument put forth by Goodchild and Janelle (2004), that geographic space can provide a mechanism for integrating social sciences and science to policy, the opportunity exists for improved economic efficiencies in local governments if actionable information can be made available to decision makers, planning offices and citizens about the cause and effect relationship between the built environment they are enabling and the fiscal consequences of their decisions. The theory-based, transferable and verifiable methods developed in this research will enable the study area and other communities to avoid certain unintended and undesirable consequences of development. A model of the spatial component of public services costs will enable communities to make decisions on land-use and development with a full knowledge of the fiscal impacts of the proposed change. Informed decision making in issues of land-use change and conversion will help minimize the negative externalities of sprawling urban form as well as help protect agriculture, natural resources and quality of life; all issues with global applicability.

1.7 Chapter One Summary and Conclusion

The cultural and economic reasons why the built environment is constructed at low-densities and in far-flung patterns are well known. There is a distinct cultural construct where isolated dwellings are associated with greater degrees of freedom and isolated living provides a retreat from the ills of urban living. The economic reasons are the lack of accurate information on the spatial component of development costs and the ability to pass the costs of growth on to the general public. The literature indicates low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. Inefficiencies occur due to average cost user charges which undercharge outlying low-density areas while overcharging interior or high-density areas.

The need for the evaluation of the influence of urban form on the provision of local government services dates back to the 1950s. Yet, existing methods for fiscal analysis
and modeling do not incorporate urban form. By incorporating urban form as a driving variable in production / allocation function based econometric model it may be possible to determine the spatial component of the costs of public service provision.

Development of this research will yield a number of innovations including evaluation of the feasibility of applying spatial modeling techniques to emerging methods in fiscal modeling and quantification of urban form. This significance of this research will be realized when a quantification of the influence of urban form on the costs of development, possibly through a process of social learning, will make clear to decision makers and planners the cause and effect relationship between the built environment they are enabling and the fiscal consequences of their land-use decisions. The next step is to survey the extensive body of literature which looks at the relationships between urban form and local government costs of services.
Chapter Two

Review of the Literature

Chapter two is an overview of the body of literature pertinent to the discussion of the relationship between urban form and the costs of public service provision. The first section of this review begins with a look at the two primary pricing structures for public services, average and marginal cost pricing. The second section of the review focuses on fiscal analysis and modeling. The subset of the literature that addresses modeling public service costs is surveyed in detail including emerging methods, principally the production function. The third section is a review of the possible components of a production function fiscal model. Potential model components include level of service as a dependent variable and a variety of community socioeconomic and demographic characteristics as independent variables. This section also explores means of incorporating the spatial structure of the built environment in a production function based fiscal model. The approach is to quantify urban form in such a way that it may be included as an independent variable in a production analysis similar to the way socioeconomic and demographic characteristics are incorporated. The review culminates with a summary of these research threads, an identification of gaps in the literature, and suggestions to address these gaps presented as three research questions.

2.1 Average and Marginal Cost Pricing of Public Services

The economics literature presents two structures for the pricing of public services, marginal cost pricing and average cost pricing. Downing (1973) defines average cost pricing as setting the constant price equal to the average cost of providing a service to all customers. Theory suggests average cost pricing results in a product that is both under produced and under consumed (Downing, 1977a). Downing (1973) defines marginal cost pricing as an arrangement where price is equal to the long run marginal cost of providing a service to each customer. He argues marginal cost pricing could be called optimal pricing based on traditional welfare theory that marginal cost pricing will, assuming all necessary conditions are met, lead to an optimal allocation of resources.
The economics literature has a long history of advocating for the use of marginal cost pricing in order to maximize the general welfare. The advocacy begins with Dupuit’s 1844 discussion of bridge tolls in *On the measurement of the Utility of Public works* (Dupuit, 1952). Hotelling (1938) gives Dupuit credit for, “...an argument ... to the effect that the optimum of the general welfare corresponds to the sale of everything at marginal cost” (p. 242). The argument for marginal cost pricing is extended by Hotelling (1938) to address railroads, power plants and other utilities with large fixed costs. Hotelling states that sales at marginal cost with overhead paid from taxes on income, property (land) and inheritance would result in a system where everyone would be better off (Hotelling, 1938). Gaffney (1962) draws upon the work of Hotelling and Dupuit in a discourse on land and rent extends the argument for marginal cost pricing to include public services provision, concluding:

> The logic is inescapable. Price should be equated to marginal cost in every possible dimension, until the point where the cost of fiddling with prices exceeds the gains (Gaffney, 1962, p. 160).

The economics literature states unequivocally that marginal cost pricing is superior to average cost pricing in enhancing the general welfare, being fair and equitable, and would lead to a better built environment. Yet, there are no documented instances of a marginal cost pricing scheme having been implemented for local government public services. Downing (1973) argues this is because determination of marginal costs of service provision would be a difficult and expensive challenge. Downing (1977b) mentions marginal cost pricing may not be implemented because of the possibility it might interfere with other social goals. However, from the perspective of the economics literature, the determination of marginal, or actual costs of service provision for each consumer, is a solid theoretical foundation for both charging for public services and evaluating proposed changes to the built environment.

### 2.2 Local Government Provision of Public Services and Urban Form

The literature addressing local government costs of public service provision and urban form dates back to the 1950s. Plane (2003) characterizes the 1950s as, “...a watershed in
U.S. settlement patterns” (p. 107) in part due to the then apparent and accelerating deconcentration of the built environment. In the 1950s researchers were beginning to contemplate the implications of those changes on the cost to local governments for providing services.

Among the earliest studies, Wheaton and Schussheim (1955) found costs of services including capital expenditures, operation and maintenance for streets, sewers, water distribution systems and fire protection increase as density decreases. Isard and Coughlin (1957) evaluated hypothetical subdivisions, finding costs of services for streets and sewage increase as density decreases. The Urban Land Institute (1958) demonstrated similar results for capital costs (Downing, 1973). These studies consistently support two ideas: 1) public service costs increase as the distance from the site of production to the site of consumption increases, and 2) public service costs increase as density decreases.

Gaffney (1964) combined economic theory and concepts of density. For the provision of public services, efficiencies could be realized through the sharing of common resources and exploiting economies of scale. Specific to economies of scale, he distinguishes between density and the size of an operation by stating that decreasing costs brought about by economies of scale occur not just by finding new customers, but by finding them in a given perimeter. Gaffney (1964) lays the groundwork for Downing’s (1973, 1977a) discussions of marginal and average cost pricing by stating that utilities using average cost pricing make money in high-density central areas, usually near their distribution centers, and lose money in low-density and outlying areas. Gaffney argues, “It is abundantly clear that costs are a direct function of distance from center” (Gaffney, 1964, p. 129). Therefore, rates should be adjusted so that residents who are centrally located pay lower rates and those on the urban fringe pay higher rates. Referring to outlying areas where residents do not pay higher rates Gaffney invoked the term “subsidy” (Gaffney, 1964, p. 128). Gaffney continues:

But, one may object, the outlander may not be willing to pay so high a price. That is the idea precisely! When it costs us more to carry water out to someone than it is worth to
him, then we are well advised not to do it. He will be constrained not to move out into areas of high-cost water (and all other utilities), and we will have ceased to subsidize random lateral expansion, or suburban sprawl. This is the policy of neutral or passive containment. I commend it most sincerely (Gaffney, 1964, p. 129).

John Kain discussed inter-neighborhood facilities in *Urban Form and the Costs of Services* (1967). Kain explained central facilities such as water treatment plants benefit from economies of scale that offset what might be considered to be additional costs of inter-neighborhood transmission infrastructure. In other words, the economies of scale of a water treatment plant, even when accounting for additional infrastructure, are more cost effective than individual facilities (in this example, individual wells) He pointed out the cost of this inter-neighborhood infrastructure is dependent on the size and shape of the area being served (Frank, 1989).

Paul Downing first began exploring the effects of urban form on the cost of services in *The Economics of Urban Sewage Disposal* (1969) and expanded the scope of his research to more broadly address service provision in the 1973 article, *User Charges and the Development of Urban Land*. In setting up the analysis, Downing (1973) cites authors Vickrey (1963) and Hirsch (1970) who present arguments similar to Gaffney (1964), where outlying and scattered developments are more costly to serve than centrally located and compact developments. Downing cites Wheaton and Schussheim (1955) as well as Isard and Coughlin (1957) as evidence of probable nuance in cost of services based on urban form.

Downing’s primary argument in *User Charges and the Development of Urban Land* is that costs are affected by development location and other characteristics including, and he emphasizes the importance of, density. He states available data show low-density fringe developments are more expensive to serve and outlying areas do not pay the full cost of their services (Downing, 1973). He argues against average cost pricing by saying it results in undercharging “…outlying low density developments…” and overcharging, “…high density central developments” (Downing, 1973, p. 637). Furthermore, average cost pricing
leads to the premature development of residential land on the urban fringes and provides a barrier to dense development. Downing concludes, “...an average cost charge may worsen the pattern of development” (Downing, 1973, p. 637).

One of the most frequently cited studies addressing costs of services and urban form is The Costs of Sprawl by the Real Estate Research Corporation (1974). The Real Estate Research Corporation (RERC) study extends Isard and Coughlin (1957) and Downing (1969) in exploring the effects of development patterns on costs of services with an emphasis on density (Downing, 1999). The RERC study estimated capital and operating costs of public services for several different densities (Gustely, 1978). Results showed costs of service provision for low density to be roughly twice as expensive as for high-density development (Carruthers and Ulfarsson, 2003). Gustely (1978) adds the caveat that development location and associated distribution costs were not included in the RERC study. The finding that capital costs were higher in low-density development than in high density development has been criticized but largely withstood the test of time (Parsons Brinckerhoff, 1998). The conclusions of the RERC study continue to be cited:

... the Costs of Sprawl study was unequivocal: ... for a fixed number of households, “sprawl” is the most expensive form of residential development in terms of economic costs, environmental costs, natural resource consumption, and many types of personal costs... (RERC 1974) (Capital District Regional Planning Commission, 2007, pp. 2-3).


... the use of average cost pricing in both public and private utility-type services provides an incentive to develop a city in inefficiently low densities with excessive geographic area... The argument, in its simplest form, is that low-density developments and more distant developments are more expensive to serve than more proximate high-density developments. An average cost user charge undercharges the outlying low-density areas while overcharging the interior or high-density areas. Thus the central city residents subsidize outlying residents. The result of the subsidy is thought to be a general tendency for development to move outward and to occur at a lower density than is economically
efficient. The corrective action proposed is to charge each location the full marginal costs of providing services to that location. In this way, the subsidy is eliminated, and efficient development will follow (Downing, 1977b, p. xii).

Downing’s argument for marginal cost pricing is supported in the book by Johnson (1977) who argues marginal cost pricing helps in attaining an efficient allocation of resources which in turn may help in the efficient development of urban areas.

In addition to arguing for marginal cost pricing of public services, the book explores why marginal cost pricing is not implemented. Roberts (1977) argues the lack of marginal cost pricing is due to, “…legal institutions, rather than intrinsic difficulties” (p. 53). Bahl and McGuire (1977) state marginal cost pricing is not likely to become public policy because it is not politically feasible and there would be substantial measurement problems. Hyman (1977) establishes the lack of established measures of level of service outputs as one of the problems in marginal cost pricing and makes an explicit call for research computing units of service output and marginal costs of those units.

Downing and Gustely (1977) go into further detail on the nuances and difficulties of marginal cost pricing. They state that in order to develop marginal cost user charges it is necessary to understand how costs vary based on development characteristics. They state land use, density, and distance from production can affect cost of services. They suggest a need for further research when they say, “…these elements in the cost function have been given little attention in the economic literature on the cost of providing local government services” (p. 63).

Gaffney (1977) further articulates the argument in favor of marginal cost pricing of public services, stating it is both an ideal of economics and a goal to be pursued. He reiterates the difference between decreasing costs, volume of service, density, and expanding service area. He argues costs can be decreased only by increasing volume inside a service area (i.e. increasing density), not by expanding a service area and increasing the distance from load center to consumer. He attempts to establish increasing costs due to density as
a fundamental truth akin to economies of scale, “A counterpart of decreasing cost to volume is increasing cost to distance” (Gaffney, 1977, p. 173-174). Gaffney address equity issues raised by his 1964 article in stating the worst biases against mass systems for service provision are that the people who live in density don’t benefit from lower prices. Gaffney also makes explicit the simple but previously unstated point that costs and distance functions will vary from service to service (Gaffney, 1977). In turn, efficient user charge will vary between services (Downing, 1977a).

In discussing costs of services it is important to note the distinction between capital and operating costs. Capital costs are large infrastructure costs. A public safety example of a capital cost is a new police station. Operating costs are the day to day expenditures associated with providing a service. Public safety examples of operating costs are officer’s salaries and fuel for vehicles. Early research, probably due to the methods employed, suggests capital costs are more sensitive to density and distance than operating costs (Downing and Gustely, 1977). More recently, Bise (2002) argues that operating costs are often overlooked in discussions of costs of services provision yet they typically account for 80 per cent of budget expenditures.

In the summary and conclusion to *Local Service Pricing Policies and Their Effect on Urban Spatial Structure* Downing reiterates the fundamental argument of most contributors to the book. Public service costs have been shown to increase substantially as the distance from the site of production to the site of consumption increases. Similarly, public service costs have been shown to increase as density decreases. Average cost pricing leads to a more dispersed built environment where development is less dense than economically justified and residents who are centrally located subsidize those who live in outlying areas. There is a gap between theory and practice as marginal cost pricing structures have not been implemented. Downing also advances the spatial component of the argument by mentioning the cost of distributing a product or service to a site will depend upon the occupancy and densities of other sites. Downing recommends research addressing the
geographic distribution of gainers and losers from average and marginal cost pricing schemes (Downing, 1977a).

Gustely (1978) decries average cost pricing for the now familiar reasons, ties average cost pricing to inefficient development and mentions the inequity in subsidizing fringe developments and over-charging centrally located and dense developments. Considering the implementation of marginal cost pricing Gustely (1978) confirms Vickrey (1963) and Downing (1973) in saying the implementation of marginal cost pricing would have a long term beneficial effect on urban form and offer the potential for substantial improvements in outlying areas.

Frank (1989) developed an extensive literature review covering the costs of providing services given alternative development patterns. He concluded, “...development spread out at low densities increases the costs of public facilities” (Frank, 1989, p. 5).

Bierhanzl and Downing (1998) reiterate Dupuit’s argument for marginal cost pricing. They state the absence of a link between consumption and payment in the pricing of public sector goods, “…leads to an absence of incentives to consume efficiently” (p. 178). They suggest user charges for public services be set to equal marginal costs. They point out there are at least two margins, one based on use and the other based on location. Following the logic of Tiebout (1956) that says people will move to the area that offers the mix of services and charges that best matches their preferences, they suggest Gaffney’s (1964) recommended policy of neutral or passive containment will be effective. They argue accurate marginal cost user charges provide explicit cost signals that allow people to choose their preferred mix of services and fees (Bierhanzl and Downing, 1998, p. 180).

Parsons Brinckerhoff Quade & Douglas, Inc. (1998) summarize a number of related studies including Archer (1973), Duensing (1977) and Duncan et al. (1989) that suggest higher infrastructure costs for low-density and outlying development. They report costs of
development are highest in areas of low density and where development is a significant distance from centers of service provision. High density and centrally located developments led to the lowest service costs (Parsons Brinckerhoff, 1998).

Speir and Stephenson (2002) address water and sewer costs of different residential development patterns. They see their results confirming previous work (e.g. Esseks and Sullivan, 1999; Burchell et al., 1992; Duncan et al., 1989; Frank, 1989) where denser housing patterns are less expensive to supply with services. Their literature review raises several interesting points. First, many studies suggest the costs of certain services are not sensitive to spatial pattern. They mention schools (Burchell et al., 1992; Frank, 1989), solid waste collection, police and fire services (Burchell and Listokin, 1995). Conversely, costs of infrastructure intensive services such as roads, water and sewer are sensitive to spatial pattern (Burchell and Listokin, 1995; Duncan et al. 1989; Peiser, 1984; Downing and Gustely, 1977). They also state the influence of urban form is not made clear by previous studies because spatial pattern has not been clearly separated from other factors (e.g. population) (Speir and Stephenson, 2002).

Carruthers and Ulfarsson (2003) mention Pendall’s (1999) study looking at 159 counties of the 25 largest metropolitan areas of the United States. Pendall found low-density developments require greater public expenditures than high density developments (Carruthers and Ulfarsson, 2003). Carruthers and Ulfarsson, in work similar to Pendall (1999), found:

... in a cross-section of 283 metropolitan counties we have found that density has a negative influence on the cost of infrastructure, including roadways and sewers (Carruthers, 2000b; Carruthers and Ulfarsson, 2002). Results suggest that per capita spending on infrastructure declines at greater densities but increases with the spatial extent of urbanized land area and property values (Carruthers and Ulfarsson, 2003, p. 506).

Carruthers and Ulfarsson (2003) re-affirm most of the findings of the 50 plus years of applied research on the implications spatial pattern on cost of services provision. They consider their key finding to be that per capita costs of most services decline with density.
They note one exception to this rule. Their results indicate sewerage costs may not decline with density and they suggest further research. They put forth a number of more recent references for the assertions of Gaffney, Downing and others. For example, low-density development does not allow for the cost-effective provision of local government services (Kaiser et al. 1995; Altshuler and Gomez-Ibanex, 1993); low-density developments lead to greater costs due to necessarily higher infrastructure costs (Carruthers, 2002a; Porter, 1997; Nelson et al. 1995; Kelly, 1993 and Knapp and Nelson, 1992). Low-density development may undermine the costs of providing law enforcement and public education and average costing compounds these problems by leading to an inefficient built environment (Brueckner, 2000; Lee 1981). Finally, their work associates what they call political fragmentation, an abundance or over-abundance of levels of government, with low-density development through lowering of densities and promotion of growth at the urban fringe (Carruthers, 2003; 2002b; Carruthers and Ulfarsson, 2002; Pendall, 1999; Lewis, 1996; Shen, 1996). They also provide guidance for future research, suggesting the need for evaluating cost of services given differing measures of urban form and looking at quality of service provision and how it is affected by the built environment (Carruthers and Ulfarsson, 2003).

Deal and Schunk (2004) use techniques from ecology and system dynamics to model impacts of land-use change including fiscal impacts in a build-out of a township (sub-county) area in Illinois. In providing context for their research they explain the current preference toward low-density developments stating they are less expensive for both the developer and property owner, but are more expensive for the community and society at large. They state low commuting costs, in part caused by economic prosperity and subsidized transportation systems, promote development in outlying areas. They also argue for further research in fiscal modeling:

...planning decisions are heavily influenced by fiscal analysis, even though current methods for analyzing the fiscal impacts of spatial economic variables, i.e., land use patterns, are often incomplete and rather short-term oriented (Deal and Schunk, 2004, p. 92).
Deal and Schunk advocate for high resolution modeling, stating such detailed modeling, “...allows for discerning the macro-level implications of micro-level behaviors” (Deal and Schunk, 2004, p. 79). Discussing their model:

One of the strongest features of the spatially explicit approach of our model is the emergence of macro-behavior based on micro-assumptions. This gives the discussion about the fiscal impacts of urban development a new dimension, since spatially explicit models can be based on micro-level data and micro-level assumptions made at the smallest spatial resolution. That is, aggregate macro-level information (e.g., on road costs etc.) is replaced by site specific information (Deal and Schunk, 2004, p. 93).

The results of their modeling effort offer several implications for individual and societal costs based upon changes in land use. Finally, their results show ...

... spatially explicit dynamic modeling has various conceptual advantages over other approaches to modeling urban dynamics, both from a theoretical and a practical point of view. However, model validation and the assessment of the uncertainty of large-scale spatial dynamic models deserve considerable future attention (Deal and Schunk, 2004, p. 79).

Section Summary and Conclusion for Local Government Provision of Public Services and Urban Form

The economics literature states unequivocally that marginal cost pricing is superior to average cost pricing in both enhancing the general welfare and being fair and equitable. Specific efforts to ascertain the effect of the built environment on the cost of government services began in the 1950s. All studies, through 1977 and beyond, lend support to Downing’s (1977a) concluding remarks to Local Service Pricing Policies and Their Effect on Urban Spatial Structure: public service costs have been shown to increase substantially as the distance from the site of production to the site of consumption increases, public service costs have been shown to increase as density decreases, and average cost pricing leads to a more dispersed built environment. Carruthers and Ulfarsson (2003) state the important point, and what they consider to be their key finding, that per capita costs of services decline with increasing density.

There are a number of potential reasons why marginal cost pricing has not been implemented. The hypothesized reasons include the inertia inherent in legal institutions, that it is not politically feasible, there are measurement problems and there is a lack of
established level of service measures. Hyman (1977) takes the final point and uses it as the basis for calling for research in marginal cost implementation and service units in particular.

Downing and Gustely (1977) state development of marginal cost pricing requires an understanding of how cost varies based upon development characteristics. They suggest further research on elements that influence cost of services including land use, density and distance from production centers. Downing (1977b) recommends research in the geographic distribution of gainers and losers from average and marginal cost pricing schemes. Speir and Stephenson (2002) recommend research which clearly separates spatial pattern from other factors in the cost function, such as population. Carruthers and Ulfarsson (2003) recommend more detailed research on spatial pattern and quality (or, level) of service provision. Deal and Schunk (2004) recommend research on the influence of land use patterns on the fiscal impacts of service provision. They see the need for spatially precise modeling which, “...allows for discerning the macro-level implications of micro-level behaviors (Deal and Schunk, 2004, p. 79). Micro-level, or site specific information may be aggregated to determine broader impacts.

2.3 Fiscal Analysis and Modeling: The Prior Research

The purpose of fiscal impacts modeling is to evaluate the public costs and revenues associated with development (Burchell, Listokin and Dolphin 1989). Modeling, as a subset of the general literature associating urban form with cost of services, also began in the 1950s. The general method employed in Wheaton and Schussheim (1955), Isard and Coughlin (1957) and Urban Land Institute (1958) was to gauge cost of services based on estimates of capital and operating costs calculated from the physical requirements (e.g. size and length of pipe) of a number of development alternatives (Downing and Gustely, 1977). According to Frank (1989), Wheaton and Schussheim’s (1955) methods were important as they established the need to make distinctions in classifying capital facilities and service costs. These distinctions are between capital and operating costs as well as among capital facilities types based upon reasonable criteria of who should pay. For
example, curb and gutter in a new development would be paid for by the new
development whereas a central facility such as a water treatment plant would be paid for by the entire community.

Another early modeling effort came from Stone (1973) in *The Structure, Size, and Costs of Urban Settlements*. Stone estimated the costs of main roads based on community size, shape and centralization of employment. Stone used a network model for roads and traffic simulation, a gravity model for trip distribution and performed model iterations for different community sizes, shapes and forms (Frank, 1989).

Downing and Gustely (1977) and Gustely (1978) document two methods for studies addressing costs of services resulting from differing urban forms: engineering estimates, as discussed above, and regression studies. One of the first regression studies was done by Brazer (1959). Brazer found population to be unimportant but density to be “...clearly associated with all expenditure categories except recreation” (Downing and Gustely, 1977, p. 63). Hirsch’s (1970) results were the opposite of Brazer. Hirsch used regression to break down public service operating costs and found density not to be significant. Clark et al. (1971) used similar regression methods in addressing residential solid waste collection. They evaluated density among drivers of collection costs and found it to be significant in one study area and insignificant in another. Among various criticisms of these regression studies, Downing and Gustely (1977) put forth these early efforts did not (and could not) measure variations in cost within a community. As documented by Carruthers and Ulfarsson (2003), recent regression analysis by Ladd and Yinger (1991) and Ladd (1992; 1994) suggests density leads to higher per capita public service costs.

In 1978 Burchell and Listokin released the seminal work in fiscal impact analysis *The Fiscal Impact Handbook: Estimating Local costs and Revenues of land development*. They define fiscal impact analysis as, “A projection of the direct, current, public costs and revenues associated with residential or nonresidential growth to the local jurisdiction(s) in which
this growth is taking place” (p. 1). Burchell and Listokin (1978) identify two broad categories of fiscal analysis: the average cost approach and the marginal cost approach. According to Coupal et al. (2002) the average cost approach is based on the use of ratios or multipliers for each unit of service provided. The approach is simple and widely used. The American Farmland Trust’s costs of community services study methodology (AFT, 2006) is based on this average cost approach. Marginal cost approaches are based in the calculation of specific fiscal impacts based upon case studies and/or statistical models (Coupal et al., 2002). The marginal cost approach extends average cost analysis by taking into account excesses or deficiencies in capacity that might exist for provision of services when new development may cross a threshold which would result in a significant new capital expenditure. Coupal et al. (2002) suggest marginal cost approaches are more strongly grounded in economic theory than average cost approaches.

Burchell and Listokin (1978) describe in detail six fiscal impact analysis techniques. Three are average cost approaches: per capita multiplier, service standard and proportional valuation. Three are marginal cost approaches: case study, comparable city, and employment anticipation. The per capita multiplier method is based on average municipal costs per person and is the most widely used of the average cost techniques. The method is inexpensive to apply, has the advantage of being based in data that are readily available, and due to its relatively low cost is recommended for alternatives analyses where the more detailed case study method would likely be prohibitively expensive. The service standard method is based on average employment levels and the relationship of capital expenditures to operating expenditures. It provides more detail than the per capita multiplier method as it results in future workforce estimates instead of simply producing estimated expenditures by category. The proportional valuation method is a straightforward and fast means of determining the fiscal impact of non-residential facilities. When using the proportional valuation method costs are based on the share of property value a non-residential facility adds to the community’s tax base (Burchell and Listokin, 1978).
The case study approach is a detailed marginal cost approach. This method entails interviews with local public officials in order to determine if there are plans or needs to expand services. It is a detailed and time consuming method but is the most accurate way to gauge the potential for future capital expenditures. Bise (2002) states, “The case study-marginal cost method is the most realistic for evaluating fiscal impacts” (p. 1). Burchell and Listokin’s comparable city method is a marginal cost method where relationships between community size, growth rate and local expenditures are used to calculate the effect of population change. The method is intended for situations where new growth is expected. Burchell and Listokin suggest the method has excellent potential due to its simplicity and modest implementation cost. The employment anticipation method is based on the relationships between industrial and commercial employment and costs and revenues. It predicts changes in costs and revenues based on changes in employment (Burchell and Listokin, 1978).

Parsons Brinckerhoff Quade & Douglas, Inc. developed a model for estimating the full social costs for scenarios of alternative land developments at the regional, metropolitan planning organization, level. The model, SCALDS, uses Microsoft Excel as a platform for developing eighteen interconnected spreadsheets which gauge the costs of regional land-use scenarios. Full social costs are defined as the total impacts, both costs and benefits, resulting from a change in urban form (Parsons Brinckerhoff, 1998). Deal and Schunk (2004) use SCALDS as the fiscal impact assessment sub-model to their land-use change impact assessment model. Speir and Stephenson (2002) also use spreadsheet technology for an engineering technique analysis evaluating sixty residential development scenarios.

Applied fiscal impact modeling efforts and academic research are typically based on case examples. Heikkila and Craig (1991) measure the fiscal impacts of population change using data from Vancouver, British Columbia. Grosskopf et al. (1994) use an economic distance function approach to estimate efficiencies in the provision of public law enforcement.
services in Dallas, Texas. Deller, Marcouiller and Green (1997) look at the fiscal impacts of recreational housing development on counties in Wisconsin. Coupal et al. (2002) focus on measuring the net fiscal impacts of rural residential development on Wyoming county governments. The American Farmland Trust (AFT) conducted at least 125 case studies, primarily looking at county governments in the United States, between the mid-1980s and 2006 (AFT, 2006).

**Emerging Methods: The Production Function Approach to Fiscal Modeling**

The newest approach to fiscal impact modeling is the production function approach articulated by Heikkila and Davis (1997) and Heikkila (2000). Correctly specified, a production function is a mathematical statement indicating the combination of inputs which results in a specific level of output (Votey and Phillips, 1972). The production function may be used to summarize a situation where a firm uses multiple inputs to produce a single output (Coelli et al., 2005; Kumbhakar and Lovell, 2000).

Government service provision may be modeled with a production function where level of service outputs are related to local government inputs and neighborhood (socioeconomic and demographic) attributes (e.g. Heikkila, 2000). In the production modeling of local government services, the public agency is presumed to behave like a firm in that it competes in private input markets in order to provide services. Heikkila's aim in using the production function is to correct a flaw in the current approach to evaluating fiscal impacts where inputs (expenditures) are used as a proxy measure of outputs. The production function makes inputs and outputs of local government service provision explicit (Heikkila, 2000).

Production modeling of public services began with Bradford, Malt and Oates (1969). They use a production function to relate levels of service measures as production outputs with labor, capital and land as well as environmental variables (socioeconomic and demographic characteristics) as production inputs. Craig (1987) develops a model of crime deterrence that includes both a production and an allocation function. The goal of an
allocation function is to ascertain government preferences on input mix as well as the productivity of inputs for public services provision. Behrman and Craig (1987) specify a production function where the quantity of public service output is determined by both local government inputs and neighborhood (socioeconomic and demographic) characteristics. Behrman and Craig (1987) develop an allocation model of police resources in order to estimate an input parameter of their production model. Craig and Heikkila (1989) develop several functions for the production of public safety. Their allocation function captures government service provision as well as productivity of inputs across neighborhoods.

Heikkila (1990) specifies a production function for local government services where level of service outputs are a function of local government expenditures on inputs and neighborhood characteristics. He argues that the inclusion of local government expenditures on inputs is consistent with the standard definition of a production function. These input expenditures are viewed as productive resources analogous to the use of land, labor, and / or capital by a firm. Heikkila and Craig (1991) develop a similar production model where public safety is a function of local government expenditures on police, neighborhood characteristics and income. Expenditures are determined with an allocation function based on neighborhood characteristics and income. The income parameter is a neighborhood characteristic but is indicated separately for emphasis. The authors state that neighborhood characteristics relevant to the production and allocation functions will usually differ, but may overlap. Heikkila and Kantiotou (1992) duplicate Heikkila and Craig’s (1991) model for the allocation of local government resources and production of public safety. In the allocation function local government expenditures on police are explained by income and other neighborhood characteristics. The production function approach is reiterated in Heikkila (2000) and Heikkila and Davis (1997).
A general example of a production function is:

\[ y = f(x) \]  \hspace{1cm} (1)

where,

- \( y \) is output,
- \( f(.) \) is the production function technology; and,
- \( x \) represents both fixed and variable factors of production.

Heikkila (1990) presents a function for evaluation of local government service provision:

\[ S = f(n, x_s) \]  \hspace{1cm} (2)

where,

- \( S \) represents level of service;
- \( f(.) \) is the production function technology;
- \( x_s \) are local government expenditures on inputs; and,
- \( n \) represents a combination of neighborhood characteristics.


> Consistent with the standard definition of a production function, \( s \) represents the maximum level of service that can be obtained from the existing technology \( f \) with an allocation of resources \( x_s \) within the urban setting described by \( n \) (p. 27).

In order to measure level of service impacts, it is necessary to estimate the structure of the underlying production relationship (Heikkila, 2000). **Equation (2)** establishes the relationship between inputs (local government expenditures and neighborhood characteristics/urban space) and outputs (level of service) (Heikkila, 2000). Heikkila justifies the inclusion of neighborhood characteristics in an argument similar to that above that addressed urban form and the cost of government services:

> The cost of providing a given level of service—be it in education, public safety, mobility, or any other dimension of government activity—is directly tied to the immediate urban setting. When development occurs, that setting is changed and so too is the cost of maintaining a given level of service...This, in essence, is what fiscal cost impacts are all about (Heikkila, 2000, p. 149)....As urban development occurs, those neighborhood
attributes undergo change, and therefore so too does the production relation (Heikkila, 2000, p. 152).

The use of demographic and socioeconomic characteristics in fiscal analysis is not unique to Heikkila. Schwartz (1993) took a detailed look at the inclusion of socioeconomic characteristics in the production of public services. Bradford et al. (1969) assess the provision of public goods through a production model for public goods that includes an environmental variable representing various socioeconomic and demographic characteristics. Stephenson et al. (2001) implicitly support the inclusion of neighborhood characteristics in a fiscal analysis when they note spatial forms may influence costs of services by influencing service standards.

The goal of including level of service in a fiscal analysis is to clarify and distinguish between inputs (e.g. expenditures) and outputs (level of service). Advantages to including level of service in a fiscal analysis and entering level of service into a community’s planning dialogue include the idea that quantifying level of service and associated costs allows more constructive dialogue because the fiscal consequences of changing level of service are more apparent (Downing and Gustely, 1977, p. 4). Identified levels of service facilitate impact and user fees as costs and associated levels of service become more clearly related (Tischler, 2002a, p. 3-4).

A limitation of the production function approach articulated by Heikkila is that it is not spatially precise. As a potential augmentation to regression analysis, Heikkila mentions GIS and decision support systems as promising technologies for further model development. He mentions production models for infrastructure-based services (e.g., water lines) incorporate spatial relationships and “...cannot be satisfactorily modeled using regression techniques” (Heikkila, 2000, p. 159). Heikkila then issues an explicit call for research rooted in GIS and decision support software that is analogous to the production function approach but explicitly incorporates spatial factors:

... researchers need to develop GIS models of production that are able to capture the spatial dimension of infrastructure-based service delivery. In principle, this approach is
compatible empirically and theoretically with other approaches to estimating the service-
and welfare-based impact measures. Much more work is required before planning
researchers can claim to have successfully developed GIS production models that are
consistent with this approach (Heikkila, 2000, p. 159).

Heikkila notes GIS offers geographic representation of urban areas which are stronger
than urban economic models. GIS is open to modification therefore allowing production
models with neighborhood characteristics to be developed. Additionally GIS, when
supplemented with decision support software, are able to generate level of service based
impact assessments that are theoretically consistent with arguments presented in his
work (Heikkila, 2000).

Beyond Heikkila’s call for the inclusion of geographic information in fiscal modeling, fiscal
impact analyses and models, to date, do not explicitly incorporate space and central place
issues into estimation techniques. Goodchild and Janelle (2004, p. 10) state that a model
is spatially precise, “when it differentiates behaviors and predictions according to spatial
location.” Theoretical studies, fiscal impact analyses and fiscal impact models are largely
lacking in spatial precision.

The limitations of spatial precision in fiscal modeling can be seen in numerous projects.
For example, Craig and Heikkila (1989), Heikkila and Craig (1991) and Heikkila and
Kantiotou (1992) calculated fiscal impacts based on data at the neighborhood level in
Vancouver, B.C. The neighborhoods are generally slightly larger than one square mile in
size. The methods used, as they hinge on the areal units of the data, do not appear to lend
themselves to a finer grained analysis. Coupal et al. (2002) focus on measuring the net
fiscal impacts of rural residential development on Wyoming county governments and
results are presented at the county level.

The TischlerBise consulting firm, which specializes in fiscal impact analysis, has done some
work which differentiates geographic areas at the sub-county level. TischlerBise also
provides some of the most spatially precise work in fiscal modeling. Two examples serve
to illustrate the level of spatial precision in the work of TischlerBise. In a case study marginal approach evaluation of land-use scenarios for Howard County, Maryland they divided the county into five geographic areas based on demographics, capital facility capacities and other characteristics (Tischler, 2002b, p. 1). TischlerBise presents what they call an innovative project example from Greeley, Colorado where tiered road fees are assessed at the sub-county level, based on traffic analysis zones, some well under one square mile in size (Bise L.C., 2007a).

In a non-peer reviewed conference proceedings Bronow (1999) illustrates a proprietary model called ‘FISCALS GIS’ which appears to conduct fiscal analysis at the parcel level. Bronow summarizes the features of the software, but does not detail methods or tie the model to the existing fiscal impacts literature. Nedović-Budić et al. (2006) use spreadsheet models, GIS models and GIS based planning support to create and evaluate scenarios in order to examine the possible fiscal and social impacts of different recreational use and facility siting options of a development in a nature preserve in Illinois (Nedović-Budić et al., 2006). In the analysis fiscal impacts are gauged based upon numbers of tourists for a number of different scenarios. It is not clear if or how spatial data drive tourism estimates. In all cases the concept of spatial heterogeneity, the lack of stability within space of behavior and relationships, suggests fiscal impacts may not be homogeneous across a jurisdiction or study area and point to analysis at a finer-grained, more precise spatial resolution as an opportunity for further research.

Although these examples are not fiscal modeling, the linking of spatial and/or landscape indices and econometric modeling is seen in the work of Frenkel and Ashkenazi (2008a), Baumont et al. (2004), Bastian et al. (2002) and Geoghegan et al. (1997). Frenkel and Ashkenazi (2008a) develop a sprawl index rooted in spatial metrics that serves as a dependent variable in a regression analysis of the factors that influence sprawl. Baumont et al. (2004) apply spatial econometric techniques to population densities to analyze urban structure in the area of Dijon, France. They develop a production function for
population density which is driven by population density in the central business district, distance from the central business district and the rate of population density change. Their production function does not include measures of spatial autocorrelation. Bastian et al. (2002) specify a hedonic price model with spatially defined attributes, including a landscape metric as a proxy for view composition. Geoghegan et al. (1997) combine spatial metrics and economic modeling in a regression based hedonic price model. In aggregate, these works implicitly suggest the environment may be quantified with spatial indices and these indices may in turn serve as useful inputs to regression based modeling, including production modeling.

Section Conclusion of Fiscal Analysis and Modeling: Prior Research and Emerging Methods

Fiscal impact modeling draws upon 60 years of research and case examples but models are not yet spatially precise. Burchell and Listokin (1978) are supported by Bise (2002), Coupal et al. (2002) and others in suggesting the case study marginal cost method is the most realistic method for fiscal impact evaluation. Early regression studies did not measure variations in costs within a community, and therefore would not be suitable for developing marginal or spatially defined costs of services. Currently existing fiscal impact models are aggregated spatially at the county level, within one square mile blocks, or, as with as seen in Bise (2007a) are large aggregations of parcels. The use of spatial technologies such as GIS is recommended in fiscal modeling. The opportunity exists and the literature suggests the need to expand upon and refine current methods in fiscal impact modeling and in order to develop higher resolution spatial models.

As a way forward, Heikkila and Davis (1997) and Heikkila (2000) present a production function approach to modeling fiscal impacts. Heikkila (2000) sees strong potential for GIS and GIS-based decision support software for fiscal modeling and recommends tying GIS based models to the output based measures of fiscal impact developed in his research.
2.4 Elements of the Production Function

Production functions are routinely estimated using regression analysis. For fiscal modeling, as equation (2) suggests, the dependent variable (level of service outputs) may be regressed on multiple independent variables (government inputs and neighborhood characteristics) (Heikkila, 2000). While local government inputs (capital and labor) are straightforward; level of service measures, neighborhood characteristics and the potential for incorporating urban form all require a more detailed overview.

Level of Service

Following Heikkila, for evaluation of local government provision of services the production function requires a quantifiable level of service measure as the production output. Level of service is indicative of the output and / or effects produced through local government expenditures and other elements of the production function. According to Stephenson et al. (2001) this concept refers to the quality of services provided by local government (p. 4).

Both level of service measures and local government expenditures may be analyzed by department or other sub-category. Burchell and Listokin (1978) suggest six major groupings: general government, public safety, public works, health and welfare, recreation and culture, and education, and several subcategories such as police and fire. Germane to the econometric model presented in chapter five, Wyoming county government costs are reported in the following categories: administration, agricultural department, airports, assessor, attorney, clerk, commissioners, construction, coroner, courthouse, district court, elections, emergency management, equipment/land/buildings, fair, fire protection, health (not hospitals), hospital boards, jail, justice or circuit court, library, natural resources, other, parks / recreation / museums, planner, protective inspections, road and bridge, sheriff, social services, solid waste and landfill, surveyor and engineer, and treasurer. In Wyoming, public schools, while administered at the county level report income and expenditure separately from county government.
Regardless of the particular breakdown of government into specific services, Heikkila (2000) points out each service must be addressed individually because the production function and cost relationships for each service element are unique. Only by linking specific considerations to each service can theoretically sound methods that are more broadly applicable be developed (Heikkila, 2000). Heikkila and Davis (1997) summarize various service elements along with level of services measures and associated inputs and analytical approaches in Table 1, below. Individual discussions of specific service elements follow.

**TABLE 1: Production Functions and Urban Services (Heikkila and Davis, 1997, p. 206)**

<table>
<thead>
<tr>
<th>Service</th>
<th>Level of Service Index (x)</th>
<th>Government Inputs (x)</th>
<th>Relevant Neighborhood Context (a)</th>
<th>Model Type 1 = f(x,a)</th>
<th>Examples of Helpful and/or Relevant Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>Standardized test scores</td>
<td>Teachers, schools, supplies</td>
<td>Socio-economic characteristics</td>
<td>Regression models</td>
<td>Arnott and Rowe (1987), Dynarski, Schwab and Zampelli (1989)</td>
</tr>
<tr>
<td>Policing</td>
<td>Absence of crime</td>
<td>Police, equipment</td>
<td>Socio-economic characteristics</td>
<td>Regression models</td>
<td>Craig and Heikkila (1990), Heikkila and Craig (1991)</td>
</tr>
<tr>
<td>Fire Protection</td>
<td>Absence of loss of life &amp; property; NBPU grade of service</td>
<td>Firefighters, equipment, water supply</td>
<td>Built form, socio-economic characteristics</td>
<td>GIS simulation model of response time</td>
<td>Brueckner (1981); Chauken, Ignall and Walker (1973); National Board of Fire Underwriters</td>
</tr>
<tr>
<td>Water Supply</td>
<td>Water pressure and quality</td>
<td>Water mains, pumping stations</td>
<td>Elevation, land use</td>
<td>GIS simulation models</td>
<td>Ormsbee and Lansey (1994); Clark and Stevie (1981)</td>
</tr>
<tr>
<td>Storm and Sanitation</td>
<td>Environmental quality</td>
<td>Sewer mains, treatment plants</td>
<td>Elevation, land use</td>
<td>GIS simulation models</td>
<td>Atanasio and Danici (1994); Heikkila (1990)</td>
</tr>
<tr>
<td>Transportation</td>
<td>Accessibility, mobility</td>
<td>Roads, transit systems</td>
<td>Socio-economic characteristics, land use</td>
<td>GIS simulation models</td>
<td>Arentze, Borgers and Timmermans (1994); Sthie (1995); Moore and Gordon (1990)</td>
</tr>
</tbody>
</table>

Discussing level of service measures for education, Heikkila suggests standardized test results or other output oriented measures are appropriate, but student-teacher ratios or other input oriented measures are not appropriate (Heikkila, 2000).

For measuring levels of service for fire protection services Heikkila recommends the Standard Schedule for grading cities published by the National Board of Fire Underwriters. Heikkila writes the grade of service is a good measure of level of service and the methods used by the underwriters are “…an implicit model of service production” (Heikkila, 2000, p. 162). Addressing level of service as measured in emergency response times,
Stephenson et al. (2001) write that allowing increases in response times can limit increases in police and emergency service costs.

Per Heikkila (2000) the reason communities expend funds on police is to enhance public safety. The appropriate measure for level of service is then the absence of crime or similar measure of security and public well-being. Heikkila provides a detailed recommendation for modeling the production of public safety and presents a case example from Vancouver, B.C. in the book *The Economics of Planning*. Heikkila recommends using regression analysis in a production function framework:

... where the effectiveness of expenditures on policing resources is influenced by intervening neighborhood attributes such as income levels, unemployment rates, age structure and ethnicity (Heikkila, 2000, p. 160).

Heikkila (2000) recommends the level of service assessment of transportation services be evaluated in terms of accessibility. Heikkila states destinations are a function of land use therefore land-use change will result in changes in accessibility. He cites Hanson and Schwab (1987) and Weibull (1980) in suggesting accessibility be measured as a weighted sum of destinations where weights are inversely proportional to distance.

In considering a level of service measure for water and sewer service, Parsons Brinckerhoof (1998) argue infrastructure, especially feeder hook-ups to trunk lines, is more important than usage (Parsons Brinckerhoff, 1998, p. 42).

**Neighborhood Characteristics**

As urban development occurs, neighborhood attributes change and so will a production function evaluation of service provision. Neighborhood characteristics that may be included in a production function include density, demographics, distance, political fragmentation, population, growth rate and scale. These data may come from a variety of sources but Heikkila (2000) notes these sorts of data are often maintained by planning departments. The following are highlights from the literature surrounding the above list of neighborhood characteristics and how they may influence a fiscal model.
The literature relating cost of services to urban form regularly mentions *density*. Typically, low density is associated with higher costs of service provision and higher density is associated with lower per capita costs of service provision. Nicholas *et al.* (1991) found costs that increased as density decreased were school transport costs, road maintenance, and water and sewer operating costs. Costs that did not increase as density decreased were public school capital costs, law enforcement, emergency services, health and welfare and general costs of government (Capital District Regional Planning Commission, 2007). In a recommendation relevant to fiscal modeling that incorporates urban form, Carruthers and Ulfarsson (2003) recommend density calculations ought to be based on both population and employment. They also provide a notable caveat in citing Burchell *et al.* (1998) who state problems associated with low density may also be a result of extreme separation of land uses (Carruthers and Ulfarsson, 2003).

Stephenson *et al.* (2001) provide documentation of the intuitively sensible proposition that low density developments will consume greater amounts of land thereby demanding more extensive road networks and requiring greater capital investments. They note, on the other hand, that compact developments may require fewer miles of roads but greater levels of services (e.g., durable construction, snow removal). They issue a direct call for a level of service measure in stating these differing service standards will result in different costs and provide a caution against the idea of evaluating road costs based on spatial pattern alone (Stephenson *et al.*, 2001, p. 5). Stephenson *et al.* (2001) augment the discussion by pointing out social science research finds positive correlation between crime rates and population density.

Parsons Brinckerhoff (1998) cite Ladd (1992) in noting that educational costs vary directly with density and inversely with *growth rate*. Higher densities lead to higher per capita and per student costs. Faster growth rates lead to lower per capita and per student costs. They add two caveats from Altshuler and Gomez-Ibanez (1993). Firstly, density comparisons are
usually made between urban and suburban areas, not within urban or suburban areas. Secondly, most studies do not address the level of service of the educational product delivered (Parsons Brinckerhoff, 1998, p. 44).

Bise (2007b) writes that next to revenue structure, no other aspect of a community has as great an impact on fiscal solvency as the demographic and market characteristics of differing land uses (p. 4). Parsons Brinckerhoff (1998) cite Burchell and Listokin (1996) in observing educational costs vary directly with the wealth of the jurisdiction. They report wealthier areas place greater demands for quality and other outputs on the educational system and they are willing to pay for those demands. Stephenson et al. (2001) note the demographic profile of a population can influence costs by changing demand for services. The example put forth is the influence on the number of school age children on local government, presumably educational, budgets. At the same time Stephenson et al. (2001) note many studies assume demographics remain constant as spatial attributes vary. Tischler (2002b) suggests household size and market value, as well as other demographic variables, are essential to fiscal analysis. Bise (2007b) suggests average household size, pupil generation rate, market value of housing units, trip generation rate, density per acre, and average household income are important demographic and market variables for residential development. Bise suggests square feet per employee, trip generation rate, market value per square foot, sales per square foot (retail), and floor area ratio are important variables for non-residential developments (Bise, 2007b). Bierhanzl and Downing (1998) use log of income as an explanatory variable in a model of government spending.

Along with density, the literature relating cost of services to the spatial structure of the built environment regularly mentions distance from production center to area of consumption as being critical to calculating costs. Downing (1977b) articulates the argument most succinctly, stating, “Marginal costs of collection and transmission are a function of distance and density” (p. 452). Longer distances are associated with higher
costs. Downing and Gustely (1977) argue costs for capital intensive services such as water supply and sanitary sewer increase substantially as distances increase. They suggest operating costs for less capital intensive services such as police, fire and garbage removal are sensitive to the distance between the public facility and residential area. Gustely (1978) affirms the argument for capital intensive services but argues distance costs are not significant for police and fire protection.

There is also an argument to the effect that distance no longer matters. The conventional spatial perspective, the idea that distance does matter, is in essence a restatement of Tobler’s first law of geography, "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). First articulated by Cairncross (1995, 1997), and sometimes called the radical spatial perspective, the argument that distance no longer matters is discussed by Shen (2004):

...the literature ... shows an increasing presence of views that underplay, or even totally dismiss, the importance of geographic location and physical distance. These views, collectively called “the radical spatial perspective” ... reflect the fact that transportation and communications technologies have drastically modified spatial relationships that were once largely dependent on physical distance (Shen, 2004, p. 263).

Hall (2007) notes transportation and communication costs, although there have been trends of decline, never reach zero. Shen suggests the impacts of the radical spatial perspective tend to be exaggerated, but nevertheless calls for a, “...reexamination of spatial perspectives and analytical frameworks” (Shen, 2004, p. 263). Bradshaw and Muller (2004) address the conventional versus radical spatial perspective by making a distinction between services which must be provided locally and are dependent on density of demand and contrasts this group of services with those that can be provided from a distance:

Many policies can be implemented from a distance with little loss of policy effectiveness and efficiency, such as environmental research laboratories or state tax collection bureaucracies. Others are tied to the distribution of demand, such as trash collection, mosquito abatement, or calibration of scales and gasoline pumps (Bradshaw and Muller, 2004, p. 303).
Appearing relatively recently in the literature is the idea that political fragmentation may increase the cost of local government service provision. From the work of Burchell et al. (1998), Downs (1994, 1999), Foster (1997) Lewis (1996) and Fischel (1985), Carruthers and Ulfarsson (2003) note new local governments and special districts are often formed to assist in service provision in growing and urbanizing areas. They state:

This process is fundamental to the perpetuation of sprawl because new incorporations and service districts literally enable suburban development to proceed at the urban fringe ... the process of political fragmentation compounds questions regarding the relationship between the character of urban development and service expenditures by simultaneously promoting the physical dimensions of urban sprawl and seeking to achieve greater cost-effectiveness in service deliver (Carruthers and Ulfarsson, 2003, p. 506).

In incorporating these concepts into their research they measure political structure by counting per capita municipalities and per capita special districts where higher values correspond to greater political fragmentation (Carruthers and Ulfarsson, 2003).

A fundamental measure of growth in the built environment is population. In previous work, Bierhanzl and Downing (1998) use percent change in population growth to capture growth rates and the log of population density to account for jurisdiction size and economies or diseconomies of scale. Ladd (1994) discusses the relationship between population change and economies of scale. Where those economies of scale exist, increases in population size may result in decreasing average costs of service provision. Diseconomies of scale, on the other hand, with an increasing population will result in increasing costs. The idea of economies and diseconomies of scale in public service provision is tied to Burchell and Listoken’s (1978) mention of excess or deficient service capacity. Economies of scale require excess service capacity. Where there is near threshold or deficient service capacity an increasing population could result in substantial additional costs resulting from the need for additional capital improvements (e.g. a new sewage treatment plant) where there is no change in output. Also relevant is Gaffney’s (1964) argument that decreasing costs due to increasing economies of scale are subject to a population increase within a given perimeter.
**Scale** is an issue inherent in every geographical analysis, including the evaluation of neighborhood characteristics. Parsons Brinckerhoff state there exists some consensus that costs of different development patterns only become apparent, “... at the corridor, subregion or regional scale” (Parsons Brinckerhoff, 1998, p. 16). They also state the use of counties as a unit of spatial analysis is problematic because the typically large size obscures urban densities. Carruthers and Ulfarsson (2003) further the argument against counties as a unit of spatial analysis in stating counties are not suitable for measuring density because any population increase will necessarily lead to an increase in density. In this case, the simple solution is to measure population, population change and / or density at some sub-county level.

**2.5 Incorporating Urban Form into the Production Function**

There are a number of definitions of urban. Urban form is defined by Gleeson (2006) as the density, extent and appearance of the urban environment (p. 11). Urban form is also defined by Anderson *et al.* (1996):

> Urban form may be defined as the spatial configuration of fixed elements within a metropolitan region. This includes the spatial pattern of land uses and their densities as well as the spatial design of transport and communication infrastructure (Anderson *et al.*, 1996, p. 9).

The definition provided by Anderson *et al.* (1996) raises a number of interesting points including tying urban form to land use and characterizing urban form by fixed elements. The term fixed elements suggests urban form would be more properly characterized using buildings (more fixed) then population and / or employment density, which are less fixed.

Cervero and Kockelman provide useful context by explaining their use of the term, ‘built environment’:

> As used here, ‘built environment’ means physical features of the urban landscape (i.e. alterations to the natural landscape) that collectively define the public realm, which might be as modest as a sidewalk or an in-neighborhood retail shop or as large as a new town (Cervero and Kockelman, 1997, p. 200).
By combining the idea of fixed elements with Cervero and Kockelman’s (1997) conception of the built environment we approach the way the term urban form is used in this dissertation. Here, urban form primarily indicates the pattern, including both land use and density, of the built environment. As such the use of the term here de-emphasizes the appearance aspect of Gleeson’s definition. Inherent in the use of the term urban form in this research is the element of the spatial heterogeneity, or lack of spatial uniformity per Anselin and Getis (1992), of the built environment.

Local government service elements may be divided into three categories: those that have a spatial component, some spatial component, and no spatial component to the cost of service provision. While there is a lack of quantitative evidence indicating how specific services might be categorized, the literature provides general guidance. Discussed above are how infrastructure based services are likely to be sensitive to urban form. Additionally, Stephenson et al. (2001), while acknowledging education is often the largest part of a local government’s budget, suggest these expenditures are not sensitive to the spatial aspects of development. They cite Burchell et al. (1998), Burchell (1992), Duncan et al. (1989) and Frank (1989) in stating teacher salaries, administration and construction are not substantially affected by dispersion, distance and density. However, citing Downing and Gustely (1977) and Esseks and Sullivan (1999), the costs of bus transportation for education are sensitive to urban form (Stephenson et al., 2001). The literature is conflicted as to whether costs of fire and emergency service provision will be influenced by the arrangement of the built environment. Stephenson et al. (2001) cite Ladd (1992) in suggesting the built environment may influence service standards for fire and police.

Quantifying Urban Form
The number of services provided by local government that are likely to be influenced by urban form establishes a need to quantify urban form. Clifton et al. (2008) provide an overview of the state of the art in their paper, *Quantitative analysis of urban form: a multidisciplinary review*. They mention reasons for quantifying urban form including research and planning, measuring differences between cities, measuring change over time.
and for planning-support system based impact analysis of development alternatives. They mention potential social and economic consequences to differing land-use patterns. They also present five categorical perspectives on urban form: landscape ecology, economic structure, transportation planning, community design and urban design (Clifton et al., 2008, p. 18). While these perspectives provide further detail for the need to quantify urban form, only landscape ecology offers methods for doing so. There is, therefore, a need for further research. Irwin and Bockstael (2007) concur:

A dearth of fine-scale land use data has prevented spatially explicit quantification of urban land use patterns beyond the extent of a single county or urban area. Yet it is precisely this fine-scale pattern with which the debate over sprawl and its impacts is principally concerned—the lack of contiguous residential development that increases public service costs; the spatial diffusion of households and jobs that magnifies traffic congestion and increases greenhouse gas emissions; and the fragmentation of undeveloped land that alters habitat, degrades natural resources, and eliminates functional open spaces (Irwin and Bockstael, 2007, p. 20672).

Tsai (2005) provides valuable context in the discussion of quantifying urban form. Tsai sought to quantify urban form using population and employment densities in order to quantitatively ascertain differences between sprawling and compact development. As shown in Figure 1, Tsai splits urban form into a number of different elements: metropolitan size, density, degree of equal distribution and degree of clustering. Tsai’s dimensions of urban form, as they are rooted in population and employment statistics touch upon both intensity and land use (residential and commercial / industrial). However, following Anderson et al. (1996) it is possible to improve upon the characterization of urban form using population and employment numbers but using more fixed elements, such as land-use pattern. Potential means of assessing urban form that incorporate land-use pattern as a fixed element include spatial metrics and measures of spatial autocorrelation.
As detailed below, this research considered two approaches for quantifying urban form, spatial metrics from the landscape ecology literature and measures of spatial autocorrelation.

**Spatial Metrics**

The pioneering work in the quantification of landscape pattern comes from the field of landscape ecology where landscape structure, the pattern and organization of landscape elements, may be quantified using landscape metrics. Herold *et al.* (2005) use the term “spatial metrics” in extending the concept of landscape metrics to analysis of the built environment. Spatial metrics quantify the pattern and organization of landscape elements.
that comprise the built environment. Herold et al. (2005) suggest the application of landscape type metrics to the built environment are brought about by an interest in quantifying, “...the spatial component in urban structure (both intra- and inter-city) and in the dynamics of change and growth processes” (Herold et al. 2005, p. 371).

Recent examples of an index based analysis of the built environment using spatial and/or landscape metrics include Parker and Meretsky (2004), Alberti (2005) and Van Eck and Koomen (2008). Parker and Meretsky (2004) use spatial metrics to assess the outputs of an agent-based model. Their goal is to illustrate links between landscape pattern and a number of externalities brought about by mixing more intensely developed (e.g. urban or residential) and less intensely developed (e.g. agricultural) land uses. They state explicitly the need to develop models that explore relationships between landscape pattern and socioeconomic variables (Parker and Meretsky 2004, p. 234). Alberti (2005) uses a number of landscape metrics to quantify urban patterns with the aim of assessing the influence of urban pattern on the environment. Van Eck and Koomen (2008) draw from spatial metrics to develop indicators which allow a scenario based comparison of land-use patterns.

A drawback to the use of spatial metrics in quantifying pattern is that metric calculations are not based on observation values associated with individual areal units. While spatial metrics are suitable for measuring pattern, the exclusion of attribute data from calculations precludes integrating the intensity of the built environment with pattern analysis. However, spatial metrics may be directly compared with other measures of landscape pattern as a means of ascertaining the effectiveness of these other measures to capture changes in pattern over time.

A summary of the measures of urban form, based upon spatial metrics, spatial autocorrelation statistics and other techniques is presented in Appendix I. The purpose of the table is to succinctly summarize the assessments of urban form reviewed here. The table in Appendix I clearly illustrates most indices are not based on observation values
associated with individual areal units. Of those indices that are based on observation values associated with individual areal units, most are population or employment data. Spatially explicit population data in the United States are limited to the years of the decennial census. Spatially explicit employment data are extremely rare. A way forward is suggested by Porat et al. (2008) in their use of spatial autocorrelation measures to analyze annual data associated with urban form.

**Spatial Autocorrelation**

The application of the Moran’s $I$ measure of spatial autocorrelation to the built environment has recently begun to be explored. Tsai (2005) uses measures of spatial autocorrelation to summarize population and employment distributions. Porat et al. (2008) use Moran’s $I$ to characterize construction initiation data where observations are measured floor area. Their goal is to help explain the evolution of urban structure. They ground their work in a literature review which offers broad support for the idea that measures of spatial autocorrelation may be extended to the built environment to assess pattern and changes over time. At the core of their research is the use of Moran’s $I$ to reveal spatial homogeneity, randomness or heterogeneity as well as delineate areas based on development concentration (urban core, surrounding area or variants). Porat et al. (2008) indicate that when applying Moran’s $I$ to the time dimension the statistic may be used to assess temporal changes in pattern, reveal characteristics of past patterns, and provide insight into changes in patterns. They also suggest the disaggregation of the built environment by land use enables greater insights into processes of pattern and change associated with those uses.

Measures of spatial autocorrelation have a number of characteristics which make them well suited for quantifying pattern in the built environment. Measures of spatial autocorrelation are useful for understanding spatial structure and spatial heterogeneity (e.g. Aspinall, 1999; Boots and Tiefelsdorf, 2000). Goodchild (1986) argues measures of spatial autocorrelation are important as they give precise value to something that would otherwise be interpreted subjectively and they provide information about spatial data
that are not available with other forms of statistical analysis. Frizado et al. (2009) point out spatial statistics, including measures of spatial autocorrelation, are useful for cluster identification in part because these measures look beyond the bounds of a single areal unit to consider interactions within a specified neighborhood. Miller (2004) makes the point explicitly that spatial autocorrelation statistics provide information which may be useful for quantifying patterns:

Although spatial autocorrelation is often treated as confounding (e.g., something to be corrected in regression modeling), it is information bearing since it reveals the spatial associations among geographic entities... Similar to spatial autocorrelation, spatial heterogeneity is not just parameter drift to be corrected: it is information bearing since it reveals both the intensity and pattern of spatial associations. Disaggregate spatial statistics such as local indicators of spatial association ... capture spatial association and heterogeneity simultaneously (Miller, 2004, p. 284).

Miller’s mention of disaggregate spatial statistics raises the point that a number of spatial autocorrelation statistics offer both global and local statistics. Global statistics present an average assessment of clustering across a study area whereas local statistics, which are often a decomposition of the global statistic, allow an assessment of distribution in space that may vary within a study area (Fotheringham et al. 2002). Goodchild (1986) argues global measures of spatial autocorrelation are a means of data summary analogous to a mean and/or median. Local measures may be used to identify spatial heterogeneity, spatial outliers, clusters and hot spots (Boots and Tiefelsdorf, 2000) and provide focus on areas that are exceptions to the generalities presented in a global statistic (Fotheringham and Brunsdon, 1999).

Goodchild (1986) observed that nearly all spatially distributed data exhibit some degree of spatial autocorrelation. Following De Smith et al. (2009) there are several standard options for regression analysis in the presence of spatial autocorrelation. One may ignore the spatial autocorrelation, allow the global constant to vary locally as is done with geographically weighted regression, or “…include additional elements into the regression model that take explicit account of the observed pattern of spatial autocorrelation” (De
Smith et al. 2009, p. 299). The inclusion of additional elements is typically done with spatial autoregressive modeling in the form of a spatial lag model or a spatial error model.

Geographically weighted regression, spatial lag and spatial error models are all based on cross-sectional or panel data. A fundamental input in local government fiscal modeling, expenditures by service category, as well as potentially relevant demographic and socioeconomic characteristics, are often not available as cross-sectional or panel data. Changes in landscape pattern necessarily occur over time so it is necessary to step beyond cross-sectional analysis which is temporally static and utilize time series and/or panel data. Lacking panel data, geographically weighted regression, spatial error and spatial lag models do not appear to be appropriate for the analysis of landscape change and associated fiscal modeling. The methods incorporated in this analysis vary from these more traditional means of incorporating spatial effects. Instead, this analysis suggests the inclusion of a spatial index in time series regression analysis.

The suitability of using measures of spatial autocorrelation in regression analyses may be evaluated by ascertaining whether spatial autocorrelation statistics meet required regression assumptions. Key assumptions used in ordinary least squares, two-stage least squares and times series analyses are random sampling of input data, normal distribution of input data and homoskedastic distribution (independence) of residuals.

Anselin (2002) provides a solid reasoning in support of the random sampling with spatial data by invoking the concept of superpopulation or spatial random process:

.. a cross-sectional data set on economic variables for US states is not a sample from a population of imaginary states, but its spatial pattern (e.g. as shown by a map for state incomes) is a single observation from all the possible stochastic patterns that an underlying mechanism may generate. In order to carry out statistical inference, a notion of a superpopulation or spatial random process (e.g. a Markov random field, MRF). This assumes the existence (conceptually) of a stochastic process that may generate many possible spatial patterns, of which the observed data is one. The objective of the analysis is then to characterize the spatial process by means of the observed spatial pattern (Anselin, 2002 p. 255).
The normal distribution of spatial autocorrelation measures largely depends upon whether they are local or global statistics. Boots (2002) notes the distributions of global Moran’s I and Geary’s c statistics may be assumed normal when there are greater than fifty observations. However, the local statistics are not normally distributed (Boots, 2002, p. 170-171). Tests for the normal distribution of the data included in this analysis support these observations.

The lack of independence of spatial data is well known and is very much the essence of spatial autocorrelation. Miller et al. (2007) point out the assumption of independence violates one of the guiding principles of geography, Tobler’s law, mentioned above. The situation is summarized by Fotheringham and Brunsdon (1999) and Fotheringham et al. (2002). From a theoretical perspective, spatial data are usually not independent therefore regression modeling with spatial data may be suspect. A practical solution to the problem seen in spatial regression models is to ease the assumption that error terms for individual observations are independent which can be done if necessary steps are taken to insure that the dependence in the error is accounted for. Easing this assumption allows observations of proximal error terms to be correlated (Fotheringham and Brunsdon, 1999; Fotheringham et al., 2002).

**Accurately capturing the nature of spatial dependence**

The spatial index developed in the next chapter is based on the Moran’s I measure of spatial autocorrelation. A critical issue in calculating Moran’s I statistics is determination of the spatial weights matrix informing the calculation. As noted by Bivand (2008), Cliff and Ord (1973) put forth the initial conceptualization and definition of a general weights matrix, the purpose of which is to allow for a selection of weights based on an *a priori* conceptualization of the structure of spatial dependence.

Fotheringham et al. (2002) explain the weights matrix as an attempt to quantify the concept of proximity, to answer the subjective question, “What is meant by nearby?” (p. 103). Frizado et al. (2009) point out varying definitions of a weights matrix will lead to
different conceptions of neighbors and result in different calculations of spatial autocorrelation (p. 32). Speaking of spatial weights matrices, Bivand (2008) notes:

The arbitrary nature of the representation of spatial processes seems unavoidable, with the need to handle $n \times (n - 1)$ possible interactions, when we only have $n$ observations (Bivand 2008, p. 14).

As a spatial weights matrix has great bearing on resulting autocorrelation statistics, the issue of the specification of spatial weights is, per Anselin (1988), a “crucial operational issue in spatial econometrics” (p. 16) as well as, “one of the more difficult and controversial methodological issues in spatial econometrics” (p. 19-20).

Anselin approaches the issue of the specification of spatial weights from a theoretical perspective. He argues the characterization of spatial dependence specified in a weights matrix be guided by spatial interaction theory and based on a theoretical conceptualization of the structure of dependence (Anselin 1988, p. 21). Further insight is provided by Anselin (2003). Here, the problem of specification of weights is split into three general categories depending on connectedness structure, one based on distance, another based on contiguity and a third based on a specification of the number of nearest neighbors (see Getis and Aldstadt 2004 for additional permutations). The choice of connectedness structure is based on analytical context and is in many ways data driven. For example, in order to use the contiguity structure a polygonal data structure is needed. When using distance measures, a point structure is needed (Anselin, 2003). When conceptually justifiable, GIS functionality such as the ability to convert polygon features to points and the ability to create Thiessen or Voronoi polygons from points provides some flexibility to change between polygonal and point data structures. This, in turn, yields some flexibility to choose between contiguity and distance based connectedness measures.

All three categories of connectedness structure have limitations. As something of a warning Anselin (2003) states, “Spatial weights based on a simple Distance Threshold
criterion often lead to a very unbalanced connectedness structure” (p. 85). Distance based conceptions of clustering are typically evaluated with inverse distance weighting (IDW) where values near an observation carry a greater weight than values distant from an observation. Similarly to surface interpolation with IDW, calculation of local Moran’s I statistics using IDW to conceptualize spatial relationships results in locally high values, or bulls eyes, around isolated data locations. Bivand points out Griffith (1995) in Some Guidelines for Specifying the Geographic Weights Matrix Contained in Spatial Statistical Models demonstrated:

... that a parsimonious specification of the relationships between observations is to be preferred to one making assumptions about say distance decay (Bivand, 2008, p. 14).

This suggests the relative simplicity of a polygon contiguity conception of clustering is likely preferable to relying on assumptions about distance decay. A problem with the application of the polygon contiguity assessment of clustering on parcel data is that parcels which are functionally contiguous may not be spatially contiguous. For example, two residences located mid-block on the same street may be separated by an alley. This separation may result in features with no neighbors whatsoever and invalidate test results.

Using the nearest neighbor connectedness structure only some number (K) of neighbors specified are evaluated for spatial interaction. The number of nearest neighbors structure is, going back to spatial interaction theory, interpreted as meaning the number of conceptually relevant neighbors. Anselin (2002) notes the k-nearest neighbors conception of clustering is a commonly used when working with parcel data when the size of the parcels varies widely. Nevertheless, in this application the k-nearest neighbors structure likely results in an incorrect connectedness structure for the valuation of local government service provision where many if not most features in a data set are interacting.

Beyond the choice of connectedness structure, there is an inherent contradiction in work incorporating weights matrices. That is, specifying relationships in order to discover them
Within the context of a warning about this circular reasoning, Anselin as well as Cliff and Ord provide a point of departure by mentioning that in order to specify a spatial weights matrix the spatial structure of data have to be assumed to be known prior to specification (Anselin, 1988; Cliff and Ord, 1973). Following this reasoning, it is argued here that *a priori* knowledge of the spatial structure of the data set inform the specification of spatial weights and contribute to the accuracy of that specification.

### 2.6 Global and Local Analyses

The discussion above of global and local indicators of spatial association points to a new research direction in quantitative geography emphasizing local analysis. Per Fotheringham *et al.* (2000) traditional spatial modeling efforts have operated at what is referred to as the global level. The assumption is that an average global value output from such analyses are representative of processes taking place across the study area. In contrast, local analyses incorporate the concept of spatial heterogeneity in explicitly acknowledging that spatial processes are likely to differ within study areas. Fotheringham *et al.* (2000) discuss the importance of local analysis:

> ... where the focus of attention is on testing for the presence of differences across space rather than on assuming that such differences do not exist. The movement encompasses the dissection of global statistics into their local constituents; the concentration on local exceptions rather than the search for global regularities; and the production of local or mappable statistics rather than on global or ‘whole-map’ values (Openshaw *et al.* 1987). As Jones and Hanham (1995) recognize, this trend is important not only because it brings issues of space to the fore in spatial data analysis and spatial modeling, but also because it refutes the rather naive criticism that quantitative geography is unduly concerned with the search for global generalities and ‘laws’ (Fotheringham *et al.* 2000, p. 93).

For fiscal modeling with the goal of determining the spatial component of development costs, it is variation within a study area that is of principle interest. This suggests the importance of local analysis techniques in fiscal modeling that seeks to determine the relationship between urban form and public service costs.

### 2.7 Research Questions

There is a rich and varied literature surrounding fiscal impact analysis and the related issue of the quantification of urban form. The engineering estimate based studies and early
regression models addressing the impacts of changing land use on local government provision of service provide the cornerstone rationale for research in fiscal modeling and, specifically, point to distance, density and pattern as drivers of costs of service and infrastructure provision. Applied fiscal impacts analysis demonstrates useful average cost methods and points toward the more difficult case study marginal cost approach for greater accuracy. The spatial heterogeneity of the built environment coupled with the low degree of spatial precision in econometric research in fiscal modeling suggests fiscal impacts may not be homogeneous across a level of analysis and points to a finer-grained, more precise spatial resolution as an opportunity for further research. Spatial metrics and/or measures of spatial autocorrelation may be used to quantify pattern. We may therefore identify a gap in published research where the quantification of urban form and the incorporation of that measure in a regression analyses may yield a more richly specified production function. Distillation of these numerous research and analytical threads and the goal of advancing these lines of inquiry led to the following questions which will be used to guide this research:

**Research Question Number One**

**How can an index be developed that captures urban form?**

This question is based in the themes and suggested research summarized in the review of literature above. Early studies addressing the impacts of changing land use on local government provision of service point to distance, density and pattern as drivers of costs of service provision. Emerging methods in fiscal modeling support the inclusion of neighborhood attributes and suggest the inclusion of spatial characteristics in evaluation of local government provision of service. Speir and Stephenson (2002) make an explicit call for research that separates spatial pattern from other factors that may influence the cost of local government service provision.

The literature suggests measures of spatial autocorrelation are more appropriate than spatial metrics for quantifying urban form. Measures of spatial autocorrelation may be used to quantify pattern and intensity of development. The literature further suggests
Moran’s I as an appropriate measure of spatial autocorrelation for this application. The next logical step is to investigate if an index can be developed that captures urban form. Question one may be answered by looking at the Moran’s I measure in detail to ensure theoretical considerations are addressed as well as addressing any practical issues that come up in empirical research. The literature suggests a potential practical issue is the selection of a weights matrix. Question one is addressed and answered in chapter four, “An index capturing urban form for modeling within data scarce environments” beginning on page 89 reiterated in chapter six, “Discussion and conclusion of the spatial structure of the built environment and costs of public services” beginning on page 147.

Research Question Number Two
How can urban form be incorporated into an econometric model explaining local government service provision?

The engineering estimate based studies and early regression models that address the impacts of changing land use on local government provision of service provide the cornerstone rationale for research in fiscal modeling. These studies point to distance, density and pattern as drivers of costs of service and infrastructure provision. Applied fiscal impacts analysis demonstrates useful average cost methods and points toward the marginal cost approach for greater accuracy. The spatial heterogeneity of the built environment coupled with the low degree of spatial precision in fiscal modeling suggests fiscal impacts may not be homogeneous across a level of analysis and points to higher resolution spatial modeling as an opportunity for further research. Newer technologies, now principally GIS-based, offer additional tools and the promise of new methods for capturing the spatial and temporal nature of land-use change. Emerging methods in fiscal modeling leverage the production function to specify inputs and outputs of local government provision of service based on local government inputs and neighborhood characteristics. A spatial index may be used to quantify urban form. This research leverages a spatial index as a driver in a production function based fiscal model for local government service provision in an attempt to answer research question two. The process
is detailed in chapter five, “A Spatially Determined Production Function to Model the Fiscal Impacts of Community Development” beginning on page 115.

Research Question Number Three

How can an econometric model that incorporates urban form be used to identify areas that are fiscally efficient?

In the spirit of developing spatially precise marginal cost evaluation of the cost of local government service provision this dissertation evaluates the spatial implications of the production relationship developed in chapter five, including the statistically significant spatial index. The concept implemented in identifying areas that are or are not fiscally efficient is not marginal cost, but Heikkila’s idea of a service-based fiscal impact. Mapped results are presented and discussed within chapter five on page 136.

2.8 Chapter Two Concluding Statements

The goals of this chapter are 1) to review the literature associating costs of public service provision with urban and to review the literature of fiscal modeling, and 2) to establish the need and clear directions for the research presented in chapters three, four and five. The body of literature highlighted above addresses the economic theory and application examples of fiscal modeling and GIS enabled modeling of the fiscal implications of local government provision of services. The concepts and relationships found in the literature are presented as premises suggesting future research, specifically the three research questions presented in section 2.7. However, before attempting to answer those questions it is necessary to detail the methods incorporated in this investigation.
Chapter Three
Methods

Chapter three presents the overall framework for this research inquiry, the research design, methods and ethical considerations. The framework for inquiry overviews the epistemology, or the approach to developing and advancing knowledge, used in this research. The research design section offers a general discussion of the case study as a research strategy and provides justification for the study area chosen in this investigation. The heart of this chapter is a detailed look at the analytical framework and methods used to answer the three research questions developed in chapter two. This chapter concludes with an overview of the ethical issues that pertain to this investigation.

3.1 A Framework for Research Inquiry

This framework for research inquiry touches upon knowledge claims and assumptions researchers make about how and what they will learn over the course of an inquiry. From Creswell (2003):

> These claims might be called paradigms (Lincoln and Guba, 2000; Mertens, 1998); philosophical assumptions, epistemologies, and ontologies (Crotty, 1998); or broadly conceived research methodologies (Neuman, 2000). Philosophically, researchers make claims about what is knowledge (ontology), how we know it (epistemology), what values go into it (axiology), how we write about it (rhetoric), and the process for studying it (methodology) (Creswell, 2003, p. 6).

A key element in supporting the process of study (methods) is the epistemology, or approach to developing and advancing knowledge used in this inquiry. Creswell (2003) lists several alternative knowledge claims, post-positivism, constructivism, advocacy/participatory and pragmatic. These knowledge claims are assumptions used by researchers which guide how and what they will learn in an inquiry. Broadly, these alternative knowledge claims are not discrete and unrelated, but are points on a continuum of research paradigms. The continuum is put forth by Thomsen (2003) following Cantrell (1993) and summarized in Table 2. The table summarizes and contrasts research perspectives. The ends of the continuum are positivism where knowledge is
gained through experiments and critical science where interpretation of phenomena is developed within social and economic contexts.

**TABLE 2:** Contrasting Views Underlying Alternative Research Paradigms (Thomsen, 2003 after Cantrell, 1993, p. 83-84)

<table>
<thead>
<tr>
<th>Underlying assumptions and beliefs about:</th>
<th>Positivism</th>
<th>Interpretivism</th>
<th>Critical Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose(s) of research</td>
<td>Discover laws and generalisations which explain reality and allow to predict and control</td>
<td>Understand and interpret daily occurrences and social structures as well as the meanings people give to the phenomena</td>
<td>Emancipate people through critique of ideologies that promote inequity and through change in personal understanding and action that lead to transformation of self-consciousness and social conditions</td>
</tr>
<tr>
<td>Nature of reality (ontology)</td>
<td>Single, givens, fragmentable, tangible, measurable, convergent</td>
<td>Multiple, constructed through human interaction, holistic divergent</td>
<td>Multiple, constructed through human interaction, holistic divergent, social and economic; embedded in issues of equity and hegemony</td>
</tr>
<tr>
<td>Nature of knowledge (epistemology)</td>
<td>Events are explained based upon knowable facts, real causes or simultaneous effects; law-like regularities exist</td>
<td>Events are understood through mental process of interpretation which is influenced by and interacts with social context – mutual simultaneous shaping</td>
<td>Events are understood within social and economic context with emphasis on ideological critique and praxis</td>
</tr>
<tr>
<td>Relationship between knower and the known</td>
<td>Independent, dualism</td>
<td>Interrelated, dialogic</td>
<td>Interrelated, influenced by society and commitment to emancipation</td>
</tr>
<tr>
<td>Role of values in research</td>
<td>Value free</td>
<td>Value bounded</td>
<td>Value bounded; ideological critique and concern for inequities</td>
</tr>
</tbody>
</table>

Informing this discussion of epistemology is the acknowledgement that this research is an exercise in quantitative geography. Fotheringham *et al.* (2000) list the elements of quantitative geography, “...the analysis of numerical spatial data; the development of spatial theory; and the construction and testing of mathematical models of spatial processes” (p. 4). While Fotheringham *et al.* note the influence of positivism in early work in quantitative geography, they go on to say quantitative geography is not grounded in any particularly philosophical stance. Rather, that quantitative data and theoretical
reasoning are, “…an efficient and generally reliable means of obtaining knowledge about spatial processes” (Fotheringham et al. 2000, p. 4). The implicit suggestion is that pragmatism is an appropriate epistemology for a good deal of contemporary quantitative geographic research.

It is acknowledged that for this research positivist and to a lesser extent post-positivist knowledge claims generally appear appropriate. The issue investigated here is being examined through experiments, the approach here is reductionist (complex social phenomena are reduced to small, discrete and testable data and ideas), and the research seeks to advance knowledge about the relationship among variables all the while acknowledging the element of human conjecture and social and economic contexts in knowledge construction. However, Nyerges and Jankowski present the argument that, from a planning perspective, the positivist approach and GIS are inappropriate:

Another perspective ... argues that GIS might be a step backward due to its positivistic approach, encouraging rational planning the decision process rather than opening the decision process to participatory behavior (Nyerges and Jankowski, 2010, p 7).

Geertman (2006) provides a bridge between post-positivism and pragmatism as he elaborates on pragmatism in a way that embraces post-positivist conceptions of knowledge construction with ties to participation, collaboration and social learning.

... the philosophy of pragmatism ... can be considered as more of a different attitude than as an alternative to Habermas’s theory of communicative action, which also draws on the US pragmatists (Harrison, 2002). They stress the empirical basis of knowledge and recognize that knowledge stems from the reconstruction of experience, which the learner does in the context of society (see Farrah, 2001). Truth on that basis is not foundational. Ideas that are community derived acquire a truth status when they prove their worth in practice for solving problems (Oranje, 2002). In fact, the emphasis on experiences of planning practice as a source of practical knowledge within this planning style shows close resemblance to the well-known US pragmatic tradition of ‘social learning’ or ‘learning by doing’ (for example, Friedman, 1987)(Geertman, 2006, p. 874).

The most striking contrast between pragmatism and positivism / post-positivism relevant to this research is the concern, embedded within pragmatism, with applications and solutions to problems (Patton, 1990 in Creswell, 2003). Certainly, in this inquiry the
problem, informed modeling of the fiscal provision of local government services, is more important than the methods being tested. Finally, from the pragmatic perspective, research occurs in political, social, historical and other contexts (Creswell, 2003). Clearly, as argued in the discussion of the cultural influences on development pattern put forward in the background section of Chapter One (page 5), local government operations function within those stated contexts. Altogether, pragmatic knowledge claims, to a greater degree than positivist or post-positivist knowledge claims, accurately capture the approach used to develop knowledge in this inquiry.

3.2 Research Design: The Case Study as a Research Strategy
As detailed in chapter two, the research strategy employed in the development of the vast majority of fiscal modeling efforts is the case study. Yin (2003) presents a number of circumstances within social science research that are directly relevant to fiscal modeling where the case study is the preferred strategy. Circumstances when the case study is preferred are when examining contemporary events where relevant behaviors cannot be manipulated. This is certainly the case with fiscal modeling where a researcher may observe phenomena associated with the costs of local government public service provision without, at least initially, influencing the phenomena. Bachor (2002) complements this idea in noting the efficacy of the case study in capturing the characteristics or performance of an individual or collective, in this case, a local government. Yin’s second relevant circumstance where the case study is recommended is for investigating phenomenon within a real-life context when boundaries between the phenomena and context are not clearly evident (Yin, 2003). This research is in some ways an effort to delineate a boundary between the cost of local government public service provision and the urban form within which the phenomena occurs. Clearly then, any boundaries between phenomena and context are not at this time evident.

Even given this strong cornerstone rationale for the use of a case study as a research strategy in fiscal modeling there is a potential drawback. A common criticism of case example evaluations of the relationship between costs of services and the spatial
structure of the built environment is the results from such studies are not broadly applicable because they are derived from specific case study areas (e.g., Carruthers and Ulfarsson, 2003, p. 505). Bachor (2002) addresses the issue of generalizability in a practical manner by suggesting believability is increased by clearly illustrating how evidence was selected for inclusion in a case study. He adds graphs and images can provide information that allows the reader to better understand the context and design of a study. Yin (2003) explores the issue of the applicability of results in a discussion of the question, “How can you generalize from a single case?” (p. 10).

...case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes... in doing a case study, your goal will be to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization) (Yin, 2003, p. 10).

The issue of generalizability is addressed outside the realm of case study (and within the realm of geographic information science) by Fotheringham et al. (2002). In a discussion of spatial regression, Fotheringham et al. (2002) discuss interest in both global and local modeling. They note studies where quantitative methods were used to investigate spatial processes that resulted in researchers being criticized for being too rooted in the search for broad generalizations. The search for broad generalizations, within the realm of these criticisms, is at the expense of investigating local exceptions (Fotheringham et al., 2002). This suggests a need for a balanced approach where attention focuses both on broadly generalizable phenomena and any localized irregularities.

In addressing this tension between particularity and generalization Stake (2000) discusses case studies in terms of “typification” (p. 439), meaning the development of generalizations and early steps toward theory building. Stake points out that ultimate interest likely lies more in general phenomenon or results from several cases rather than outcomes from a single case. A process that is likely to help identify general phenomena is “triangulation” (Stake, 2000, p. 443). Triangulation is a way of processing multiple observations, or case examples, to clarify meaning. Stake notes measurements are more accurate than differences, and therefore differences between two studies should not be
trusted as much as conclusions from one (Stake, 2000). Triangulation based on similarities is therefore stronger than triangulation based on differences.

It is apparent the use of the case study for research in local government fiscal modeling is appropriate. The value of case studies is apparent but less clear. Case studies are, in the words of Yin, “…generalizable to theoretical propositions…” (Yin, 2003, p. 10) and these generalizations, in the case of quantitative research, are strengthened when supported with data. Bachor (2002) extends this argument beyond quantitative research when he suggests generalizations must be based on evidence revealed to the reader. By juxtaposing the ideas from Yin (2003) with Stake (2000) the strengthened generalizations from quantitatively based case studies could be enhanced using multiple studies. While the work presented here is one case study, this rationale is a solid basis for applying these methods to other areas to see if similar conclusions may be reached.

### 3.3 Justification of the Study Area Chosen

Selection of a case study for this research was informed by Yin (2003) and Stake (2000) with an emphasis on finding a case that presented clear opportunities for learning and research. Stake (2000) elaborates on the idea of opportunities for leaning, stating that greater accessibility and cases where one can spend more time are desirable.

Eisenhardt (1989) addresses case selection in a broad discussion of generalizability and developing theory from case studies. She overviews the entire process of case study investigation from the development of research questions through generalizability to theoretical saturation. Key portions of her argument germane to selecting a case include tightly linking the process of theory building to data and a priori specification of constructs, or factors that shape initial theory building. The idea of linking theory building to data goes back to Glaser and Strauss (1967). This link is the “…intimate connection with empirical reality…” that enables theory development (Eisenhardt, 1989, p. 532). Specified constructs allow measurement and, if the constructs remain important as the study unfolds, make for more solid ground for theory building. She adds that one of the goals of
choosing cases is to select those that are, “...are likely to replicate or extend the emergent theory.” (Eisenhardt, 1989, p. 537)

Darke et al. (1998) list several factors in case selection. Selection of case must be related to the research question. The case selected must be at the same scale as the research question (e.g. must be of sufficiently broad to answer the question) and must offer sufficient data to answer the question. Darke et al. (1998), in an idea analogous to Stake’s argument for accessibility and choosing a case where one can spend time, Darke et al. (1998) raise the practical matter that the study must be able to be accomplished within the scope of given resources and be able to result in the output required (e.g., a doctoral dissertation).

Bleijenbergh (2010) states the selection of case should be based on the research question. She argues the most important consideration in selecting a case is the relevance of the case to the research objective.

Yin supports Eisenhardt’s (1989) and Darke et al.’s (1998) argument for basing the selection of a case study in part on data availability. Yin (2003) argues the selection of a pilot site, and this methods development research may be viewed as a pilot study, may be selected based on helpful people at a potential site, strong data resources, the availability of other documentation or geographic convenience.

In summary, a case study should be selected based on practical matters such as accessibility, be where one can spend more time, it should be able to be accomplished with available resource and lend itself to the product required. The selection of case should be related to the research question and allow one to answer that question, including having sufficient data available. A study site should also have characteristics, or constructs, that allow one to replicate or extend existing theory.
The area selected for this investigation was Albany County, Wyoming, USA. Selection of a case for this study was based not on whether the case clearly represented a generalizable or unusual example, rather whether the case provided potential for research and ultimately learning. There were three criteria used in this evaluation. The case must be able to contribute to the answering of the research questions articulated above. Areas with moderate or strong growth are of interest because these areas in the American West raise new debates about land use, including how much and what type of growth can be accommodated (Travis, 2007). These issues and this approach are not limited to the American West but are in fact relevant to areas experience growth and land use change around the globe. Therefore, study areas with stagnant or negative growth were not considered for analysis. Albany County has been experiencing moderate growth, especially in rural areas, since at least 1990. Based on recent growth patterns within the local government area, a spatial index tied to fiscal modeling is relevant.

Secondly, Albany County, with a centrally located node of service provision and population concentration in and around the City of Laramie, presents a close approximation of a monocentric urban or central place type model. The monocentric model, although often a simplification, allows straightforward empirical estimation (Su and DeSalvo 2008). That the study area is approximately congruent with a monocentric model, an \textit{a priori} construct, is also a factor relevant to and potentially beneficial for theory building.

The third criterion for case selection was data availability. In Albany County and across Wyoming there are a wide variety of demographic, socioeconomic, and fiscal data available at the county level. Additionally, Albany County has developed a spatially accurate and well-attributed cadastral database which can be leveraged to track change in urban form.

\textbf{3.4 Methods for Research Question #1}

Research methods were developed by focusing on the three research questions presented in \textit{chapter two} beginning on page 55. Discussion of methods is therefore broken down by
question. While the general approach is mixed methods, an overview of the specific techniques and procedures required for this research are discussed in the remainder of this chapter. Prior research used in both framing the research questions and developing these methods is presented in chapter two, beginning on page 15.

The methods used to answer the first research question, “How can an index be developed that captures urban form?” depend upon high quality parcel data. The principle data used to develop the index capturing change in the pattern of the built environment for Albany County was the 2008 cadastral layer from the County GIS office. The data contain 18,642 parcel records. Relevant attributes include activity code, building year built, land value and building value. The activity code attribute, while designed and used by the County Assessor’s office for taxation purposes, is also a reasonable surrogate for land use. The activity code attribute uses categories that are nearly identical to commonly used land use classifications. Typical examples of land use classifications are agricultural, residential, commercial, industrial and mixed-use. The activity codes in the data are agricultural, commercial, commercial vacant land, industrial, mobile home, residential, residential vacant land and tax exempt.

Python scripting (ESRI, 2010) was used to develop the 2008 parcel layer into panel data. Records from the 2008 cadastre were selected based on the year built attribute and exported as a time series of cadastral layers dating from 1990 through 2007. Python scripting automates otherwise repetitive manual GIS processes thereby both saving time and ensuring consistent application of methods. The resulting time series of cadastres documents land-use change over eighteen years in the county.

Given this time series of observation values, the next step in developing the spatial index was to determine the appropriate weights matrix for calculation of the autocorrelation statistics. The approach to developing a spatial weights matrix was to compare outputs from various weights matrices with other non-arbitrary assessments of clustering.
Preliminary conceptions of clustering and distribution may be contrasted with outputs from differing specifications of spatial weights in order to verify a weights matrix accurately reflects the pattern of the built environment in the county. In order to evaluate alternative specifications of spatial weights matrices values of local measures of spatial association from the output of alternative specifications of spatial weights matrices were compared with other non-arbitrary specifications of the clustering of the built environment. Building values, assessed by the Albany County Assessor’s Office and measured in dollars, were chosen as the basis of the spatial autocorrelation calculations as they are a relatively fixed parcel-based measure of the intensity of the built environment and are a reasonable surrogate for demand for services. This follows Anderson et al.’s (1996) definition of urban form which emphasizes the importance of “fixed elements” in measuring urban form. The use of building values is preferred as a basis for quantifying urban form to less fixed alternatives such as population and / or employment data.

The following is an example, based upon residential land use, of how spatial weights were determined. As illustrated in Figure 2, three non-arbitrary specifications of the clustering of the built environment for residential land use were considered: (A) the sum of residential building values, (B) the count of residential parcels, and (C) the count of residential parcels divided by distance to town. The calculations presented in Figure 2 were performed within a grid layer developed for other planning analyses in the study area. For visual clarity, the representations in Figure 2 are presented as a percent of maximum value and incorporate a 1,000x vertical exaggeration. The three specifications of clustering considered here are remarkably similar. As a point of departure for development of a spatial weights matrix, the conception of clustering derived from a spatial matrix should appear similar to the specifications of clustering in Figure 2.
FIGURE 2: Alternative Conceptions of the Clustering of the Built Environment for Residential Land Use
The primary choice in specification of the weights matrix was between distance and contiguity based conceptions of clustering. The nearest neighbors conception of clustering was discarded as spatial interaction theory suggests the nature of service provision varies considerably from relations among some number of nearest neighbor parcels. Given the noncontiguous nature of building values data throughout the county, a spatial weights matrix based upon point data (cell centroids) with weights calculated using inverse distance weighting (IDW) is intuitively appealing. Congruent with theory suggesting potential problems with IDW, clustering specified by IDW resulted in locally high values for isolated observations as well as a ring of extremely low local Moran’s I statistics at the edges of the primary concentration of clustering in the study area, the City of Laramie. The pattern of local Moran’s statistics for all spatial indices calculated using inverse distance weighting violated the preliminary conceptions of clustering in Figure 2.

In order to alleviate problems with parcels functionally adjacent but spatially separated (e.g. across an alley) experiments were conducted with first order polygon contiguity conception of clustering using the planning analysis grid. In addition to solving the problem of cells that are functionally but not actually contiguous, the grid allows compatibility with other planning models used in the study area and faster processing (4,500 cells for the grid with cells 1 square mile in size vs. 18,000 parcels). The grid also smooths values of clustering and dispersion such that the characterization of alternative specifications of spatial weights may be more easily ascertained. The basis of the grid is the set of public land survey system sections in the county therefore grid cells are approximately one square mile in size. Section lines often correspond with property boundaries so the grid is not completely arbitrary. The simplification of using a regular tessellation, as opposed to performing calculations on the parcels themselves, also allows differing specifications of weights matrices to be more easily interpreted.

In order to use the grid to assess various weights matrices building values from the parcel data set were summed within each grid cell. Conceptually, this may be viewed as a three
step process. Step 1, shown in **Figure 3A**, is mapping the building value attribute Albany County residential parcel data. Step 2, **Figure 3B**, is overlaying parcel based building values data with the analysis grid. Step 3, **Figure 3C**, is summing building values from the parcel layer for each grid cell.

![Figure 3: Steps in Developing Observation Values](image)

The polygon contiguity conception of clustering based on the sum of building values within grid cells is illustrated in **Figure 4A**. As shown in **Figure 4A**, residential clustering and dispersion based upon a first order polygon contiguity conception of clustering is inaccurate. In addition to a central core area and other nodes of development, there exists a random assessment of the distribution of building value throughout the entire study area, including in what is mostly un-built agricultural land and other open space. However, if the subset of cells where building value is equal to zero are removed after calculating local I statistics, the result (**Figure 4B**) is a conception of clustering similar to the preliminary conceptions illustrated in **Figure 2**. The operation is an implementation of the
extract by attributes spatial analysis functionality. Cells are queried based on building values. Where the building value is greater than zero, the local Moran’s I statistic (Figure 4A) is moved to the corresponding cell in a separate grid (Figure 4B). Where the building value is equal to zero, no value is assigned to the corresponding cell (Figure 4B). The extraction is conceptually justified as it allows observations (the spatial index) to be developed that separate meaningful observations (those cells where building values are present) from noise (those cells where building values are zero). This makes intuitive sense as it is the built environment, and not empty space that would likely be significant in a regression relating spatial pattern with public service expenditures.

**FIGURE 4:** Calculated Residential Clustering and Dispersion Based on Polygon Contiguity

A comparison of plots of the local Moran’s index vs. the sum of building values within grid cells (Figures 5 and 6) sheds light on the distributions of local I statistics for the set of all cells and the set of cells where observation values equal to zero were removed. Figure 5 is a scatterplot of the data presented in Figure 4A which include all local I calculations. Figure 6 is a scatterplot of the data presented in Figure 4B which omits calculations based on observation values of zero. As can be seen by comparing Figures 5 and 6, removing calculations based on observation values of zero does not change the presentation of the plot. The outliers, the larger local I statistics, are retained. What is lost are a random assessment of clustering where the local I statistics are approximately zero. With the
removal of cells where the sum of building values equals zero from the calculation of the spatial index it is proper to say the spatial index developed here is a modified Moran’s I which differs from the original Moran’s I. The primary drawback to this method is the global assessment of clustering falls outside the -1.0 to 1.0 range of Moran’s I calculations.

FIGURE 5: Scatterplot Representing the Data in Figure 4A, Local Moran’s I Statistics with All Cells
A drawback to the use of a grid rather than the time series parcel data is the introduction of potential variability into the analysis from the modifiable areal unit problem (MAUP). The MAUP may be present when the scale of the grid differs from the scale of the process under study (Anselin and Getis, 1992 p. 26). Fotheringham et al. (2000) trace identification of the problem to sociologist W.S. Robinson’s 1950, *Ecological Correlations and the Behavior of Individuals*. Fotheringham et al. (2000) then present the issue very generally saying, in essence, the results of a spatial analysis may vary if the data are differently aggregated. For the purposes of this research, the influence of the modifiable areal unit problem may be tested for by experimenting with grids of different cell sizes.

**FIGURE 6**: Scatterplot Representing the Data in Figure 4B, Local Moran’s I Statistics without Cells where the Observation Value is Zero
Spatial Metrics (see Irwin and Bockstael 2007 and Herold et al. 2005) may be used to further validate the spatial index. Fragstats spatial pattern analysis software may be used to calculate contagion, a measure of landscape structure (McGarigal et al. 2002). Contagion is a landscape level metric where one value represents the entire study area. Contagion cannot be used to evaluate an individual land-use (or class in the parlance of landscape metrics) so all land uses will be evaluated together.

3.5 Methods for Research Question #2
Investigation of question #2, “How can urban form be incorporated into an econometric model explaining local government service provision?” requires developing an econometric model that incorporates a measure of urban form for one element of local government service provision within the selected case study area. Policing services in Albany County are investigated here but the following discussion should be relevant to all local government services with a spatial component to their provision or distribution.

Following Stephenson et al. (2001) who suggest the challenge is to isolate spatial factors from other influences on costs of services, a model of the spatial component of the costs of public service provision seeks to assess if and how spatial attributes and neighborhood characteristics are significant factors in determining a relationship between costs of services and urban form. Building a production relationship that incorporates urban form requires a discussion of economic theory, development of an econometric model and finally development of the production function itself.

**Economic Theory**
A local government may be viewed as an entity that provides public services. It competes in the private market for inputs used to provide those services. Local government is modeled similarly to a private firm in regard to input usage. It is presumed that local government strives to be cost effective in its use of limited resources (inputs). Thus, inputs are used for production relative to their respective costs.
A graphical representation of the relationship between different quantities of production inputs and resultant production outputs is presented in Figure 7. Figure 7 illustrates how different combinations of inputs will yield the same output. In Figure 7 the relationship of a two input production function, inputs $X_j$ and $X_k$, is plotted. The budget constraint is a straight line where the slope indicates the ratio of input prices and the distance from the origin is indicative of the size of the budget. The slope of the isoquants at any point is the ratio of the marginal products ($MP_j/MP_k$) as well as the marginal rate of technical substitution between inputs $X_j$ and $X_k$ at that point, $MRTS (X_j,X_k)$. Figure 7 also serves to illustrate the relationships between inputs with changing costs. The figure illustrates both price increases (a shift from $X_{j1}$ to $X_{j2}$) or price decreases where (a shift from $X_{j2}$ to $X_{j1}$) resulting in production at a new lower output level (a shift from $\bar{Y}_1$ to $\bar{Y}_2$) or new higher output level (a shift from $\bar{Y}_2$ to $\bar{Y}_1$), respectively. Within the context of budget constraints for local government provision of services, a manager or decision maker cannot continually substitute increasing levels of inputs if the cost of those inputs is increasing.

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**FIGURE 7:** The Marginal Rate of Technical Substitution of Production Inputs
Heikkila and colleagues model local government service provision with a production function. From Heikkila and Craig (1991):

\[ S = f(X, N_s, Y_s) \]  \hspace{1cm} (3)

where,
- \( S \) represents level of public service;
- \( f(.) \) is the production function technology;
- \( X \) is local government expenditures on inputs determined by an allocation function;
- \( N_s \) represents a combination of neighborhood characteristics; and,
- \( Y_s \) represents median income.

Equation (3) represents a production function that generates a measured level of service output determined by local government expenditures on inputs and neighborhood characteristics.

Inherent in the production of a level of service is the allocation of resources used in providing that service. Based on Heikkila and Kantiotou (1992), an allocation function is presented as follows:

\[ X = g(N_x, Y_x) \]  \hspace{1cm} (4)

where,
- \( X \) are local government expenditures on inputs;
- \( g(.) \) represents an allocation function;
- \( N_x \) represents a combination of neighborhood characteristics; and,
- \( Y_x \) represents per capita personal income.

Heikkila and Kantiotou’s version of the allocation model is leveraged because the inputs and outputs in equations (3) and (4) are explicit. Our interest is in the relationship between urban form and the costs of public services. For our purposes, the variable \( Y_x \) may be considered to be a neighborhood characteristic and included in the vector \( N_x \). We further modify the argument for the allocation function summarized in equation (4) by suggesting the inclusion of a variable (SI) that specifies the influence of urban form on local government expenditures on inputs to public services provision. While urban form may be legitimately viewed as a neighborhood characteristic, we indicate it separately in equation (5) in order to emphasize this potential influence:
\[ X = g(N_x, SI, I) \]  

where,  
\( X \) represents local government expenditures on public safety;  
\( g(\cdot) \) represents an allocation function;  
\( N_x \) represents a combination of neighborhood characteristics;  
\( SI \) is a spatial index that captures urban form by land use; and,  
\( I \) represents a vector of variable inputs.

Following Bradford, Malt and Oates (1969) the inputs \((I)\) in equation (5) may include officers, cars, communication systems \( et cetera \). The emphasis of \( I \) in equation (5) is on variable inputs, or operating costs, rather than fixed inputs or capital costs. For the provision of policing services an example of variable costs is the number of officers, an example of fixed costs is the price of the police station. While acknowledging the likelihood of thresholds which might yield a greater need for capital equipment, it is assumed here that in communities of similar area and population, regardless of the spatial pattern of the built environment, capital costs will be approximately equal and not be influenced by spatial pattern.

Following Craig (1987), the goal of an allocation function is to ascertain government preferences on input mix as well as the productivity of inputs for public services provision. A hedonic framework is useful for ascertaining allocation preferences as a hedonic models capture the interactions of supply and demand in a market (Palmquist, 1991), in this case service provision. Van Kooten (1993) defines a hedonic model as:

\[ P_{\text{implicit}} = f(c_1, ..., c_n; Q_1, ..., Q_m) \]  

where,  
\( P_{\text{implicit}} \) is the estimated price of a good,  
\( C \) are private housing characteristics, and,  
\( Q \) are public good characteristics (van Kooten, 1993, p. 141).

Equation (5) is analogous to van Kooten’s hedonic model, equation (6), where expenditures on public safety are a function of neighborhood characteristics and
characteristics of the service in question. Neighborhood characteristics \( N \) and \( SI \) in equation (5) may be seen as being analogous to the public good characteristics \( Q \) in equation (6). Inputs \( I \) in equation (5), the variable inputs to the production of policing services, are analogous to the good characteristics summarized as \( C \) in equation (6).

Recall Heikkila and Kantiotou’s allocation function, equation (4), is based entirely on neighborhood characteristics. Equation (5) incorporates per capita personal income, if appropriate, within the variable \( N \) and extends the logic of Heikkila and Kantiotou’s allocation function by leveraging the hedonic framework to include characteristics of the service in question. Equation (5) fully develops Craig’s (1987) idea of using an allocation function to ascertain preferences as well as productivity of inputs.

The inclusion of \( SI \) in equation (5) serves to evaluate the premise that low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. As presented in equation (5) urban form directly influences expenditures.

**The Econometric Model**

The econometric model, based upon equation (1) is presented in Equation (3). It explains the production of public safety as a function of law enforcement expenditures, neighborhood characteristics and unobserved factors. The econometric model specified in equation (5) is based on equations (4) and (6). Equation (5) explains law enforcement expenditures as a function of neighborhood characteristics, urban form, other inputs and unobserved factors.

In an econometric model the potential exists for endogeneity due to the possibility of simultaneous causality between local government input expenditures to policing services and measures of public safety. The endogeneity of law enforcement input expenditures is often depicted as a given in econometric analysis. As articulated by Fisher and Nagin (1978), the nature of the potential endogeneity is simultaneous causality between
explained and explanatory variables. Examples of simultaneous causality are provided by Levitt (1997, 2002) who discusses simultaneity between law enforcement personnel and crime rate and Corman and Mocan (2000) who consider the simultaneity of crime and punishment.

Following Fisher and Nagin (1978) and Levitt (1997, 2002) there exists theoretical potential for endogeneity between law enforcement expenditures and measures of public safety when specified in an econometric model. In the case where inputs are endogenous, the production function for public safety may be developed with instrumental variable methods. Using two stage least squares (2SLS), input data may be instrumented using one or more variables. Law enforcement expenditures are likely to be endogenous with public safety therefore we use a 2SLS approach. Law enforcement expenditures may be instrumented with neighborhood characteristics, a spatial index and other variables using the first stage as the estimation of the allocation function, see equation (7). Variable, $\overline{X}$, is an explanatory variable in the estimation of the production of public safety, as shown in equation (8).

$$\overline{X} = \beta_a + \beta_b SI + \beta_c I + \beta_d N_1 + u_1$$  \hspace{1cm} (7)

$$S = \beta_0 + \beta_1 \overline{X} + \beta_2 N_2 + u_2,$$  \hspace{1cm} (8)

where,
$X$ are law enforcement expenditures;
$SI$ represents the spatial index;
$S$ represents a measure of public safety;
$N_1, N_2$ represent vectors of neighborhood characteristics;
$I$ represents other inputs;
$\theta$ is an estimated parameter on the relevant variable; and,
$u$ are residuals.

**Developing the Production Function**

For the production of policing services, Heikkila and Davis (1997) suggest the level of service measure be the degree of the absence of crime, measured here as a public safety
index. The public safety index may be a function of local government inputs, neighborhood characteristics and pattern of development. Local government inputs may include officers, administrators and any other operating costs. Neighborhood characteristics considered in the production of policing services are typically demographic and socioeconomic measures. Examples include income, unemployment, age structure, gender and ethnicity (Heikkila, 2000). Pattern of development may be quantified with a spatial index which quantifies the clustering or dispersion in the built environment.

The other elements of the regression analysis, including the public safety index, all local government inputs, neighborhood attributes and the spatial index are time series data covering 18 years from 1990–2007. In all cases data represent 18 observations (n=18). Driving variables in this analysis are summarized in Table 3 and illustrated in Figure 8. The public safety index is the inverse of the crime rate. Crime rates were calculated based upon index crime data from the Wyoming Department of Criminal Investigation (2007). Earlier editions of the same title were used to capture data from the 1990s. Wyoming Department of Criminal Investigation methods were followed for calculation of crime rates, but population data from the Wyoming Division of Economic Analysis was incorporated in the calculations rather than Wyoming Department of Criminal Investigation population estimates. Data on the rural population of Albany County are drawn from the same sources (Wyoming Division of Economic Analysis 2010 a, b; 2009). Data on the number of county law enforcement officers are published by the Wyoming Department of Criminal Investigation (2007). The Albany County Sheriff’s budget is found in data on Wyoming county government expenditures which are disaggregated by category of service provided. These data are published by the Wyoming Department of Audit (2008). Historic data in a continuous series from 1991 through the present are maintained by the Department of Agricultural and Applied Economics at the University of Wyoming. These and all other fiscal data are inflation adjusted to 2007.
### TABLE 3: Definition of Variables

<table>
<thead>
<tr>
<th>Included Variables</th>
<th>Definition</th>
<th>Source</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI</td>
<td>Public safety index, the inverse of crime rate</td>
<td>Calculated from data on index crimes reported by the Albany County Sheriff’s Dept. and published by the WY Dept. of Criminal Investigations as well as population data from the WY Div. of Economic Analysis</td>
<td>Index</td>
</tr>
<tr>
<td>$L_{E^{xp}}$</td>
<td>Operating Expenditures of the Albany County Sheriff’s Dept.</td>
<td>Wyoming Dept. of Audit</td>
<td>Millions of $USD 2007</td>
</tr>
<tr>
<td>Res</td>
<td>Spatial index representing residential urban form</td>
<td>Model</td>
<td>Spatial Index</td>
</tr>
<tr>
<td>Res$^2$</td>
<td>Spatial index representing residential urban form squared</td>
<td>Model</td>
<td>Spatial Index</td>
</tr>
<tr>
<td>LEO</td>
<td>Officers in the Albany County Sheriff’s Dept.</td>
<td>WY Dept. of Criminal Investigations</td>
<td>Individuals</td>
</tr>
<tr>
<td>LEO$^2$</td>
<td>Officers in the Albany County Sheriff’s Dept. squared</td>
<td>WY Dept. of Criminal Investigations</td>
<td>Individuals</td>
</tr>
<tr>
<td>Rural Population</td>
<td>Population of the unincorporated areas of Albany County</td>
<td>WY Div. of Economic Analysis</td>
<td>Individuals</td>
</tr>
<tr>
<td>SE</td>
<td>Cost of Living, a summary of price data</td>
<td>WY Div. of Economic Analysis</td>
<td>Index</td>
</tr>
<tr>
<td>Unemployment</td>
<td>Per cent of labor force unemployed</td>
<td>United States Department of Labor, Bureau of Labor Statistics</td>
<td>Per cent</td>
</tr>
<tr>
<td>t</td>
<td>Time</td>
<td>---</td>
<td>Years</td>
</tr>
</tbody>
</table>
In order to create a times series of fiscal data from 1990 through 2007, law enforcement expenditures for 1990 were modeled based on annual percent changes occurring over the time period of the analysis where data are available. Cost of living indices, a summary of price data, are made available by the Wyoming Division of Economic Analysis. Regional data for southeast Wyoming, including Albany County, were incorporated in this analysis. Categorically, the data cover food, housing, apparel, transportation, medical, recreation and personal care as well as “all items” (Wyoming Division of Economic Analysis, 2008). Unemployment data are made available by the United States Department of Labor, Bureau of Labor Statistics (U.S. Dept of Labor, 2008). A time variable was included to detrend the data. Votey and Phillips (1972) suggest the inclusion of a time value may also account for technological change.

3.6 Methods for Research Question #3

Question #3: How can an econometric model that incorporates urban form be used to identify areas that are fiscally efficient?

The fiscal implications of change in urban form may be evaluated on a cell by cell basis with a ceteris paribus analysis of change in the spatial index and the first stage of the 2SLS
results (the allocation model). The abstraction of a *ceteris paribus* analysis is useful as it allows the calculation of the influence of each cell on the law enforcement expenditures needed to maintain the existing level of service. This is analogous to what Heikkila refers to as a service-based impact, defined as “...the minimum cost of restoring service levels to what they were prior to the development in question” (Heikkila, 2000, p. 154). Here, Heikkila’s definition of a service-based impact is modified to capture the estimated cost of providing service from a hypothetical state of no development to existing development on a cell-by-cell basis. This may be thought of as a spatially defined service-based impact. Following Heikkila and Kantioutou (1992), the spatially defined service-based impact is defined as:

\[ J_i = H (S_1; SI_1) - H (S_1; SI_2) \]  

(9)

where,
- \( J \) represents the spatially defined service-based impact for each grid cell \( i \);
- \( H (.) \) is a differenced spatial cost function based on \( SI \);
- \( S_1 \) represents level of service;
- \( SI_1 \) is a spatial index that captures existing urban form by land use; and
- \( SI_2 \) is a recalculated spatial index.

As with the calculation of the spatial index, the grid cells in this analysis are those cells with a residential building value greater than zero. Spatially defined service-based impacts may be calculated for each cell using the following steps:

1. For each cell in the analysis individually remove that cell by setting the building value to zero, re-calculate the local Moran’s I statistics for all cells, then recalculate the spatial index (global statistic). The output from this step consists of an estimated value for Res (the spatial index) calculated as if the cell in question had no residential building value.

2. Leveraging the regression results, the estimated value of the spatial index for each cell may be used to calculate a new estimated value for LE\(_{\text{EXP}}\). The spatially defined
service-based impact for each cell, measured in dollars, is calculated by subtracting the estimated value for \( \text{LE}_{\text{EXP}} \) from the original value (see equation 9).

3. Step three is development of a revenue model. Tax Revenue for Albany County can be broken into three parts: property tax, sales tax and lodging tax. As property tax is the primary input to county revenues paid by a landowner, it is the emphasis of the investigation here. Property taxes may be estimated with a simple three step model that is identical to the calculation used by the county tax assessor. The first step is assigning the correct mill levy (a specified tax rate) to each parcel based upon tax district. The second step is to calculate the assessed valuation. The final step consists of multiplying the assessed valuation by the mill levy which results in an estimate of actual property tax for each parcel.

4. The spatially defined service-based impact for each cell developed in step two may be contrasted with the revenue model developed in step three to estimate fiscal efficiency in a spatially precise fashion. The annual share of overall property tax dedicated to the provision of policing services is approximately 14.5 per cent over the time period of the study. Evaluation of fiscal efficiency is accomplished by aggregating property tax revenues by grid cell, then calculating a Boolean value indicating whether or not a grid cell contributes more in revenue than the value of the service-based impact of the cell, or vice versa. A simple if / then formula comparing spatially defined service-based impacts and revenues is used to make the determination.

Two examples, based on preliminary results, serve to illustrate this process. In the first example we explore the service-based impact of removing a core area cell, represented by a star in Figure 9a. The Local Moran’s \( I \) statistic for the cell is 336.27701 indicating the cell is highly clustered. The global spatial index when the cell is removed is 5.579451. The global spatial index decreases when the cell is removed. Adding the cell back in increases
the spatial index to the original value of 7.055, thereby demonstrating the presence of a core area cell increases clustering in the built environment. Comparing the original LE\textsubscript{EXP} with the second calculation of LE\textsubscript{EXP} results in a spatially defined service-based impact of -$3,730,796 for the cell. In this example, the presence of a core area cell corresponds with a decreased service-based impact, demonstrating that an increase in clustering decreases local government expenditures on law enforcement.

In the second example, shown in Figure 9b and also based on preliminary results, we explore the fiscal consequences of removing an outlying cell. The Local Moran’s I statistic of the highlighted cell in Figure 9b is 0.002549. This low value indicates the cell is not clustered. The global spatial index when the cell is removed is 7.077269. The spatial index increases when this cell is removed. Adding the cell back in decreases the spatial index to the original value of 7.055, thereby demonstrating the presence of an outlying cell decreases clustering in the built environment. Comparing the original LE\textsubscript{EXP} with the second calculation of LE\textsubscript{EXP} yields a service-based impact of $44,209. In this case, the presence of an outlying cell corresponds with an increased service-based impact, demonstrating that a decrease in clustering increases local government expenditures on law enforcement.
FIGURE 9: Core Area (9a) and Outlying (9b) Cells

3.7 Research Ethics

Unlike some newer, public-engagement oriented methods addressing fiscally efficient locations for development, there is not a public participatory component to this research. Therefore, ethical issues associated with this research are limited to the collection and use of socioeconomic data (neighborhood characteristics) as well as general issues of data sharing and storage.
The assessment of neighborhood characteristics in fiscal modeling raises ethical issues. A core idea of this research and of action and participatory research in general is that an inquiry will not marginalize or dis-empower respondents (Creswell, 2003, p. 63). Issues associated with education, policing, crime, unemployment and demographics as incorporated in this study will be addressed and presented in such a way as to not marginalize or dis-empower any citizen in the study area of this research. Nor will data or results be presented such that they work to the advantage of one group or individual at the expense of another. Furthermore, this research will not use language or words biased against groups or individuals because of racial or ethnic group, age, disability, gender or sexual orientation.

Data will not be shared with individuals not involved in the project. If necessary, personal agreements will be established to clearly indicate ownership of data. Finally, data for the study will be kept for some period of time. Creswell (2003) cites Sieber (1998) who recommends storing data for 5-10 years after a study is complete. At that time data should be discarded so they will not be appropriated for unsuitable purposes (Creswell, 2003).
Chapter Four
An Index Capturing Urban Form for Modeling within Data Scarce Environments

This chapter presents the justification and methods supporting an index which captures urban form. This index is applied to the production modeling of local government services in chapter five. Much of the content in the introductory, analytical framework and methods subsections of this chapter is also found in earlier chapters in this dissertation. Those subsections of this chapter are very much a distillation of relevant sections of the introduction, literature review and methods chapters of this dissertation. The intent of consolidating key background elements and results is to make portions of the dissertation suitable for publication in academic journals. Chapter four was consolidated with chapter five and submitted as one article to Environment and Planning B: Planning and Design on July 19, 2010 and is currently under review.

An earlier version of this work was presented at the U.S. Environmental Protection Agency sponsored workshop, The Economics of Land-Use Change: Advancing the Frontiers held in Washington D.C. on June 25-26, 2009 and at the Western Regional Science Association 49th Annual Meeting held in Sedona, Arizona on February 21-24, 2010.

4.1 Abstract

This study develops an index for quantifying pattern in the built environment suitable for evaluation in time series regression analysis. The goal is to incorporate urban form in a fiscal model of public service provision. An index is necessary where demographic and economic data are not available in cross-sectional or panel form, but are available in time series. The index developed here is based on the Moran’s I measure of spatial autocorrelation calculated from observations of building values aggregated spatially within grid cells. By leveraging Moran’s I, the index captures local and global statistics representing the intensity of the built environment by land-use category. Local statistics quantify the contribution of individual cells to overall clustering and global statistics are suitable for inclusion as a spatial index in time series regression analysis.
4.2 Introduction

Documentation of the need for the evaluation of the influence of land-use patterns on the provision of local government services dates back to the 1950s. In the late 1940s and 1950s researchers began to note changes in the pattern of the built environment and began to speculate on the social and economic impacts of those changes (Isard and Whitney 1949; Branch 1951; Isard 1951; Berry 1959; and Carol 1960). Subsequent literature, beginning with Wheaton and Schussheim (1955), indicates low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. Areas diverge from optimal patterns of land use because of information asymmetries and the ability to pass the costs of growth on to the general public. Inefficiencies occur due to average cost user charges which undercharge outlying low-density areas while overcharging interior or high-density areas. Economic efficiencies may be improved with charges based upon the actual costs of providing services to each location. This solution is rarely implemented and often considered to be infeasible (e.g. Bahl and McGuire 1977) due to a lack of information linking land-use pattern and local government expenditures.

The index presented here was developed in order to provide additional information to econometric models attempting to link social and demographic characteristics and land-use pattern with level of service outputs and local government expenditures on public services. This extends six decades of research. Studies such as Wheaton and Schussheim (1955), Isard and Coughlin (1957) and Urban Land Institute (1958) began to associate cost with pattern using straightforward multipliers. The conclusions were that costs increase with density and distance. Early regression models including Brazer (1959), Hirsh (1970) and Clark et al. (1971) sought to link costs with density, distance and socioeconomic data. Conclusions were mixed and the studies could not identify cost variations within a community. Recent case examples from applied economics research continue to lack spatial precision. Heikkila (2000), Heikkila and Davis (1997), Schwartz (1993) and Bradford et al. (1969) advanced the state of the art when they recommended the inclusion of
neighborhood, principally socioeconomic characteristics in fiscal modeling. The linking of spatial and/or landscape indices and econometric modeling is seen in the work of Baumont et al. (2004), Bastian et al. (2002) and Geoghegan et al. (1997). Frenkel and Ashkenazi (2008a) develop a sprawl index that serves as a dependent variable in a regression analysis of the factors that influence sprawl. Speir and Stephenson (2002) state the influence of urban form has not been distinctly separated from other factors influencing costs of services. These works implicitly suggest the built environment may be quantified with spatial indices, and that these indices may serve as useful inputs to econometric modeling. In aggregate, these works suggest an opportunity to include the spatial heterogeneity of the built environment as an influencing factor in fiscal models of local government service provision.

Early studies addressing the impacts of changing land use on local government provision of service point to distance, density and pattern as drivers of costs of service provision. Emerging methods in fiscal modeling support the inclusion of neighborhood attributes and suggest the inclusion of spatial characteristics in evaluation of local government provision of service. Measures of spatial pattern may be used to quantify pattern and intensity of development. Through distillation of these numerous research and analytical threads a question arises. How can an index be developed that captures urban form?

4.3 Analytical Framework
The analytical framework guiding development of the spatial index presented here consists of three primary components: 1) the evaluation of alternative approaches for quantifying landscape pattern, primarily landscape metrics and measures of spatial autocorrelation; 2) evaluation of the suitability of including a spatial index in a regression analysis; and 3), developing the index in such a way that it accurately captures the nature of spatial dependence within a study area.

The pioneering work in the quantification of landscape pattern comes from the field of landscape ecology where the pattern and organization of landscape elements may be
quantified using landscape metrics. Herold et al. (2005) use the term “spatial metrics” in extending the concept of landscape metrics to analysis of the built environment. They suggest the application of landscape type metrics to the built environment are brought about by an interest in quantifying, “...the spatial component in urban structure (both intra- and inter-city) and in the dynamics of change and growth processes” (p. 371).

A drawback to the use of spatial metrics in quantifying pattern is that metric calculations are not based on observation values associated with individual areal units. While spatial metrics are suitable for measuring pattern, the exclusion of attribute data from calculations precludes integrating the intensity of the built environment with pattern analysis. However, spatial metrics may be directly compared with other measures of landscape pattern as a means of ascertaining the effectiveness of these other measures to capture changes in pattern over time.

The application of the Moran’s I measure of spatial autocorrelation to the built environment has recently begun to be explored. Tsai (2005) uses measures of spatial autocorrelation to summarize population and employment distributions. Porat et al. (2008) use Moran’s I to characterize construction initiation data where observations are measured floor area. Their goal is to help explain the evolution of urban structure. They ground their work in a literature review which offers support for the idea that measures of spatial autocorrelation may be extended to the built environment to assess pattern and changes over time. At the core of their research is the use of Moran’s I to reveal spatial homogeneity, randomness or heterogeneity as well as delineate areas based on development concentration (urban core, surrounding area or variants). Porat et al. (2008) indicate that when applying Moran’s I to the time dimension the statistic may be used to assess temporal changes in pattern, reveal characteristics of past patterns, and provide insight into changes in patterns. They also suggest the disaggregation of the built environment by land use enables greater insights into processes of pattern and change associated with those uses.
Measures of spatial autocorrelation have a number of characteristics which make them well suited for quantifying pattern in the built environment. Measures of spatial autocorrelation are useful for understanding spatial structure and spatial heterogeneity (e.g. Aspinall 1999; Boots and Tiefelsdorf 2000). Measures of spatial autocorrelation offer an improvement over landscape metrics as measures of spatial autocorrelation incorporate both location and attribute information. Goodchild (1986) argues measures of spatial autocorrelation are important as they give precise value to something that would otherwise be interpreted subjectively and they provide information about spatial data that are not available with other forms of statistical analysis (p. 5). Frizado et al. (2009) point out spatial statistics, including measures of spatial autocorrelation, are useful for cluster identification in part because these measures look beyond the bounds of a single areal unit to consider interactions within a specified neighborhood. Miller (2004) makes the point explicitly that both global and local spatial autocorrelation statistics provide information which may be useful for quantifying pattern.

Global spatial autocorrelation statistics present an average assessment of clustering across a study area whereas local statistics, which are often a decomposition of the global statistic, allow an assessment of distribution in space that may vary within a study area (Fotheringham et al. 2002). Goodchild (1986) puts forth that global measures of spatial autocorrelation are a means of data summary analogous to a mean and/or median. Local measures may be used to identify spatial heterogeneity, spatial outliers, clusters and hot spots (Boots and Tiefelsdorf, 2000) and provide focus on areas that are exceptions to the generalities presented in the global statistic (Fotheringham and Brunsdon, 1999).

Goodchild (1986) made the observation that nearly all spatially distributed data exhibit some degree of spatial autocorrelation (p. 22). Following De Smith et al. (2009) there are several standard options for regression analysis in the presence of spatial autocorrelation. One may ignore the spatial autocorrelation, allow the global constant to vary locally as is
done with geographically weighted regression, or “...include additional elements into the regression model that take explicit account of the observed pattern of spatial autocorrelation” (De Smith et al. 2009, p. 299). The inclusion of additional elements is typically done with spatial autoregressive modeling in the form of a spatial lag model or a spatial error model.

Geographically weighted regression, spatial lag and spatial error models are all based on cross-sectional or panel data. A fundamental input in local government fiscal modeling, expenditures by service category, as well as potentially relevant demographic and socioeconomic characteristics, are often not available as cross-sectional or panel data. Changes in landscape pattern necessarily occur over time so it is necessary to step beyond cross-sectional analysis which is temporally static and utilize time series and/or panel data. Lacking panel data, geographically weighted regression, spatial error and spatial lag models do not appear to be appropriate for the analysis of landscape change. The methods incorporated in this analysis vary from these more traditional means of incorporating spatial effects. Instead, this analysis suggests the inclusion of a spatial index in time series regression analysis.

The suitability of using measures of spatial autocorrelation in regression analyses may be evaluated by ascertaining whether spatial autocorrelation statistics meet required regression assumptions. Key assumptions used in ordinary least squares, two-stage least squares and times series analyses are random sampling of input data, normal distribution of input data and homoskedastic distribution (independence) of residuals.

Anselin (2002) provides a solid reasoning in support of the random sampling with spatial data by invoking the concept of superpopulation or spatial random process:

This assumes the existence (conceptually) of a stochastic process that may generate many possible spatial patterns, of which the observed data is one. The objective of the analysis is then to characterize the spatial process by means of the observed spatial pattern (Anselin, 2002 p. 255).
The normal distribution of spatial autocorrelation measures largely depends upon whether they are local or global statistics. Boots (2002) notes the distributions of global Moran’s I and Geary’s c statistics may be assumed normal when there are greater than fifty observations. However, the local statistics are not normally distributed (Boots, 2002, p. 170-11). Tests for the normal distribution of the data included in this analysis support these observations.

The lack of independence of spatial data is well known and is very much the essence of spatial autocorrelation. Miller et al. (2007) point out the assumption of independence violates one of the guiding principles of geography, Tobler’s law. The situation is summarized by Fotheringham and Brunsdon (1999) and Fotheringham et al. (2002). From a theoretical perspective, spatial data are usually not independent therefore regression modeling with spatial data may be suspect. A practical solution to the problem seen in spatial regression models is to ease the assumption that error terms for individual observations are independent which can be done if necessary steps are taken to insure that the dependence in the error is accounted for. Easing this assumption allows observations of proximal error terms to be correlated (Fotheringham and Brunsdon, 1999; Fotheringham et al., 2002).

The final concern within the analytical framework surrounding development of a spatial index is developing the index in such a way that it accurately captures the nature of spatial dependence within a study area. The spatial index developed here is based on the Moran’s I measure of spatial autocorrelation. A critical issue in calculating Moran’s I statistics is determination of the spatial weights matrix informing the calculation. Fotheringham et al. (2002) explain the weights matrix as an attempt to quantify the concept of proximity, to answer the subjective question, “What is meant by nearby?” (p. 103). Frizado et al. (2009) point out varying definitions of a weights matrix will lead to different conceptions of neighbors and result in different calculations of spatial autocorrelation. As a spatial weights matrix has great bearing on resulting autocorrelation
statistics, the issue of the specification of spatial weights is, per Anselin (1988), a “crucial operational issue in spatial econometrics” (p. 16) as well as, “one of the more difficult and controversial methodological issues in spatial econometrics” (p. 19-20).

Anselin approaches the issue of the specification of spatial weights from a theoretical perspective. He argues the characterization of spatial dependence specified in a weights matrix be guided by spatial interaction theory and based on a theoretical conceptualization of the structure of dependence (Anselin 1988 p. 21). Further insight is provided by Anselin (2003). Here, the problem of specification of weights is split into three general categories depending on connectedness structure, one based on distance, another based on contiguity and a third based on a specification of the number of nearest neighbors (see Getis and Aldstadt (2004) for additional permutations). The choice of connectedness structure is based on analytical context and is in many ways data driven. For example, in order to use the contiguity structure a polygonal data structure is needed. When using distance measures, a point structure is needed (Anselin 2003). When conceptually justifiable, GIS functionality such as the ability to convert polygon features to points and the ability to create Thiessen or Voronoi polygons from points provides some flexibility to change between polygonal and point data structures. This, in turn, yields some flexibility to choose between contiguity and distance based connectedness measures.

Both generally and when considering application to the built environment all three categories of connectedness structure have limitations. As something of a warning Anselin (2003) states, “Spatial weights based on a simple Distance Threshold criterion often lead to a very unbalanced connectedness structure” (p. 85). Distance based conceptions of clustering may be evaluated based upon a fixed distance specified sphere of influence or inverse distance weighting (IDW). Lacking spatial interaction theory suggesting discrete sphere(s) of influence for local government service provision, a fixed distance conception of clustering was not explored here in detail. IDW values near an observation carry a
greater weight than values distant from an observation. Therefore, similarly to surface interpolation with IDW, calculation of local Moran’s I statistics using IDW to conceptualize spatial relationships results in locally high values, or bull’s eyes, around isolated data locations. A problem with the application of the polygon contiguity assessment of clustering on parcel data is that parcels which are functionally contiguous may not be spatially contiguous. For example, two residences located mid-block on the same street may be separated by an alley. This separation may result in features with no neighbors whatsoever and invalidate test results. Using the nearest neighbor connectedness structure only some number (K) of neighbors specified are evaluated for spatial interaction. The number of nearest neighbors structure is, going back to spatial interaction theory, interpreted as meaning the number of conceptually relevant neighbors. This likely results in an incorrect connectedness structure for the valuation of local government service provision where many if not most features in a data set are interacting.

Beyond the choice of connectedness structure, there is an inherent contradiction in work incorporating weights matrices. That is, specifying relationships in order to discover them (Anselin 1988, p. 21). Within the context of a warning about this circular reasoning, Anselin as well as Cliff and Ord provide a point of departure by mentioning that in order to specify a spatial weights matrix the spatial structure of data have to be assumed to be known prior to specification (Anselin, 1988; Cliff and Ord, 1973). Following this reasoning, it is argued here that a priori knowledge of the spatial structure of the data set inform the specification of spatial weights and contribute to the accuracy of that specification.

4.4 The Study Area, Data and Methods

The area of investigation was Albany County, Wyoming, USA. Albany County is located in southeastern Wyoming, in an arid, high plains portion of the Central Rocky Mountains. The county is large (4,307 square miles or 11,114 square kilometers) and sparsely populated. The county government and 27,664 of the county’s 32,758 people are located in the city of Laramie. The other incorporated town is Rock River with a population of 213 (Wyoming Division of Economic Analysis 2009). Populations dispersed throughout the
County, with the number of people in parenthesis, include the unincorporated communities of Albany (80), Centennial (191), the Buttes (31), and Woods Landing-Jelm (100) (Census 2000). In terms of land use, approximately one third of the county is state or federally owned public range and forest land, 62 per cent of the land in the county classified as agricultural, four per cent of the county is residential, while commercial and industrial lands comprise less than one per cent of the total land area.

Following Stake (2000) Albany County was chosen as the study area because it presents clear opportunities for learning and research. There were three criteria used in this evaluation. Based on recent growth patterns within the county, a spatial index tied to fiscal modeling is relevant. Secondly, Albany County, with a centrally located node of service provision and population concentration in and around the City of Laramie, presents a close approximation of a monocentric model. The monocentric model, although often a simplification, allows straightforward empirical estimation (Su and DeSalvo 2008). The third criterion for case selection was data availability. In Albany County and across Wyoming there are a wide variety of demographic, socioeconomic, and fiscal data available at the county level. Additionally, Albany County has developed a spatially accurate and well-attributed cadastral database which can be leveraged to track change in urban form.

The data set used to develop the spatial index is the 2008 Albany County cadastral layer. The data contain 18,642 parcel records. Relevant attributes include activity code, building year built, and building value. The activity code attribute, while designed and used by the County Assessor’s office for taxation purposes, is also a reasonable surrogate for land use. The activity codes in the data are agricultural, commercial, commercial vacant land, industrial, mobile home, residential, residential vacant land and tax exempt. Building values, assessed by the Albany County Assessor’s Office and measured in dollars, were chosen as the basis of the spatial autocorrelation calculations as they are a parcel-based
measure of the intensity of the built environment and are a reasonable surrogate for demand for services.

In order to provide a sense of the distribution of the built environment in the county, several maps are presented. Figure 10 on page 100 presents 2007 residential building values in Albany County by parcel. The figure may be compared with Figure 12A on page 104 which presents residential building values aggregated within grid cells. The reason for the visual prominence of residential building value within the City of Laramie when viewed as aggregated grid cells (in Figure 12A) is the total value of the many smaller parcels in and around the city may be seen more easily (than in Figure 10). A map showing 2007 residential parcel size in Acres is included as Figure 11 on page 101. Figure 11 illustrates that residential parcels within the City of Laramie are generally smaller than residential parcels distributed throughout the remainder of the county.
FIGURE 10: Residential Building Values by Parcel
Python scripting (ESRI, 2010) was used to develop the 2008 parcel layer into panel data. Records from the 2008 cadastre were selected based on the year built attribute and
exported as a time series of cadastral layers dating from 1990 through 2007. Python scripting automates otherwise repetitive manual GIS processes thereby both saving time and ensuring consistent application of methods. The resulting time series of cadastres documents land-use change over eighteen years in the county.

Given this time series of observation values, the next step in developing the spatial index was to determine the appropriate weights matrix for calculation of the autocorrelation statistics. The approach to developing a spatial weights matrix was to compare outputs from various weights matrices with other non-arbitrary assessments of clustering. Preliminary conceptions of clustering and distribution may be contrasted with outputs from differing specifications of spatial weights in order to verify a weights matrix accurately reflects the pattern of the built environment in the county. In order to evaluate alternative weights matrices, local measures of spatial association from the output of alternative specifications of spatial weights matrices were compared with other non-arbitrary specifications of the clustering of the built environment. Building values were chosen as the basis of the spatial autocorrelation calculations as they are a parcel-based measure of the intensity of the built environment and are a reasonable surrogate for demand for services.

The following example illustrates how spatial weights were determined. The example is based upon residential land use. As illustrated in Figure 12, three non-arbitrary specifications of the clustering of the built environment were considered: (A) the sum of residential building values, (B) the count of residential parcels, and (C) the count of residential parcels divided by distance to town. The calculations presented in Figure 12 were performed within a grid layer developed for other planning analyses in the study area. For visual clarity, the representations in Figure 12 are presented as a percent of maximum value and incorporate a 1,000x vertical exaggeration. The three specifications of clustering considered here are remarkably similar. As a point of departure for
development of a spatial weights matrix, the conception of clustering derived from a spatial matrix should appear similar to the specifications of clustering in **Figure 12.**
FIGURE 12: Alternative Conceptions of the Clustering of the Built Environment for Residential Land Use
The primary choice in specification of the weights matrix was between distance and contiguity based conceptions of clustering. The nearest neighbors conception of clustering was discarded as spatial interaction theory suggests the nature of service provision varies considerably from relations among some number of nearest neighbor parcels. Given the noncontiguous nature of building values data throughout the county, a spatial weights matrix based upon point data (cell centroids) with weights calculated using inverse distance weighting is intuitively appealing. Congruent with theory suggesting potential problems with IDW, clustering specified by IDW resulted in locally high values for isolated observations as well as a ring of extremely low local Moran’s I statistics at the edges of the primary concentration of clustering in the study area, the City of Laramie. Patterns of local Moran’s statistics for spatial indices calculated using inverse distance weighting at a variety of distance bands all violated the preliminary conceptions of clustering in Figure 12.

In order to alleviate problems with parcels functionally adjacent but spatially separated, experiments were conducted with first order polygon contiguity conception of clustering using the planning analysis grid. In addition to solving the problem of cells that are functionally but not actually contiguous, the grid allows compatibility with other planning models used in the study area and faster processing (4,500 cells vs. 18,000 parcels). The basis of the grid is the set of public land survey system sections in the county, therefore grid cells are approximately one square mile in size. Section lines often correspond with property boundaries so the grid is not completely arbitrary. The simplification of using a regular tessellation, as opposed to performing calculations on the parcels themselves, also allows differing specifications of weights matrices to be more easily interpreted. A drawback to the use of a grid is the introduction of potential variability into the analysis from the modifiable areal unit problem. In order to evaluate the influence of the modifiable areal unit problem the analysis was conducted on two grids with differing cell sizes. The first grid contains cells one square mile in size and in the second the cells are one square kilometer.
In order to use the grid to assess various weights matrices building values from the parcel data set were summed within each grid cell. Conceptually, this may be viewed as a three step process. Step 1, shown in Figure 13, is mapping the building value attribute of the Albany County residential parcel data. Step 2, step two, is overlaying parcel based building values data with the analysis grid. Step three is summing building values from the parcel layer for each grid cell.

The polygon contiguity conception of clustering based on the sum of building values within grid cells is illustrated in Figure 14A. As shown in Figure 14B, residential clustering and dispersion based upon a first order polygon contiguity conception of clustering is inaccurate. In addition to a central core area and other nodes of development, there exists a random assessment of the distribution of building value throughout the entire study area, including in what is mostly un-built agricultural land and other open space. However,
if the subset of cells where building value is equal to zero are removed after calculating local $I$ statistics, the result (Figure 14B) is a conception of clustering similar to the preliminary conceptions illustrated in Figure 12. The first order polygon contiguity approach where observation values equaling zero are removed provides the most accurate conception of clustering of all tested weights matrices. This makes intuitive sense as it is the built environment, and not empty space that would likely be significant in a regression relating spatial pattern with public service expenditures.

**FIGURE 14**: Calculated Residential Clustering and Dispersion based on Polygon Contiguity

A comparison of plots of the local Moran’s index vs. the sum of building values within grid cells sheds light on the distributions of local $I$ statistics for the set of all cells and the set of cells where observation values equal to zero were removed. Figure 15 is a scatterplot of the data presented in Figure 14A which include all local $I$ calculations. Figure 16 is a scatterplot of the data presented in Figure 14B which omits calculations based on observation values of zero. As can be seen by comparing Figure 15 with Figure 16, removing calculations based on observation values of zero does not change the presentation of the plot. The outliers, the larger local $I$ statistics, are retained. What is lost are a random assessment of clustering where the local $I$ statistics are approximately zero. With the removal of cells where the sum of building values equals zero from the calculation of the spatial index it is proper to say the spatial index developed here is a
modified Moran’s I which differs from the original Moran’s I. The primary drawback to this method is the global assessment of clustering falls outside the standard -1.0 to 1.0 range of Moran’s I calculations. However, as seen in De Pinto (2010), extending the range of Moran’s I statistics is not unprecedented.

**FIGURE 15:** Scatterplot Representing the Data in Figure 14A, Local Moran’s I Statistics with all Cells
A drawback to the use of a grid rather than the time series parcel data is the introduction of potential variability into the analysis from the modifiable areal unit problem (MAUP). The MAUP may be present when the scale of the grid differs from the scale of the process under study (Anselin and Getis, 1992 p. 26). In order to evaluate the influence of the modifiable areal unit problem the analysis was conducted on two grids with differing cell sizes.

4.5 Results
Time trends of spatial indices were developed for a number of land uses and combinations of land uses: agricultural (Ag); residential (Res); and combined residential, commercial and industrial (C&I) using two grids (with cells of 1 square mile and 1 square kilometer in size.)
The indices representing Ag, C&I and Res calculated from the grid with cells one square mile in size are presented in Figure 17. The data capture changes in urban form from 1990 through 2007. The data show commercial and industrial (C&I) land-uses becoming slightly more clustered over the time period. This accurately reflects development of big box retail, expansion of a technical school and commercial strip development within and near the limits of the City of Laramie. The spatial index for residential land use (Res) shows a decrease in clustering from 1990 - 2007. This is consistent with increasing rural residential development occurring throughout the county over the time period. The spatial index for agricultural land use (Ag) shows dispersion without a specific trend over time. The pattern of agricultural lands has changed slightly with a decrease in total area and an increase in the number of patches over the time period. All data sets are approximately normally distributed.

**FIGURE 17:** Time Trends of the Spatial Indices derived from the 1 M Grid by Land-Use Classification
Indices derived from the 1K grid present similar trends to those derived from the 1M grid presented in Figure 17. In order to truly assess the influence of the MAUP it will be necessary to see how the indices derived from different grids influence regression results. These results are presented within chapter five on page 131.

Spatial Metrics (see Irwin and Bockstael 2007 and Herold et al. 2005) were used to further validate the spatial index. Fragstats spatial pattern analysis software was used to calculate contagion, a measure of landscape structure (McGarigal et al. 2002). Contagion is a landscape level metric where one value represents the entire study area. Contagion cannot be used to evaluate an individual land-use (or class in the parlance of landscape metrics) so all land uses were evaluated together. The resulting contagion metric is well correlated with the spatial index of residential land use calculated from the 1M grid, correlation = 0.9772 (p–value = 0.000). The correlation result suggests residential development is the primary driver of change in the built environment.

4.6 Discussion and Conclusions
The relationship between urban form and local government cost of service provision has been under discussion for sixty years. Nevertheless, econometric models of local government service provision have not yet evolved to the point where they incorporate measures of urban form. This study advances research in fiscal modeling by discussing the analytical framework surrounding the issue of quantifying pattern and suggesting methods for development of an index suitable for inclusion in a time series regression model that captures urban form.

This research has yielded three primary observations. First, urban form can quantified as a spatial index, by land use, in such a way that both captures changes in the built environment and is suitable for inclusion in time series regression analysis. The index extends the effort to quantify urban form beyond concepts of density and distance clearly separates from other factors influencing costs of service provision.
Second, great care must be taken to ensure the conceptualization of space used in generating spatial autocorrelation statistics is a plausible reflection of reality. Experimentation through comparison of local indices of spatial association calculated using alternative weights matrices with preliminary conceptions of clustering appears to result in the most accurate assessment of clustering and dispersion for a study area.

Third, it may be necessary to use a Moran’s-like value rather than Moran’s I to have a justifiable and accurate characterization of local landscape pattern. The core of this approach is the conceptualization of space used in development of the spatial autocorrelation statistics and the development of a global measure of spatial autocorrelation based on a subset of calculated local measures of spatial association. By deviating from more traditional, data intensive techniques such as geographically weighted regression, spatial error modeling or spatial lag modeling it is possible to capture spatial heterogeneity for including in a regression analysis where cross-sectional and / or panel data are not available.

Future research may further validate these methods by testing issues of scale and the influence of the modifiable areal unit problem. While the test of the calculated spatial indices on two grids with differing cells sizes (one square mile versus one square kilometer) suggests changing areal units may not be a problem, the methods presented here may be applied to finer resolution grid cells (e.g. 500 meters, or 100 meters) in order to ascertain whether changing areal units have an influence on the resultant indices. Issues of scale may become apparent when statistical techniques link spatial indices with other demographic and socioeconomic characteristics, levels of local government service provision and costs of service provision. While the scale of the analysis will be the jurisdiction of the government entity providing the service in question, results may be sensitive to the scale of the various input data (Fotheringham et al. 2002).
The indices resulting from this research offer the opportunity to evaluate the fiscal implications of land-use patterns and are a step toward ascertaining location-based and spatially precise costs of local government service provision. Following Heikkila (2000), by quantifying land-use pattern and the change in that pattern over time it may be possible to link land-use pattern with the costs of local government provision for delivery based services. This may enable service charges based upon the actual costs of providing services to each location and result in improved economic efficiencies.
Chapter Five
Determining the Relationship Between Urban Form and the Costs of Public Services

This chapter presents an econometric model of the production of local government policing services in Albany County, Wyoming. The model is based in part upon the spatial index developed in chapter four. Much of the content in the introductory, background, analytical framework and estimation methods subsections of this chapter is also found in earlier chapters in this dissertation. Those subsections are a distillation of relevant sections of the introduction, literature review and methods chapters. The intent of consolidating key background elements and results is to make portions of the dissertation suitable for publication in academic journals. Chapter four was consolidated with chapter five and submitted as one article to Environment and Planning B: Planning and Design on July 19, 2010 and is currently under review.

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5.1 Abstract
This paper develops an econometric model for the provision of public safety in Albany County, Wyoming, USA. The research extends previous modeling of public services to include a spatial index representing urban form, the pattern of the built environment, as an explanatory variable for input cost. The use of an index is necessary to represent urban form as time series data. The index employed here is based on the Moran’s I measure of spatial autocorrelation calculated from observations of building values (in dollars) aggregated spatially within grid cells. By leveraging Moran’s I, the index captures local and global statistics representing the intensity of the built environment by land-use category. Local Moran’s I statistics quantify the contribution of individual cells to overall clustering. Global Moran’s I statistics are suitable for inclusion as a spatial index in time series
regression analysis. Results suggest residential development is a statistically significant driver of local government expenditures on inputs to policing services. This research contributes to the next step in fiscal impacts modeling, determination of the spatial component of public service costs.

JEL Categorization Preferences: C5, H72, R32, R52

**Keywords** fiscal modeling · urban form · public service costs

### 5.2 Introduction

Documentation of the need for the evaluation of the influence of urban form on the provision of local government services dates back to the 1950s. The literature indicates low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. Areas diverge from optimal patterns of land use because of information asymmetries and the ability to pass the costs of growth on to the general public. Inefficiencies occur due to average cost user charges which undercharge outlying low-density areas while overcharging interior or high-density areas. Marginal cost pricing, the recommended solution, is rarely implemented and often considered to be unfeasible (e.g. Bahl and McGuire, 1977) due to a lack of information linking urban form and local government expenditures.

A promising means for the development of information on the spatial component of development costs is linking econometric modeling with geographic information systems (GIS) derived indices of urban form. Following Heikkila and Craig (1991) and other works by the same authors, local government services may be modeled with a public service production function where service levels are a function of local government expenditures on inputs and neighborhood characteristics. Expenditures on inputs may be modeled with an allocation function that incorporates neighborhood characteristics and other inputs. In the production modeling of local government services, the public agency is presumed to behave like a firm in that it competes in private input markets in order to provide services.
This paper adds to this discussion by documenting an empirical example that includes a measure of urban form as a statistically significant determinant of local government expenditures on inputs for the provision of a public service.

In order to measure the influence of urban form on the allocation function this analysis includes a spatial index which captures the pattern of residential development. The spatial index is included along with other socioeconomic and demographic characteristics in an econometric model illustrating the production of public safety provided by policing services in Albany County, Wyoming, USA. Government services can be classified into two types of services: delivery-based and non-delivery based. The former are agencies like law enforcement, other emergency services, and roads that are presumed to be sensitive to spatial pattern. Policing services were selected for evaluation due to both data availability and the presumption that providing public safety is sensitive to urban form. Results show the provision of public safety in the study area is a function of local government expenditures on inputs and neighborhood characteristics. The allocation of local government expenditures on inputs is found to be sensitive to urban form, neighborhood characteristics and other inputs.

5.3 Background
Research in fiscal modeling dates back nearly sixty years and may be split into five general categories: engineering estimate studies, early regression models, applied fiscal impact analyses, econometric research, and emerging methods. Modeling associating urban form with the costs of public services provision began in the 1950s with several studies that used engineering estimation techniques. The method employed by Wheaton and Schussheim (1955), Isard and Coughlin (1957) and Urban Land Institute (1958) was to gauge cost of services based on estimates of capital and operating costs calculated from the physical requirements (e.g. size and length of pipe) of a number of development alternatives (Downing and Gustely, 1977). The general result of these studies was that the cost of services and capital expenditures increase as development density decreases.
Early regression models sought to associate costs with spatial patterns and other socioeconomic data. Brazer (1959) found population to be unimportant but density to be “...clearly associated with all expenditure categories except recreation” (Downing and Gustely, 1977, p. 63). Hirsch’s (1970) results were the opposite of Brazer. Hirsch used regression to categorize public service operating costs and found density not to be significant (Downing and Gustely, 1977). Clark et al. (1971) used regression to address residential solid waste collection. They evaluated density among drivers of collection costs and found it to be significant in one study area and insignificant in another. Among various criticisms of these regression studies, Downing and Gustely (1977) indicated that the early efforts did not, and could not, measure variations in cost within a community.

Applied fiscal impact analysis includes the work of Burchell and Listokin, the costs of community services studies published by the American Farmland Trust and the work of private consultants in fiscal impact analysis, most notably TischlerBise. Burchell and Listokin (1978) identified two broad categories of fiscal modeling: average cost and marginal cost approaches. The average cost approach is based on the use of ratios or multipliers for each unit of service provided. The American Farmland Trust’s costs of community services study methodology (AFT 2006) is based on this average cost approach. In contrast, TischlerBise uses a detailed marginal cost approach. It is a more time consuming method but, as Bise states, “The case study-marginal cost method is the most realistic for evaluating fiscal impacts” (Bise, 2002, p. 1). TischlerBise also provides some of the most spatially precise work in fiscal modeling to date. Two examples serve to illustrate the level of spatial precision in the work of TischlerBise. In using a case study marginal cost approach to evaluate land use scenarios for Howard County, Maryland they divide the county into five geographic areas based on demographics, capital facility capacities and other characteristics (Tischler, 2002, p. 1). Bise (2007) presents tiered road fees based on traffic analysis zones at the sub county level for Greeley in Weld County, Colorado.
Examples of econometric research in fiscal analysis are typically case examples and largely lack spatial precision. Craig and Heikkila (1989), Heikkila and Craig (1991) and Heikkila and Kantiotou (1992) calculated fiscal impacts based on data at the neighborhood level in Vancouver, B.C. The neighborhoods are approximately one square mile in size. The methods used, as they hinge on the areal units of the data, do not appear to lend themselves to a finer grained analysis. Coupal, McLeod and Taylor (2002) focus on measuring the net fiscal impacts of rural residential development on Wyoming county governments and results are presented at the county level. In all cases the probability of spatial heterogeneity within the built environment suggests fiscal impacts may not be homogeneous across a jurisdiction or study area and point to analysis at a more precise spatial resolution as an opportunity for further research.

Emerging methods are rooted in the application of the production function to local government fiscal modeling. According to Heikkila (1990) the goal of applying a production function framework to an analysis of public service provision is two-fold: to make inputs and outputs in the production of a service explicit as well as to enable analysis and comparison of a wide range of services.

Production modeling of public services began with Bradford, Malt and Oates (1969). They use a production function to relate levels of service measures as production outputs with labor, capital and land as well as environmental variables (socioeconomic and demographic characteristics) as production inputs. Craig (1987) develops a model of crime deterrence that includes both a production and an allocation function. The goal of an allocation function is to ascertain government preferences on input mix as well as the productivity of inputs for public services provision. Behrman and Craig (1987) specify a production function where the quantity of public service output is determined by both local government inputs and neighborhood (socioeconomic and demographic) characteristics. Behrman and Craig (1987) develop an allocation model of police resources in order to estimate an input parameter of their production model. Craig and Heikkila
(1989) develop several functions for the production of public safety. Their allocation function captures government service provision as well as productivity of inputs across neighborhoods.

Heikkila (1990) specifies a production function for local government services where level of service outputs are a function of local government expenditures on inputs and neighborhood characteristics. He argues that the inclusion of local government expenditures on inputs is consistent with the standard definition of a production function. These input expenditures are viewed as productive resources analogous to the use of land, labor, and/or capital by a firm. Heikkila and Craig (1991) develop a similar production model where public safety is a function of local government expenditures on police, neighborhood characteristics and income. Expenditures are determined with an allocation function based on neighborhood characteristics and income. The income parameter is a neighborhood characteristic but is indicated separately for emphasis. The authors state that neighborhood characteristics relevant to the production and allocation functions will usually differ, but may overlap. Heikkila and Kantiotou (1992) duplicate Heikkila and Craig’s (1991) model for the allocation of local government resources and production of public safety. In the allocation function local government expenditures on police is explained by income and other neighborhood characteristics.

The production function approach is reiterated in Heikkila (2000) and Heikkila and Davis (1997). For the production of public safety, Heikkila and Davis (1997) suggest the level of service measure be the degree of the absence of crime, measured here as a public safety index. Neighborhood characteristics considered in the production of public safety may include income, unemployment, age structure, gender and ethnicity (Heikkila, 2000).

The incorporation of a measure of urban form may yield a more richly specified econometric model of local government service provision. The engineering estimate based studies and early regression models that address the impacts of changing land use on local
government provision of service provide the rationale for this argument. These studies point to distance, density and pattern as drivers of costs of service and infrastructure provision. Applied fiscal impacts analyses demonstrates useful average cost methods and point toward a detailed marginal cost approach for greater accuracy. The spatial heterogeneity of the built environment coupled with the low degree of spatial precision in fiscal modeling suggests fiscal impacts may not be homogeneous across a level of analysis. These ideas point to a more precise spatial resolution as an opportunity for further research. Emerging methods in fiscal modeling leverage production relationships to specify inputs and outputs of local government provision of service based on local government expenditures on inputs and neighborhood characteristics.

This leads to two questions which guide this investigation. Firstly, how can urban form be incorporated into an econometric model explaining local government service provision? Secondly, how can an econometric model that incorporates urban form be used to identify areas that are fiscally efficient? The next section expands upon the ideas presented in the literature review in order to specify an economic model which provides a conceptual basis for this research.

5.4 Modeling the Production of Local Government Services
A local government may be viewed as an entity that provides public services. It competes in the private market for inputs used to provide those services. Local government is modeled similarly to a private firm in regard to input usage. It is presumed that local government strives to be cost effective in its use of limited resources (inputs). Thus, inputs are used for production relative to their respective costs.

Heikkila and colleagues model local government service provision with a production function. From Heikkila and Craig (1991):

\[ S = f (X, N_s, Y_z) \]  

where,
$S$ represents level of public service;  
$f(.)$ is the production function technology;  
$X$ is local government expenditures on inputs determined by an allocation function;  
$N_s$ represents a combination of neighborhood characteristics; and,  
$Y_s$ represents median income.

**Equation (10)** represents a production function that generates a measured level of service output determined by local government expenditures on inputs and neighborhood characteristics.

Inherent in the production of a level of service is the allocation of resources used in providing that service. Based on Heikkila and Kantiotou (1992), an allocation function is presented as follows:

$$X = g(N_x, Y_x)$$ \hspace{1cm} (11)

where,  
$X$ are local government expenditures on inputs;  
$g(.)$ represents an allocation function;  
$N_x$ represents a combination of neighborhood characteristics; and,  
$Y_x$ represents per capita personal income.

Our interest is in the relationship between urban form and the costs of public services. For our purposes, the variable $Y_x$ may be considered to be a neighborhood characteristic and included in the vector $N_x$. We extend the argument for the allocation function summarized in equation (10) by suggesting the inclusion of a variable (SI) that specifies the influence of urban form on local government expenditures on inputs to public services provision.

While urban form may be legitimately viewed as a neighborhood characteristic, we indicate it separately in equation (12) in order to emphasize this potential influence:

$$X = g(N_x, SI, I)$$ \hspace{1cm} (12)

where,  
$X$ represents local government expenditures on inputs;
$g(.)$ represents an allocation function;  
$N_k$ represents a combination of neighborhood characteristics;  
$SI$ is a spatial index that captures urban form by land use; and,  
$I$ represents a vector of inputs.

Following Bradford, Malt and Oates (1969) the inputs $(I)$ in equation (12) may include officers, cars, communication systems et cetera. The emphasis of $I$ in equation (12) is on variable inputs, or operating costs, rather than fixed inputs or capital costs. For the provision of policing services an example of variable costs is the number of officers, an example of fixed costs is the price of the police station. While acknowledging the likelihood of thresholds which might yield a greater need for capital equipment, it is assumed here that in communities of similar area and population, regardless of the spatial pattern of the built environment, capital costs will be approximately equal and not be influenced by spatial pattern.

Following Crag (1987), the goal of an allocation function is to ascertain government preferences on input mix as well as the productivity of inputs for public services provision. A hedonic framework is useful for ascertaining allocation preferences as a hedonic models capture the interactions of supply and demand in a market (Palmquist, 1991), in this case service provision. Van Kooten (1993) defines a hedonic model as:

$$P_{\text{implicit}} = f(c_1, ..., c_n; Q_1, ..., Q_m)$$  \hfill (13)

where,  
$P_{\text{implicit}}$ is the estimated price of a good,  
$C$ are private housing characteristics, and,  
$Q$ are public good characteristics (van Kooten, 1993, p. 141).

Equation (12) is analogous to van Kooten’s hedonic model, equation (13), where expenditures on public safety are a function of neighborhood characteristics and characteristics of the service in question. Neighborhood characteristics $N$ and $SI$ in equation (12) may be seen as being analogous to the public good characteristics $Q$ in
equation (13). Inputs $I$ in equation (12), the variable inputs to the production of policing services, are analogous to the good characteristics summarized as $C$ in equation (6).

Recall Heikkila and Kantiotou’s allocation function, equation (11), is based entirely on neighborhood characteristics. Equation (12) incorporates per capita personal income, if appropriate, within the variable $N$ and extends the logic of Heikkila and Kantiotou’s allocation function by leveraging the hedonic framework to include characteristics of the service in question. Equation (12) fully develops Craig’s (1987) idea of using an allocation function to ascertain preferences as well as productivity of inputs.

The inclusion of $(SI)$ in equation (12) serves to evaluate the premise that low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. As presented in equation (12) urban form directly influences expenditures.

5.5 The Study Area and Data

The Study Area

The area of investigation is Albany County, Wyoming, USA. The county is 11,114 square kilometers and has centrally located nodes of service provision. The county government and 84 per cent of the county’s population are located in the county seat, the city of Laramie. Approximately one third of the county is state or federally owned public range and forest land, 62 per cent of the land in the county classified as agricultural. Four per cent of the county is residential, while commercial and industrial lands comprise less than one per cent of the total land area.

Following Stake (2000) Albany County was chosen as the study area because it presents clear opportunities for learning and research. There were three criteria used in this evaluation. Based on recent growth patterns within the county, a spatial index tied to fiscal modeling is relevant. Secondly, Albany County, with a centrally located node of
service provision and population concentration in and around the City of Laramie, presents a close approximation of a monocentric model. The monocentric model, although often a simplification, allows straightforward empirical estimation (Su and DeSalvo 2008). The third criterion for case selection was data availability. In Albany County and across Wyoming there are a wide variety of demographic, socioeconomic, and fiscal data available at the county level. Additionally, Albany County has developed a spatially accurate and well-attributed cadastral database which can be leveraged to track change in urban form.

**The Spatial Index**

Urban form is integrated into this analysis with a spatial index. The use of a spatial index is rooted in prior research indicating density and distance may be significant drivers of costs of government service provision. The spatial index incorporated in this analysis was developed based on the Moran’s $I$ measure of spatial autocorrelation. Moran’s $I$ measures the tendency of observations proximal to one another to be similar. Output values indicate whether development is dispersed, random or clustered. An advantage of using Moran’s $I$ rather than measures of density and/or distance, is the relationship between the global and local values of the statistic. With Moran’s $I$ the contribution of local statistics representing individual areal units (cells or parcels) to the global statistic is conceptually clear and easily calculated. Another advantage to the use of Moran’s $I$ is the statistic may be used to quantify pattern by land uses. This allows insight into commonly used categories of land-use such as residential, commercial, *et cetera.*

The spatial index is based on the Moran’s $I$ measure of spatial autocorrelation calculated from observations of building values (as estimated by the county assessor and measured in dollars) aggregated spatially within grid cells. The technique allows calculation of a global statistic for spatial autocorrelation which is used to integrate time series and panel data in the production function. A key element of the method used to develop the spatial index is the removal of cells where the sum of building values equals zero from the calculation. It is therefore proper to say the spatial index implemented here is a modified
Moran’s $I$ which differs from the original Moran’s $I$ (Moran 1950). The primary drawback to this method is the global assessment of clustering falls outside the -1.0 to 1.0 range of Moran’s $I$ calculations. Theory and methods supporting the development of the index are detailed in chapter four, beginning on page 89.

**Demographic and Socioeconomic Data**

The other elements of the regression analysis, including the public safety index, all local government inputs, neighborhood attributes and the spatial index are time series data covering 18 years from 1990–2007. In all cases data represent 18 observations ($n=18$). Driving variables in this analysis are summarized in Table 4 and illustrated in Figure 18.

The public safety index is the inverse of the crime rate. Crime rates were calculated based upon index crime data from the Wyoming Department of Criminal Investigation (2007). Earlier editions of the same title were used to capture data from the 1990s. Wyoming Department of Criminal Investigation methods were followed for calculation of crime rates, but population data from the Wyoming Division of Economic Analysis was incorporated in the calculations rather than Wyoming Department of Criminal Investigation population estimates. Data on the rural population of Albany County are also from the Wyoming Division of Economic Analysis (2010 a, b; 2009). Data on the number of county law enforcement officers are published by the Wyoming Department of Criminal Investigation (2007). The Albany County Sheriff’s budget is found in data on Wyoming county government expenditures which are disaggregated by category of service provided. These data are published by the Wyoming Department of Audit (2008). These and all other fiscal data are inflation adjusted to 2007.
**TABLE 4: Definition of Variables**

<table>
<thead>
<tr>
<th>Included Variables</th>
<th>Definition</th>
<th>Source</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSI</strong></td>
<td>Public safety index, the inverse of crime rate</td>
<td>Calculated from data on index crimes reported by the Albany County Sheriff's Dept. and published by the WY Dept. of Criminal Investigations as well as population data from the WY Div. of Economic Analysis</td>
<td>Index</td>
</tr>
<tr>
<td><strong>LE_{EXP}</strong></td>
<td>Operating Expenditures of the Albany County Sheriff's Dept.</td>
<td>Wyoming Dept. of Audit</td>
<td>Millions of $USD 2007</td>
</tr>
<tr>
<td><strong>Res</strong></td>
<td>Spatial index representing residential urban form</td>
<td>Model</td>
<td>Spatial Index</td>
</tr>
<tr>
<td><strong>Res^2</strong></td>
<td>Spatial index representing residential urban form squared</td>
<td>Model</td>
<td>Spatial Index</td>
</tr>
<tr>
<td><strong>LEO</strong></td>
<td>Officers in the Albany County Sheriff's Dept.</td>
<td>WY Dept. of Criminal Investigations</td>
<td>Individuals</td>
</tr>
<tr>
<td><strong>LEO^2</strong></td>
<td>Officers in the Albany County Sheriff's Dept. squared</td>
<td>WY Dept. of Criminal Investigations</td>
<td>Individuals</td>
</tr>
<tr>
<td><strong>Rural Population</strong></td>
<td>Population of the unincorporated areas of Albany County</td>
<td>WY Div. of Economic Analysis</td>
<td>Individuals</td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>Cost of Living, a summary of price data</td>
<td>WY Div. of Economic Analysis</td>
<td>Index</td>
</tr>
<tr>
<td><strong>Unemployment</strong></td>
<td>Per cent of labor force unemployed</td>
<td>United States Department of Labor, Bureau of Labor Statistics</td>
<td>Per cent</td>
</tr>
<tr>
<td><strong>t</strong></td>
<td>Time</td>
<td>---</td>
<td>Years</td>
</tr>
</tbody>
</table>
In order to create a times series of fiscal data from 1990 through 2007, law enforcement expenditures for 1990 were modeled based on annual percent changes occurring over the time period of the analysis where data are available. Cost of living indices, a summary of price data, are made available by the Wyoming Division of Economic Analysis. Regional data for southeastern Wyoming, including Albany County, were incorporated in this analysis. Categorically, the data cover food, housing, apparel, transportation, medical, recreation and personal care as well as “all items” (Wyoming Division of Economic Analysis, 2008). Unemployment data are made available by the United States Department of Labor, Bureau of Labor Statistics (U.S. Dept. of Labor, 2008). A time variable was included to de-trend the data. Votey and Phillips (1972) suggest the inclusion of a time value may also account for technological change.

**5.6 Empirical analysis**

The empirical analysis consists of the specification of the econometric models, regression results, post-estimation tests and discussion. The spatial implications of the econometric model are presented in Section 5.7.
**Estimation Methods**

Following Fisher and Nagin (1978) and Levitt (1997, 2002) there exists theoretical potential for endogeneity between law enforcement expenditures and measures of public safety when specified in an econometric model. In the case where inputs are endogenous, the production function for public safety may be developed with instrumental variable methods. Using two stage least squares (2SLS), input data may be instrumented using one or more variables. Law enforcement expenditures are likely to be endogenous with public safety therefore we use a 2SLS approach. Law enforcement expenditures may be instrumented with neighborhood characteristics, a spatial index and other variables using the first stage as the estimation of the allocation function, see equation (14). Variable, $\overline{X}$, is an explanatory variable in the estimation of the production of public safety, as shown in equation (15).

$$\overline{X} = \theta_a + \theta_b SI + \theta_c I + \theta_d N_1 + u_1 \quad (14)$$

$$S = \theta_0 + \theta_1 \overline{X} + \theta_2 N_2 + u_2, \quad (15)$$

where,
- $X$ are law enforcement expenditures;
- $SI$ represents the spatial index;
- $S$ represents a measure of public safety;
- $N_1, N_2$ represent vectors of neighborhood characteristics;
- $I$ represents other inputs;
- $\theta$ is an estimated parameter on the relevant variable; and,
- $u$ are residuals.

**Regression Results**

The results of the 2SLS estimation of the production of public safety are presented in Table 5. Column (1) shows the estimates incorporating a spatial index calculated using a grid with cells one square kilometer in size. Column (2) shows the estimates incorporating a spatial index calculated using a grid with cells one square mile in size. The public service production function, illustrating the production of the public safety index (PSI) is shown in the lower portion of the table. The instruments for law enforcement expenditures and the
southeast Wyoming cost of living index are statistically significant. The allocation function is presented in the upper portion of **Table 5**. The results in the Table illustrate the relationship between law enforcement expenditures and the spatial index, the inputs and the neighborhood characteristics.
Table 5: Allocation and Production Estimations

<table>
<thead>
<tr>
<th></th>
<th>Allocation Fn: $LE_{EXP} = \text{dependent variable}$</th>
<th>Production Fn: $PSI = \text{dependent variable}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) 1K Grid</td>
<td>(2) 1M Grid</td>
</tr>
<tr>
<td></td>
<td>b/(se)</td>
<td>b/(se)</td>
</tr>
<tr>
<td>1/Res</td>
<td>356.048* (136.398)</td>
<td>129.315** (36.425)</td>
</tr>
<tr>
<td>$Res^2$</td>
<td>0.020*** (0.005)</td>
<td>0.066* (0.028)</td>
</tr>
<tr>
<td>Unemployment</td>
<td>-0.298** (0.085)</td>
<td>-0.264* (0.104)</td>
</tr>
<tr>
<td>Rural Population</td>
<td>-0.001 (0.001)</td>
<td>-0.002* (0.001)</td>
</tr>
<tr>
<td>LEO</td>
<td>-0.129 (0.105)</td>
<td>-0.15 (0.114)</td>
</tr>
<tr>
<td>LEO$^2$</td>
<td>0.003 (0.002)</td>
<td>0.003 (0.002)</td>
</tr>
<tr>
<td>t</td>
<td>-0.164 (0.200)</td>
<td>0.016 (0.117)</td>
</tr>
<tr>
<td>constant</td>
<td>-17.987 (8.764)</td>
<td>-7.972 (6.724)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.9017</td>
<td>0.8918</td>
</tr>
<tr>
<td></td>
<td>--------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>(1) 1K Grid</td>
<td>(2) 1M Grid</td>
</tr>
<tr>
<td>LE$^1_{EXP}$</td>
<td>18.395** (6.083)</td>
<td>19.443** (6.144)</td>
</tr>
<tr>
<td>SE</td>
<td>-4.442* (1.950)</td>
<td>-4.514* (1.944)</td>
</tr>
<tr>
<td>t</td>
<td>0.833 (0.419)</td>
<td>0.788 (0.420)</td>
</tr>
<tr>
<td>constant</td>
<td>33.693*** (8.591)</td>
<td>33.082*** (8.594)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.7327</td>
<td>0.7335</td>
</tr>
<tr>
<td>dfres</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001
The allocation function shows a statistically significant relationship between urban form (Res) and law enforcement expenditures ($\text{LE}_{\text{EXP}}$). The pattern of residential development is specified with the combination of the inverse and the quadratic form of the spatial index ($1/\text{Res}$ and $\text{Res}^2$). As the spatial index decreases (indicating a decrease in clustering or increase in sprawl), there is a corresponding increase in $\text{LE}_{\text{EXP}}$. This phenomenon occurs irrespective of grid cell size (see Table 5 columns labeled (1) and (2)).

Of the spatial indices developed for consideration, only the index for pattern of residential development (Res) turned out to be statistically significant. The spatial index for agricultural land use shows dispersion without a specific trend over time and is not statistically significant. In preliminary results (not shown) the spatial index for commercial and industrial development was occasionally significant, but showed serial-correlation with other independent variables. The spatial index for the combination of residential, commercial and industrial land uses was not a statistically significant driver of $\text{LE}_{\text{EXP}}$.

**Refining the model with post-estimation tests**

Following Wooldridge (2006) serial correlation was tested for by lagging the residuals and evaluating the significance of the residuals with a second 2SLS regression. There was no evidence of serial correlation in the estimations. Tests for heteroskedasticity were conducted with the Breusch-Pagan test. No evidence of heteroskedasticity was detected.

**Discussion of the Econometric Model**

The goal of the production function in equation (10) is to specify the inputs in the production of a public good provided by a local government. Table 5 presents estimates for the production of public safety as outlined in equation (15). Congruent with previously presented literature, public safety was found to be a function of law enforcement expenditures and the local cost of living index. In the production of public safety, the positive coefficient on $\text{LE}_{\text{EXP}}$ suggests as expenditures on policing services increase public safety also increases. The negative coefficient on cost of living (SE) implies that increases in the cost of living index have a negative impact on public safety.
Ascertaining the influence of the spatial indices on $LE_{EXP}$ is somewhat complex due to the use of the inverse of the RES spatial index in the regression analysis. The positive sign on the $1 / RES$ coefficient indicates that as residential clustering decreases, $LE_{EXP}$ increases. Figures 19 and 20 illustrate the relationship between the RES spatial index and $LE_{EXP}$. In both figures, the X-axis shows the range of the spatial index over the time period of the study. The Y-axis presents the *ceteris paribus* contribution of RES on $LE_{EXP}$ in millions of dollars. Both Figure 19 and Figure 20 illustrate that as the built environment becomes less clustered, $LE_{EXP}$ will increase. This is evidence that the cost of inputs that contribute to the production of public safety are related to clustering. Location and pattern of development do matter in the cost of local government service provision.
FIGURE 19: The Relationship Between the RES Spatial Index and Law Enforcement Expenditures Based Upon the 1K grid
FIGURE 20: The Relationship Between the RES Spatial Index and Law Enforcement Expenditures Based Upon the 1M Grid

Building upon Craig and Heikkila (1989), the allocation function in equation (12) is used to ascertain the mix of inputs for public service provision. The results of the estimation of the allocation function in Table 5 indicate a statistically significant relationship between urban form and law enforcement expenditures. Law enforcement expenditures that contribute to the production of public safety are determined by urban form, or more specifically, the clustering and distribution of the built environment. Location and pattern of development do matter in the cost of local government service provision.

The results in Table 5 also suggest a constrained optimization problem involving the optimal mix of inputs for the provision of a public service. Suppose public service provision
is dictated by an efficient marginal rate of technical substitution between service inputs. This suggests that, subject to fixed public service expenditures directed toward a given level of public benefit, changes in urban form will influence the allocation of local government inputs. Here the interpretation is that as clustering decreases (or sprawl increases) law enforcement expenditures must rise to provide a given level of public safety. Urban form therefore affects the optimal mix of resources needed for public service provision. Local governments may, within an informed political context, strive for a certain degree of economic efficiency by producing a given level of service at minimum cost. If economic efficiency is a priority, a local government may strive to minimize the costs of inputs, including increases in service costs brought by decreases in clustering.

Thus far, the county has adjusted to an increasing LE\textsubscript{EXP} by paying for it. It would require further analysis to see if there is an overall budget constraint that requires a choice between policing and other publicly provided services. This is to say that there are real opportunity costs across public service choices.

5.7 The Spatial Implications of the Regression Results
The fiscal implications of change in urban form may be evaluated on a cell by cell basis with a ceteris paribus analysis of change in the spatial index and the first stage of the 2SLS results (allocation model) from Table 5. The abstraction of a ceteris paribus analysis is useful as it allows the calculation of the influence of each cell on the law enforcement expenditures needed to maintain the existing level of service. This is analogous to what Heikkila refers to as a service-based impact, defined as “...the minimum cost of restoring service levels to what they were prior to the development in question” (Heikkila, 2000, p. 154). Here, Heikkila’s definition of a service-based impact is modified to capture the estimated cost of providing service from a hypothetical state of no development to existing development on a cell-by-cell basis. This may be thought of as a spatially defined service-based impact. Following Heikkila and Kantioutou (1992), the spatially defined service-based impact is defined as:
\[ J_i = H(S_1; SI_1) - H(S_1; SI_2) \]  \hspace{1cm} (16)

where,
\( J \) represents the spatially defined service-based impact for each grid cell \( i \);
\( H(.) \) is a differenced spatial cost function based on \( SI \);
\( S_1 \) represents level of service;
\( SI_1 \) is a spatial index that captures existing urban form by land use; and
\( SI_2 \) is a recalculated spatial index.

As with the calculation of the spatial index, the grid cells in this analysis are those cells with a residential building value greater than zero. Spatially defined service-based impacts may be calculated for each cell using the following steps:

1. For each cell in the analysis individually remove that cell by setting the building value to zero, re-calculate the local Moran’s \( I \) statistics for all cells, then recalculate the spatial index (global statistic). The output from this step consists of an estimated value for Res (the spatial index) calculated as if the cell in question had no residential building value.

2. Leveraging the regression results presented in Table 5, for each cell the estimated value of the spatial index may be used to calculate a new estimated value for \( LE_{\text{EXP}} \). The spatially defined service-based impact for each cell, measured in dollars, is calculated by subtracting the estimated value for \( LE_{\text{EXP}} \) from the original value (see equation 16). Mapped results of the calculations of spatially defined service-based impact are presented in Figures 21 and 22 for the 1K and 1M grid, respectively. The spatially defined service-based impact is labeled simply as ‘Fiscal Impact’ on the maps.
FIGURE 21: The Spatially Defined Service-Based Impact of Residential Development (1K Grid)
FIGURE 22: The Spatially Defined Service-Based Impact of Residential Development (1M Grid)

3. Step three is development of a revenue model. Tax Revenue for Albany County can be broken into three parts: property tax, sales tax and lodging tax. As property tax is the
primary input to county revenues paid by a landowner, it is the emphasis of the investigation here. Property taxes may be estimated with a simple three step model that is identical to the calculation used by the county tax assessor. The first step is assigning the correct mill levy, a specified tax rate, to each parcel based upon tax district. The second step is to calculate the assessed valuation. The final step consists of multiplying the assessed valuation by the mill levy which results in an estimate of actual property tax for each parcel. Mapped results of the revenue model are presented in Figure 23.

4. The spatially defined service-based impact for each cell developed in step two may be contrasted with the revenue model developed in step three to estimate fiscal efficiency in a spatially precise fashion. The annual share of overall property tax dedicated to the provision of policing services is approximately 14.5 per cent over the time period of the study. Evaluation of fiscal efficiency is accomplished by aggregating property tax revenues by grid cell, then calculating a Boolean value indicating whether or not a grid cell contributes more in revenue than the value of the service-based impact of the cell, or *vice versa*. A simple if / then formula comparing spatially defined service-based impacts and revenues is used to make the determination.

Results, comparing the spatially defined service-based impact with the revenue model based on the grid with cells 1 square kilometer in size, are presented in Figures 24 and 25. Figures 24 and 25 both show a core area of the county approximating the City of Laramie that is fiscally efficient. The western part of the city limits that is not indicated as being fiscally efficient is a recent annexation consisting of low-density residential and commercial properties as well as open space. The remainder of the county is not fiscally efficient for the provision of policing services.
FIGURE 23: Property Tax Revenue Model Mapped Results
FIGURE 24: Areas of Albany County that are Fiscally Efficient for the Provision of Policing Services (1K Grid)
FIGURE 25: Areas of Albany County that are Fiscally Efficient for the Provision of Policing Services (1M Grid)
5.8 Conclusion

The relationship between urban form and local government cost of service provision has been under discussion for sixty years. Nevertheless, econometric models of local government service provision have not yet evolved, until now, to the point where they incorporate urban form as a driving variable. This study advances research in fiscal modeling by suggesting methods for development of an index that captures urban form. The index enables evaluation of the fiscal implications of urban form for local government service provision. The index is then leveraged in order to identify areas that are and are not fiscally efficient for the provision of policing services by mapping the results. Developing this research has yielded a number of observations:

First, estimation results indicate that residential urban form is a driver of local government spending on policing services. As the built environment becomes less clustered, local government expenditures on law enforcement increased. Location and pattern of development do matter in the cost of local government service provision.

Second, incorporation of a spatial index in an econometric model of public service provision allows areas that are not fiscally efficient to be identified. Including a spatial index enables calculation of spatially defined service-based fiscal impacts. When contrasted with a revenue model, the result is a cell-by-cell (place by place) evaluation of fiscal efficiency.

Looking forward, a goal is to refine methods to be more spatially precise using either a finer resolution grid or parcels as the basis of the analysis. In considering grids of smaller cell sizes, there may a threshold at a larger scale (finer resolution) where local indicators of spatial association do not paint as clear a picture of clustering and dispersion for the study area as a whole. Further testing for issues associated with the modifiable areal unit problem will go hand in hand with research addressing issues of scale and space.
These results suggest this approach holds promise for the spatially precise evaluation of local government cost of service provision, more informed decision making at the local government level, and, ideally, improved resource allocation. These results affirm sixty years of research in the relationship between urban form and local government costs of services. The methods developed here are applicable to other areas and public services. The challenge is to obtain relevant, spatially accurate data.

Finally, residential, commercial and industrial growth may occur in environmentally sensitive areas. Examples in Albany County include big game seasonal ranges, wildlife migration corridors and riparian areas. The opportunity exists to develop spatially defined welfare-based evaluations of service provision that address not just costs of services but also include measures of change in the natural environment.
Chapter Five

Determining the Relationship Between Urban Form and the Costs of Public Services

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Chapter 6
Discussion and Conclusion to Determining the Relationship Between Urban Form and the Costs of Public Services

The topic of the spatial structure of the built environment and the relationship with the costs of public service provision has been under discussion in the academic literature for nearly sixty years. Studies have consistently reported that low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. The reasons areas diverge from optimal patterns of land-use are well known. There is a cultural predisposition to view dispersed dwelling as desirable that is rooted in social contract theory, especially John Locke’s idea of freedom through withdrawal from community. A second and related element to the cultural preference for dispersed development is the retreat from the declining public realm of the 20th century. The economic reason areas diverge from optimal development patterns are average cost user charges which undercharge outlying low-density areas while overcharging interior or high-density areas. In order to address these economic inefficiencies, the ideal corrective action is to charge each location the actual costs of providing services to that location. The purpose of this research then is to advance the discussion of how differences in urban form affect the costs of local government service provision by modeling the spatial component of development costs.

Following a number of papers (Heikkila, 2000; Heikkila and Davis, 1997; Ladd 1994; Schwartz 1993; Heikkila and Kantiotou, 1992; Heikkila and Craig, 1991; Heikkila, 1990; Craig and Heikkila, 1989 Craig 1987 and Behrman and Craig 1987), costs of government service provision may be modeled with a production function where level of service outputs are related to local government inputs and neighborhood (socioeconomic and demographic) attributes. The research presented here extends previous production modeling of public services to include a spatial index representing urban form as an explanatory variable in the production relationship. The inclusion of spatial pattern in the
econometric modeling of local government service provision offers the opportunity to model the spatial component of the costs of public service provision.

In concluding this dissertation, chapter six begins with a summary of research findings. Following the discussion of findings the research is put into a broader context by addressing the issue of generalizability, significance and innovation, broader impacts and recommendations for future research.

6.1 Summary of Findings
The following overview is a summary of the findings of this thesis organized by research question.

Research Question Number One
The first research question is: How can an index be developed that captures urban form?

Chapter four details the theory and methods behind construction of a spatial index that captures urban form and change in urban form over time by land use. The spatial index is based on the Moran’s I measure of spatial autocorrelation. The index is calculated from derived panel data on building values (as estimated by the county assessor and measured in dollars), aggregated within grid cells. As discussed in the results section of chapter four (beginning on page 109), the index accurately captures clustering and dispersion in the built environment and change over time in the study area. The index is therefore suitable for econometric modeling of local government service provision using time series data. As the index captures clustering and dispersion by land-use category, it enables not just analysis of the built environment as a whole, but evaluation of the influences of the specific category, or in other instances potentially categories, of land use that drive costs of service provision.

Research Question Number Two
The second research question is: How can urban form be incorporated into an econometric model explaining local government service provision?
As detailed in chapter five (beginning on page 115), urban form can be incorporated into an econometric model explaining local government provision of service. The first step, per research question number one, is to quantify urban form with an index that captures clustering, dispersion and change over time. Using regression modeling the index can be evaluated as an independent variable for incorporation into an econometric model of local government service provision.

This research develops a case study of a local government’s provision of public safety as a function of local government policing services. This research used an instrumental variable and two stage least squares estimation procedures to derive the production function for provision of public safety in the study area. The measured production output is a rural safety index defined here as the inverse of the crime rate. The production of public safety is a function of law enforcement expenditures, and neighborhood characteristics. Law enforcement expenditures may be instrumented with neighborhood characteristics, a spatial index and other variables using the first stage as the estimation of the allocation function.

In the allocation function county government expenditures on law enforcement are regressed on the inverse of the residential spatial index, the spatial index squared, the number of law enforcement officers, unemployment and rural population. A time value is included in order to de-trend the data. The spatial index is statistically significant, indicating the pattern of residential development is a determinant of law enforcement expenditures. Coefficient signs support the hypothesis that as development becomes less clustered, expenditures for law enforcement will increase. Predicted values for county expenditures on law enforcement are then used as an instrumental variable in the production of public safety. The other independent variables in this second equation are the cost of living index for Southeast Wyoming and time. Predicted values for law enforcement expenditures and cost of living index are significant with the expected signs.
illustrating that the built environment can be incorporated as a statistically significant independent variable into an econometric model explaining local government provision of service.

**Research Question Number Three**

The second research question is: **How can an econometric model that incorporates urban form be used to identify areas that are fiscally efficient?**

The fiscal implications of change in urban form may be evaluated on a cell by cell basis with a *ceteris paribus* analysis of change in the spatial index using the first stage of the 2SLS results from Table 5 (page 131). The abstraction of a *ceteris paribus* analysis is useful as it allows the calculation of the influence of each cell on law enforcement expenditures. This is analogous to what Heikkila refers to as a service-based impact. Here, Heikkila’s definition of a service-based impact is modified to capture the cost of restoring service from no development to existing development on a cell-by-cell basis and may be thought of as a spatially defined service-based impact. Detailed methods for this evaluation are presented in chapter three beginning on page 83 and again in chapter five beginning on page 136.

Mapped results of the spatially defined service-based impact are presented in chapter five, Figures 21 and 22 on pages 138 and 139 for the 1K and 1sq M grid, respectively. Both figures show a number of core area cells in and around the City of Laramie which have a spatially defined service-based impact that is less than zero. In contrast, most of the county and nearly all cells outside Laramie have service-based impact that is greater than zero.

Downing recommends research addressing the geographic distribution of gainers and losers from average and marginal cost pricing schemes (Downing, 1977a). The method and results presented here are an answer to Downing’s question. Given a spatially defined and service-based impact, areas that overpay or underpay for services may be identified by
contrasting the spatially defined service-based impacts with the share of property taxes paid and allocated to policing services on a cell by cell basis. A simple formula allows calculation of a Boolean value indicating whether or not a grid cell contributes more in revenue than it demands in services or *vice versa*. Areas are deemed fiscally efficient if they pay, through property tax revenues, the spatially defined service-based impacts for policing services. Results, presented in Figure 26 for the 1K grid, show a core area of the county approximating the City of Laramie that is fiscally efficient. The remainder of the county is not fiscally efficient for the provision of policing services. Results for the grid composed of cells one square mile in size are nearly identical. The method overviewed here and detailed in chapter five provides the answer to the third research question, how can a spatial production function model be used to identify areas that either overpay or underpay for services?
FIGURE 26: Areas of Albany County that are Fiscally Efficient for the Provision of Policing Services (1K Grid)
6.2 Generalizability

The results of the early engineering estimates and regression studies relating urban form to the cost of public service provision have resulted in a qualitative assessment that low-density developments distant from centers of service provision are more expensive to serve than more proximate and high-density developments. The results of these studies have not proven to be broadly applicable, in part due to conflicting results and in part due to, as articulated by Carruthers and Ulfarsson (2003), “...their site specific focus” (p. 505).

The previous efforts to quantify the relationship between urban form and the costs of public services shed light on the generalizability of this research. The results presented here are congruent with the majority of numerous previous studies which conclude decreasing densities and increasing distances lead to increased costs of public service provision. This research has shown that as clustering decreases, costs for the provision of policing services increase. The generalizations of prior work, supported by the results of this research, are now strengthened. Quantification of the different elements of the production and allocation functions, establishing significant relationships between those elements, and mapping the conclusions has resulted in information that may prove to be more actionable than the results of prior studies. In turn, more actionable information may result in greater generalizability than previous work. This study, although an empirical analysis of a specific case, has developed measures (e.g. the spatial index, the public safety index) and methods that may either be accepted as broadly applicable or provide a solid and standardized basis for further testing.

In assessing the generalizability of this research it is noted this is not a complete economic analysis of the impacts of changes in the built environment. A complete fiscal impact model will test these methods on the full array of public services within a study area. A complete economic model will also incorporate measures of environmental attributes. Residential, commercial and industrial growth may occur in environmentally sensitive areas. Examples in Albany County include big game seasonal ranges, wildlife migration
corridors and riparian areas. The opportunity exists to develop spatially precise welfare-based evaluations of service provision that address not just costs of services but also include measures of change in the natural environment and assessments of ecosystem services. These ideas are expanded upon in section 6.5, “Recommendations for Further Research” beginning on page 168.

6.3 Significance and Innovation

The key element of the significance and innovation of this research is that previously, a fiscal impact model that ties urban form to local government expenditures and level of service outputs has never been documented in the literature. This research therefore makes a significant and original contribution to the body of knowledge surrounding urban form and the costs of public services.

This research resulted in theory based and research validated methods for modeling the spatial component of the costs of public service provision. There are a number of innovative aspects to the methods employed in this research:

(1) Development of time series panel data from a single cadastral layer;

(2) This research quantified urban form as an index so that it is suitable for inclusion in a time-series econometric model.

(3) The result is an econometric model that ties urban form to local government expenditures on public services and level of service outputs. By separating urban form from factors that influence the costs of providing services these methods enable a determination of the spatial component of the costs of public service provision.

Development of the time series panel data from a single cadaster was enabled by the year built attribute in Albany County’s parcel database. The resulting layers serve as snapshots of the intensity of the built environment and allow assessment of change in urban form over time. These derived panel data are therefore suitable for capturing the intensity of the built environment and change over time as an index. Irwin and Bockstael (2007)
articulate the importance of these sorts of high resolution land-use data (see their quote in **chapter two on page 46**). These methods and data may also be useful in calibrating land-use change models by allowing more accurate model calibration. The model calibration technique called backcasting is in essence an attempt to predict current conditions with historical data. Multiple backcasting iterations allow fine-tuning of model parameters and should yield improved forecasting results.

The second element of the innovation of this research is the development of the spatial index. Development of the index is detailed in **chapter four beginning on page 89**. Although there are a number of indices that capture land-use and other aspects of the pattern of the built environment, this is the only index known to the author that captures the intensity of the built environment, captures change in urban form over time, and is suitable for inclusion in time series regression analysis. Additionally the index allows an extremely fine-grained assessment of the built environment as it is based on parcel data and is flexible in implementation resolution.

Carruthers and Ulfarsson (2003) suggest the conflicting evidence coming from different regression-based studies of costs of services and development pattern may be due in part to the way “...the character of urban development is measured.” (p. 507). The innovation of an index of spatial pattern may become significant if it leads toward a standardized measure or method to quantify urban form. As the spatial index developed here works in this first case example it is worthy of additional experimentation to determine if the methods and measures of spatial pattern developed here are more broadly applicable.

The third element of the innovation of this research is the econometric model which ties urban form to local government expenditures on public services and level of service outputs. In the model, urban form is clearly separated from other factors that influence law enforcement expenditures. These methods are detailed in **chapter five beginning on**
This is the first time urban form has been included as a determinant in an econometric model of local government service provision.

This project is significant because it:

1. Resulted in quantified, and potentially actionable information on the spatial component of development costs.
2. Resulted in a determination of areas that are fiscally efficient for the provision of local government services.
3. And, broadly, advanced the discussion of the relationship between urban form and the costs of local government service provision.

This research quantified the link between urban form and the cost of policing services in the study area. This indicates that expenditures on policing services are sensitive to spatial pattern and that location and pattern of development do matter in the cost of local government service provision. By leveraging the spatial index this research also resulted in a map of areas that are fiscally efficient for the provision of policing services. As stated in the introduction, the significant aspects of this research relate to the two corrective actions proposed for suboptimal land-use patterns. Mapped output indicating areas that are fiscally efficient for the provision of services allows for informed planning and decision making. Information on the spatial component of public services costs may allow local governments to develop marginal cost pricing structures for the services they provide. The identification of fiscally efficient areas for local government service provision may be used to establish service areas or similar mechanisms for identifying user charges based on geography. These potentially positive outcomes, as well as the potential of the information resulting from this research to be actionable, depend upon the degree to which this information informs planning and decision making. The integration of information with planning and decision making may occur through a process of social learning, as described in more detail below.
The incorporation of urban form in a cost of services model and the finding that urban form is a significant determinant of law enforcement expenditures advances the discussion of the relationship between urban form and the costs of public services. This work takes this discussion beyond concepts of density and distance, quantifies relationships among production and allocation inputs, and results in a specific, mapped, determination of areas that are fiscally efficient. The result is an original, innovative and significant contribution to the body of knowledge surrounding urban form and the costs of public services.

6.4 Broader Impacts
The potential broader impacts of this research are rooted in the idea that the opportunity exists for improved economic efficiencies if local governments can be made aware of the relationship between urban form and the costs of services provision. The discussion of broader impacts is grounded in the potential to assimilate these methods and results in order to bring about more informed decision making. A motivating factor for more informed decision making is the potential of these results to mitigate a number of the externalities associated with contemporary urban forms. The integration of these methods and results with planning and decision processes may be realized through a process of social learning. More informed decision making, addressing externalities and social learning all function within the context of current and future planning traditions and policy models. Therefore, this discussion begins with an overview of these trends from an international perspective.

International Planning Traditions and Policy Models
The international trends in planning traditions and planning policy models are fairly similar across western cultures. In North America, Europe and Australia there is a trend toward public engagement based planning practices rooted in information. The supporting policy models, per Geertman (2006) are pragmatic and emphasize social interaction. These trends and policy models suggesting the value of information integrated with planning through a process of social learning.
Geertman (2006) explains planning policy models as the way a planning institute, which may be looked at as a level or branch of government addressing a planning issue, transforms a problem into policy. Geertman distinguishes between planning policy models and the planning process, stating that policy models are more general and abstract in that they provide normative notions of the what and how of the planning process (Geertman, 2006). A planning process is an implementation of the current planning tradition. Planning policy models may be viewed as the operationalized epistemology and implementation of a planning tradition.

Klosterman (2000) articulates the planning traditions and policy models of the late 20th century in North America and anchors them in specific time periods. He refers to the 1960s as, “planning as applied science” (p. 47) where technology tools generate information in support of rational planning and decision processes. Klosterman refers to the 1970s as “planning as politics” when the limitations of information technology were identified. He writes that information technology is inherently political, reinforces existing power structures, and obscures rather than illuminates choices. In the 1980s information was less important than how planners communicated information. The 1990s saw the beginning of “planning as reasoning together” where information technology helps enable communication and decision making within a community in a collaborative fashion (Klosterman, 2000, p. 47).

Vonk (2006) explains the transition toward public engagement by contrasting it with an autocratic style that he summarizes as “Decide, Announce, Defend” (p. 16). Vonk argues the autocratic style led to abilities to resolve disputes; plans were implemented with difficulty if they were implemented at all. The potential benefits of public engagement were rooted in the need to include information beyond that produced by traditional science:

... it became clear that society not only possesses values that could influence change ... but that society also has information and knowledge indispensable to the planning process.
Increased public participation and participatory planning is seen as an answer (Vonk, 2006, p. 16).

Vonk (2006) argues both the autocratic style and the transition to public engagement are broadly applicable to western societies. Nevertheless, it is worth noting the European planning traditions of the 19th and 20th centuries as they do differ from those found in other parts of the world. In the late 19th and early 20th century in Europe authorities in urban areas began to work together to tackle problems such as overcrowding and substandard living conditions in urban areas. The tools employed were zoning, building rules as well as other housing schemes. The modernist movement of the early 20th century, as exemplified by Le Corbusier, sought to dramatically re-work European cities through dramatic changes in housing types and transportation. According to Vonk (2006), the objective of the modernist movement was to provide power and independence to some, but servility and powerlessness to the majority of the population. Post-World War II planning in Europe was focused on reconstruction. Subsequently, strategic plans for European cities were developed and sub-disciplines such as economic planning, transportation planning et cetera... came in to being. In the 1970s broader scale and longer-term environmental concerns began to be integrated with planning. Vonk dates the contemporary concern for sustainability planning (environmental planning integrated with social and economic concerns) to the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil (Vonk, 2006). Another current concern in planning is replacing the disappearing manufacturing economy with a new economic cornerstone, the knowledge-based economy (Vonk, 2006, p. 14).

In the Netherlands, the developing planning tradition is referred to as governance with development planning. It stands in sharp contrast with the standard permitting process. Governance with development planning is intended to provide opportunities rather than restriction. It is hoped this results in enhanced adaptation and implementation of public engagement based plans and, it is speculated, might help restore trust in government. Vonk describes this as a change towards social learning (Vonk, 2006).
From Nichols (2007), the post-World War II idea of reconstruction was also invoked in Australia. Rather than re-building areas damaged by war, what the process referred to was reconstruction on the edges of Australian cities based on new and forward looking plans and processes. The literature suggests Australia is also transitioning to new planning traditions and models. Gibson (2006) argues the standard planning permitting process is of limited utility because it does not guarantee development will be in the public interest. Kozlowski (2006) suggests the use of urban design is expanding beyond its role in local plans and zoning codes and is being thought of as a tool that is more broadly applicable to urban and regional problems and planning efforts. Gibson (2006) argues a need for a variety of planning skills (physical planning, infrastructure delivery, environmental enhancement, public engagement et cetera) for the next phase of development in Australia. Hall (2007) reiterates Vonk’s point about the desirability of a knowledge-based economy and its relevance as a basis for redevelopment in Australia.

Additional international perspective can be found in the quantitative work of Frenkel and Ashkenazi (2008a, b). They develop a number of measures of sprawl. Similar to this research, they state the significance of their study is bringing quantitative knowledge to the discussion of the issue.

Vonk (2006) summarizes the international state of planning when he notes western societies show strong similarities in their planning models and traditions. He concludes, “...historical-political determinants of planning traditions occur on a large scale” (p. 15). The idea is supported by Geertman who in his 2006 paper, *Potentials for planning support: a planning-conceptual approach* published a table that includes a historical overview of planning styles, policy models, and characteristics of information, knowledge, and instruments. Geertman’s table is reprinted as Table 6, below. Implicit in the table are that the relationships apply across western societies. His temporal breakdown of planning
traditions closely follows that of Klosterman (2000). Also noteworthy is the emphasis of pragmatism and socially constructed knowledge from the 1980s through the present time.


<table>
<thead>
<tr>
<th>Timeframe of planning traditions</th>
<th>Planning style</th>
<th>Policy model</th>
<th>Characteristics of information and knowledge</th>
<th>Characteristics of planning-support instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950s/60s and onwards</td>
<td>blueprint planning</td>
<td>comprehensive rationalism</td>
<td>value free, substantive</td>
<td>expert oriented</td>
</tr>
<tr>
<td>‘Rationality’ tradition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1960s/70s and onwards</td>
<td>process planning</td>
<td>disjointed incrementalism</td>
<td>procedural</td>
<td>process management</td>
</tr>
<tr>
<td>‘Procedural’ tradition</td>
<td>administrative planning</td>
<td>bounded rationality</td>
<td>satisfying</td>
<td>process management</td>
</tr>
<tr>
<td></td>
<td>advocacy planning</td>
<td>pluralism</td>
<td>value laden, partisan</td>
<td>empowerment</td>
</tr>
<tr>
<td></td>
<td>critical planning</td>
<td>structuralism</td>
<td>value laden, potentially distorting</td>
<td></td>
</tr>
<tr>
<td>1970s/80s and onwards</td>
<td>strategic planning</td>
<td>mixed scanning</td>
<td>strategic</td>
<td>continuous generation of combined process and substantive information</td>
</tr>
<tr>
<td>‘Strategic’ tradition</td>
<td></td>
<td></td>
<td></td>
<td>facilitation of ‘reasoning together’</td>
</tr>
<tr>
<td>1980s/90s and onwards</td>
<td>communicative planning</td>
<td>social interaction</td>
<td>socially constructed, value laden, context bound, class bound empirically based and stems from reconstruction of experiences</td>
<td>community supportive, empirically based, experimentally oriented, and information and knowledge disseminating</td>
</tr>
<tr>
<td>‘Participatory’ tradition</td>
<td>development planning</td>
<td>pragmatism</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>governance</td>
<td>integrated management</td>
<td>multidimensional</td>
<td></td>
</tr>
<tr>
<td></td>
<td>planning analytics</td>
<td>real-life rationality</td>
<td>power laden and actively produced through social interaction</td>
<td></td>
</tr>
</tbody>
</table>
Looking forward, Legates et al. (2009) put forth a planning model for the early 21st century based on georeferenced data and the application of geospatial technologies for planning and analysis of planning problems. They couch their observations on what they call a third wave of scientific planning by noting two previous waves, the city scientific movement (1909-1930) and what they call the systems revolution (1963-1973). The latter is analogous to Klosterman’s idea of planning as applied science. Observing what can only be called they lack of success of the city scientific movement, LeGates et al. (2009) observe that city scientific planners would have been more effective if they had presented themselves as informing discussion and decision makers rather than claiming it was possible to scientifically derive optimal solutions to planning problems.

LeGates et al. (2009) note planning is both normative and political, that science can produce better decision making but cannot alone solve planning problems. These ideas are supported by Vonk (2006) as noted above and Geertman (2006). Geertman expands upon the extension of science to include the political by adding a number of other social and economic elements which frame the context of planning: “…power structures; traditions; status; cultural differences; psychological barriers; financial, technical, and legal constraints; and so on” (Geertman, 2006, p. 875).

**Social Learning**

Researchers such as LeGates, Geertman and Vonk who concern themselves with the relationship between information and planning processes and the integration of information and planning are pointing toward a process of social learning for integration of scientifically-based and other types of information in collaborative planning processes. Vonk (2006) describes the transition of planning from being a rational, scientifically-based analysis to include, broadly speaking, public engagement and elements of social learning. The transition is necessitated due to high degree of complexity planning. Vonk details several challenges that make planning complex. These challenges include the fact that the planning arena deals with human processes that are less easily quantified than the laws of natural science and that processes occur on multiple spatial and temporal scales which
causes information needs and expertise needs to be high. The decision environment is also highly complex. Citing Hall (1975) there are likely to be many objectives and that are not understood by all parties. Solutions to planning issues that balance stakeholder interests with goals that also align with the policy requirements of multiple and overlapping jurisdictions are difficult to obtain. Vonk (2006) also notes communication requirements add to the complexity of social learning and public engagement to rational planning.

The context of information in political settings put forward by Vonk and Geertman is supported by Downing and Goetz. Downing (1977a) notes there are values and preferences which may be more important than the cost of public services in determining areas and sites that are developed. Goetz (2007) notes land-use decisions must not be solely based on economics, but environmental and social concerns as well as other factors not typically valued in the market are legitimate criteria for influencing decision making.

Innes makes several important points pertaining to information, social learning and planning. First, many types of information are important, not only objective information. Second, the process by which information is produced is a social process which develops shared meaning for the information. In other words, generating information brings about social learning. Third, information, rather than being used as evidence, becomes influential by becoming embedded in shared understandings, in practices and in institutions (Innes, 1998). Invoking the term “participatory tradition” Geertman (2006) supports the idea that many types of information are important to planning including “ordinary knowledge”, “the personal experiences of affected laypersons”, “common-sense reasoning” and “intuitive notions” (p. 875).

Much of the literature in social learning is comes from research in sustainability. Starting points include Milbrath (1989) who lays the ground work for social learning in a sustainability context; Thomsen (2008) and Smith and Lazarow (2006) who address the
scope of participants in a social learning process; Tabara and Pahl-Wostl (2007) and Glasser (2007) who address process and outcome concerns; and Smith et al. (2009) who summarize developments in social learning within the context of sustainability.

A primary benefit of social learning is that it may yield positive planning outcomes. Brody (2003) considers social learning to be a major factor in increases in plan quality. He defines social learning in terms of outcomes, “...a re-definition of policy goals and objectives” and changes brought about by learning, “...an alteration of belief systems, core values, or assumption of relevant publics” (Brody, 2003, p. 193). Brody (2003) looks at planning as an adaptive learning process where the primary indicator of plan quality is the quality of the previous plan and the difference is brought about by social learning. Extending this idea, Mastop and Faludi (1997) advance the idea that presentation of information to an engaged public may bring about a situation where a plan can work before it exists--because people do not wait for plans to be adopted before acting on shared understanding.

In addition to social learning leading to better plans, social learning may also lead to citizen action. Lee ties social learning to the action of political change by defining social learning as the combination of adaptive management and political change (Lee, 1993). Smith and Smith (2006) reiterate the political change aspect of social learning in stating social learning requires a combination of learning by doing, learning with others and learning by making change. Burby, citing Forester (1993), relates planning and learning to action, “Forester (1993) discusses planning as the organization of citizens’ attention toward the possibility of public action and of anticipating implementation” (Burby, 2003, p. 36).

This research developed methods and information which advance the discussion of how differences in urban form affect the costs of local government service provision. Making this information actionable will likely require more than publishing methods and results.
Given the articulated ties between social learning, developing planning traditions and policy models as well as the potential benefits of social learning from a planning context, social learning process appear to be a promising way of making research outputs relevant to planning processes. The way forward is suggested by the literature linking social learning and sustainability where effective process can lead to more informed decision making.

**More Informed Decision Making**

One of the broader impacts of developing information in support of planning is necessarily anticipated to be more informed decision making. A cornerstone of the assertion that information can be used to guide decision-makers to better planning outcomes is the idea that government in fact has a role in planning. Goetz (2007) argues this convincingly:

> Given the many diverse and conflicting interests that surround land use issues (including, for example, homebuilders, homeowners, housing coalitions, environmentalists, transportation planners) it is essential for one entity with broader perspectives and powers of law as well as persuasion to assume leadership in convening different parties and coordinating their actions (Goetz, 2007, p. 22).

Following the precepts of social learning as well as LeGates et al. (2009) the approach here is that information may inform discussions and decision making. Vonk (2006) expresses the relevance of information to planning in terms of a need to do business differently. He states planning outcomes “...that are mostly based upon short term interests with high collective priority or economic value are no longer satisfactory” (p. 17).

Geertman, who is a strong advocate for the incorporation of information and information technology in planning, also points out information in a planning context may be distorting. Although writing about planning support the argument applies to information directly:

> ...this role can also be characterized as relative and potentially distorting, directing attention to partisan solutions and away from more widely accepted solutions. As a consequence, the potential facilitating and distorting roles of information, knowledge, and instruments form two sides of the same coin and require critical reflection at all times (Geertman, 2006, p. 874-875).
Vonk argues the value of information and the need for better informed planning processes can be seen in a fairly extensive list he presents of planning failures. He argues planners are unable to manage the overwhelming complexity of current planning practice and there is therefore a need for improved information and supporting information technologies (Vonk, 2006). Jankowski and Nyerges (2008) make a similar argument when they state one of the goals of developing GIS support for participatory decision making is to reduce the cognitive workload of decision makers. They put forward that the benefits of reducing cognitive workload are greater engagement with information, illuminating initial assumptions, and ultimately greater public engagement in decision processes.

Goetz argues that land-use decision making should strive to realize the greatest net benefit. He states the question of how land is used to benefit a jurisdiction’s residents is one of the most important questions confronted by decision makers. Goetz recommends using benefit-cost analysis to weigh the economic, social and environmental elements of land-use decisions and recommends decision makers choose development alternatives with the highest benefits. Goetz bolsters his argument that alternatives must be considered by reminding us that planning is a non-repeatable experiment and construction is essentially irreversible (Goetz, 2007).

Within the context of planning and decision making presented by Goetz, the results of this study suggest decision makers will do well to encourage data development for fiscal analyses and other planning purposes, integrate fiscal analysis in their planning processes and thoughtfully consider the fiscal implications of their decisions. From this research, maps such as Figure 26 that indicate areas that are efficient for the provision public services provide information that enables a jurisdiction to modify the pricing structure of the services they provide and make clear the link between the consumption and payment. The area of Albany County indicated in Figure 26 as fiscally efficient for the provision of policing services may be viewed as a service area. Downing argues service areas provide a more accurate means of assessing charges than average cost pricing, but are not as
difficult to calculate as parcel-based marginal costs of service provision (Downing, 1977b). In a Tiebout setting, defined service areas and associated charges allow citizens to make informed decisions on location preference which incorporate a wide range of factors.

There are limits to the effectiveness of information and decision making. Informed decision making doesn’t necessarily fix bad decisions made in the past. Bahl and McGuire (1977) note that where marginal cost pricing is imposed on a built environment that is not economically efficient, these inefficiencies may persist. Suboptimal locations for centers of service provision, sometimes referred to as load centers, built to serve far flung development may remain sub-optimally located as their service area increases in density.

Additionally, informed decision making, in order to bring about change, must be coupled with the willingness and power to implement change. There are a myriad of plausible scenarios including the impacts of climate change, responses to peak oil as well as more general situations such as changing societal conditions and changing worldviews where the inclination and power to affect change are likely to differ from present circumstances. Future changes in the conditions of society and the environment, while nearly impossible to pin down specifically, will certainly alter the willingness and / or power of people to implement change. This will in turn alter the impacts of this research and informed decision making in general.

**The potential impacts of this research on the externalities associated with dispersed urban form**

McGrath (2005) mentions the idea of internalizing and externalizing the environmental costs of urbanization. The argument presented throughout this dissertation that better information can lead to improved planning decisions and improved economic efficiencies is in many ways an argument that information can be used to internalize rather than externalize the costs of public service provision. Gaffney (1964) summarizes the negative externality associated with-suboptimal pricing of public services, people who live in density don’t benefit from lower prices.
In a related issue, McGrath (2005) quantifies the effect of ignoring the externalities of sprawl due to under-priced transportation:

Had private transportation costs been socially optimal, the results presented here suggest that US metropolitan regions would be as much 12% smaller on average. To place this finding in perspective, it implies that over 3200 square miles of agricultural land may have been overdeveloped in ... 33 metropolitan regions ... due to under-priced private transportation (McGrath 2005, p. 8-9).

Full knowledge of the relationship between urban form and the costs of public services will enable communities to make decisions on land-use change with a more complete understanding of the fiscal impacts of a proposed change. Informed decision making will help minimize the negative externalities of sprawling urban form as well as help protect agriculture, natural resources, quality of life and the overall sustainability of the built environment.

6.5 Recommendations for Further Research

Fotheringham et al. (2000) argue that knowledge resulting from geographical research, both physical and human, is not accepted quickly, “...rather it emerges after a long series of tests to which an idea or hypothesis is subjected” (p. 8). With the goal of extending the methods here to yield more generalizable results and actionable information, there a number of areas suggested for future research: the application of methods to additional study areas and services, regional analysis, and scenario-based analyses. Modeling itself may be enhanced by further research in issues of issues of scale and space, model sensitivity and principle components analysis and a look at how implementation of model outputs may be enhanced. Further research may advance the body of knowledge surrounding the use of information in planning, enhancing the implementation of geospatial planning tools, and the application of social learning processes to planning issues. Finally, environmental concerns may be incorporated. This idea extends the economic arguments to more broadly address overall societal welfare.
For advancing generalizability Stake (2000) recommends “triangulation” (p. 443), defined as using multiple perceptions to clarify meaning. Triangulation can also be used as a means of going from the particular to the general, suggesting, in essence the need for further research to see what similarities and what differences may be discerned using multiple cases and even multiple methods. These ideas align well with those of Yin (2003) who states:

... scientific facts are rarely based on single experiments; they are usually based on a multiple set of experiments that have replicated the same phenomenon under different conditions. The same approach can be used with multiple-case studies but requires a different concept of the appropriate research designs ... The short answer is that case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. (Yin, 2003, p. 10).

The desire to advance the generalizability of this research suggests the need for additional case examples. While the work presented here is one case study, the methods developed here and resultant findings may be applied to other elements of local government service provision and other areas to see if similar conclusions may be reached. The most obvious opportunities are to apply the methods developed here or similar to the evaluation of additional government services within Albany County and / or to additional study areas.

The evaluation of additional study areas is an empirical means of assessing the applicability of the methods presented here and the generalizability of the conclusions of this study. Key factors in evaluating the potential of a local government as a study area are the availability of categorically specific time series data on expenditures and the availability of high quality parcel data. Here, the critical geographic data attributes were land-use classification, building year built, and building value (as a measure of development intensity). Evaluation of the availability and quality of these data are a reasonable place to start when considering developing a model similar to what is presented here for other jurisdictions. Spatially precise, or locally varying data on potential production and allocation model inputs as well as level of service measures would allow a more detailed evaluation of the non-stationarity of urban form and cost of service relationships. With detailed data, geographically weighted regression
(Fotheringham et al. 2002) would allow the calculation of locally varying parameter estimates.

The potential for modeling additional study areas also raises the issue of regional analysis through simultaneous modeling of multiple adjacent jurisdictions. Boundaries of local government service provision are rarely discrete and often overlapping. Where these issues are identified it is likely to be necessary to build models for multiple jurisdictions. The probability of spillover effects with neighboring jurisdictions point to the potential of larger-scale or regional analyses as both promising avenues for research and as being very useful for informing decision making at both local and state government levels. Eventually, the modeling of multiple jurisdictions is likely to inform regional issues of costs of services and urban form.

The evaluation of additional service types and multiple services within a study area is necessary to leverage the methods presented here into the development of a true fiscal impacts model. Total expenses per unit of analysis (cell or parcel) may be calculated by summing expenditures for all local government service elements. Those service elements that have a distinct or some spatial component may be calculated through regression analysis. Those that are determined to have no spatial component (perhaps the clerk’s office) may be included by adding average cost contribution to this expense per parcel function. By contrasting the implications of multiple services aggregated within the unit of spatial analysis with revenues it may be possible to paint a clearer picture of which cells or parcels are fiscally efficient. Evaluation of additional services will also begin to address the question raised in the literature of standardizing level of service measures.

Experimentation with additional service types and study areas opens the door to more detailed testing and model evaluation along the lines of sensitivity analysis and principle components analysis. Part of the issue, as described by Malczewski (1999), is the balance between using a large number of data inputs to model a situation as closely as possible or
using a small number of inputs which would yield a more approximate model. By creating additional case examples we may begin to find both consistencies and inconsistencies in data inputs. This type of information, especially if broadly derived, could provide valuable insight into the data and methods used in model development as well as the topic of the cost of local government service generally.

The concept of scenario analysis, or evaluation of plausible planning alternatives, extends the *ceteris paribus* analysis (presented in chapter five on page 136) to evaluated hypothetical urban forms. The possibility also exists, addressing the critique presented by Stephenson *et al.* (2001) who note many studies assume demographics remain constant as spatial attributes vary, to vary neighborhood characteristics along with urban form. Another potential scenario-based application is to leverage this sort of cost of services analysis for impact assessment of the output of land-use change models.

There are several issues which are inherently spatial that deserve greater attention in future research. A goal is to refine methods to be more spatially precise using either a finer resolution grid or parcels as the basis of the analysis. In considering grids of smaller cell sizes, there may a threshold at a larger scale (finer resolution) where local indicators of spatial association do not paint as clear a picture of clustering and dispersion for the study area as a whole. Analysis at the parcel level will require addressing issues of connectivity between parcels. Further testing for issues associated with the modifiable areal unit problem will go hand in hand with research addressing issues of scale and space.

It is also worth continuing to explore means of quantifying urban form. Tsai (2005) and Heikkila and Hu (2006) use measures of entropy to quantify dispersion across space. Tsai (2005) suggests the use of Shannon’s relative entropy based upon spatial data on population or employment. Heikkila and Hu (2006) argue against the use of relative entropy and suggest instead Theil’s (1967) decomposition method. Theil’s method lends itself comparison between study areas as it accounts for differing and potentially arbitrary
spatial units (Heikkila and Hu, 2006). Although the examples put forward by Heikkila and Hu (2006) are based on population data and Tsai (2005) suggests using entropy to characterize population or employment data and entropy index could be constructed to characterize the intensity of the built environment based on building values. Furthermore, and entropy index could be incorporated into a regression-based analysis of service provision in an identical fashion to the way the spatial index is incorporated into the analysis presented in this dissertation.

Another area for future research, given methods for addressing the critical issue of efficient provision of public services, is determining how implementation of model outputs can be enhanced. Both qualitative and analytical approaches are possible. For example, a qualitative approach is to establish best practices based on conditions. An analytical approach is to incorporate fiscal impact modeling within a deliberative framework such as multi-criteria analysis (MCA) or Bayesian model comparison which would allow for integrating modeling results with other sources of information thereby facilitating integration, comparison, and hopefully highlighting relevance.

There are also opportunities for further research in the integration of information in planning and enhancing the implementation of geospatial planning tools. There is a substantial body of literature, touched upon here with the inclusion of Geertman, Vonk, LeGates and others, on the integration of information in planning and the related issue of enhancing implementation of geospatial planning tools. Future research relating urban form and cost of services to information in planning and implementation of geospatial planning tools may be looked at as a potential series of meta-projects associated with the additional dissemination of methods and results from additional case examples as discussed above. Research on information integration will likely be grounded in planning process, public engagement and social learning. Future research could investigate ways to enhance and maximize the effectiveness of these ties.
Finally, residential, commercial and industrial growth may occur in environmentally sensitive areas. The opportunity exists to develop spatially precise welfare-based evaluations of service provision that address not just costs of services but also include measures of change, possibly valuation-based change, in the natural environment. Examples in Albany County include big game seasonal ranges, wildlife migration corridors and riparian areas. Adamowicz (2004) notes there has been substantial investigation into the valuation of environmental resources. Abler (2005) is source for a number of caveats in the use of non-market valuation methods.

6.6 Concluding Remarks
This research offers the opportunity to inform decision processes and ideally change broad patterns of growth in communities so they are more efficient, less energy intensive and more sustainable. The approach herein speaks to the argument of Clifton et al. (2008) who put forth that efforts to improve development patterns such as new urbanism and smart growth are only possible with an improved understanding of urban form.

This study advances research in fiscal modeling by suggesting methods for development of an index that captures urban form. The index enables evaluation of the fiscal implications of urban form for local government service provision. The index is then leveraged in order to identify areas that are and are not fiscally efficient for the provision of policing services by mapping the results. Developing this research has yielded a number of observations:

First, the built environment can be quantified as a spatial index of land use that captures changes in urban form. The index extends the effort to quantify urban form beyond concepts of density and distance. In developing the index, care must be taken to ensure the conceptualization of space used in generating spatial autocorrelation statistics.

Second, estimation results suggest residential urban form is a driver of local government spending on policing services. As the built environment becomes less clustered, local
government expenditures on law enforcement increased. Location and pattern of
development do matter in the cost of local government service provision.

Third, incorporation of a spatial index in an econometric model of public service provision
allows areas that are not fiscally efficient to be identified. Including a spatial index enables
calculation of spatially defined service-based fiscal impacts. When contrasted with a
revenue model, the result is a cell-by-cell (place by place) evaluation of fiscal efficiency.

These results suggest this approach holds promise for the spatially precise evaluation of
local government cost of service provision, more informed decision making at the local
government level, and, ideally, improved resource allocation. With an eye toward the
potential broader impacts as well as future research opportunities it is hope this effort is a
tangible cornerstone of research in urban form and fiscal modeling of the argument put
forth by Goodchild and Janelle (2004) that geographic space can provide a mechanism for
integrating social sciences and science to policy. The opportunity exists for improved
economic efficiencies in local governments if actionable information can be made
available to decision makers, planning offices and citizens about the cause and effect
relationship between the built environment they are enabling and the fiscal consequences
of their decisions. The theory-based, transferable and verifiable methods developed in this
research will enable the study area and other communities to avoid certain unintended
and undesirable consequences of development. Informed decision making in issues of
land-use change and conversion will help minimize the negative externalities of sprawling
urban form as well as help protect agriculture, natural resources and quality of life; all
issues with global applicability.
**Glossary of Technical and Supporting Terms**

**Economic Efficiency:** Kumbhakar and Lovell (2000) explain economic efficiency in terms of the objective of producers to minimize cost, maximize revenue, or allocate inputs so as to maximize profit.

**Fiscal Impact Analysis:** Fiscal impact analysis is defined by Burchell and Listokin (1978) as:

A projection of the direct, current, public costs and revenues associated with residential or nonresidential growth to the local jurisdiction(s) in which this growth is taking place (p. 1).

Heikkila and Kantiotou (1992) provide a definition of fiscal impact analysis even more closely relevant to this research: the evaluation of the impacts of changing land use on local government provision of service.

**Landscape Metrics:** Landscape metrics are a body of techniques from the field of landscape ecology for quantifying the pattern and organization of landscape elements. See McGarigal *et al.* (2002) for an introduction to methods and supporting references.

**Marginal Rate of Technical Substitution (MRTS):** The marginal rate of technical substitution in production economics is the ratio of the relative benefit of gain of using one production input versus another.

**Model:** Murray (2010) describes a model as a simplified representation of reality that reflects knowledge (hence the need for a basis in theory) and relationships. As with the case of the econometric models presented in chapter five, the goal of a modeling effort may be to ascertain and illuminate relationships.

**Modifiable Areal Unit Problem:** Fotheringham *et al.* (2000) describe the modifiable areal unit problem (MAUP) succinctly: the results of a spatial analysis may vary if the data are differently aggregated. The MAUP occurs when the spatial unit of analysis does not correspond exactly with the process being studies (Anselin and Getis, 1992). The MAUP
may be tested for by experimenting with different units of analysis. Paelinck (2006) proposes another solution where data are filtered for observational error then for bias in spatial aggregation (Griffith and Paelinck 2007).

**Monocentric Model:** The monocentric model is density-based modification of the von Thünen model of rent and land location. The monocentric model specifies densities will be highest at an urban center and decline as the distance from the urban center increases. The classic references for the monocentric model are Alonso (1969), Mills (1967) and Muth (1969).

**Production Function:** A production function is a technology relating inputs to outputs. Allsop (1995) puts forth a general production function where $Q = f(L,N,K,T)$. 

where,  
$Q$ is the total quantity of goods available to society,  
$L$ represents land  
$N$ represents labor  
$K$ represents capital  
$T$ represents technology (Allsop, 1995, p. 19).

**Spatial Autocorrelation:** Spatial autocorrelation is defined by Anselin (1988) as, “...the lack of independence which is often present among observations in cross-sectional data sets” (Anselin, 1988, p. 8). The concept is described in detail by Cliff and Ord (1973).

**Spatial Dependence:** From Goodchild the term spatial dependence refers to the tendency of, “...nearby locations to influence each other and to possess similar attributes” (Goodchild 1992, p. 33).

**Spatial Heterogeneity:** Per Anselin and Getis (1992) spatial heterogeneity refers to the differences in spatial dependence and relationships among variables across space:

A dependence structure that is inconsistent across the study area lacks homogeneity. In a sense, then, spatial heterogeneity can be thought of as a special case of spatial dependence. It represents a complex realization of the nature of the variable(s) under
study and the effects of the size, shape, and configuration of spatial units (Anselin and Getis, 1992 p. 24).

**Spatial Metrics**: Per Herold *et al.* (2005), the term “spatial metrics” extends the concept of landscape metrics to analysis of the built environment.

**Spatial Weights Matrix**: A spatial weights matrix is a way to represent spatial dependence. Bivand (2008) indicates Griffith (1995) demonstrated a simplified specification of spatial weights is preferred to making assumptions about distance decay. Bivand further notes:

> The arbitrary nature of the representation of spatial processes seems unavoidable, with the need to handle $n \times (n - 1)$ possible interactions, when we only have $n$ observations (Bivand 2008, p. 14).

**Urban Form**: There are a number of definitions of urban form. Urban form is defined by Gleeson (2006) as, “... the density, extent and appearance of the urban fabric” (p. 11). As defined by Anderson *et al.* (1996), urban form is:

> ... the spatial configuration of fixed elements within a metropolitan region. This includes the spatial pattern of land uses and their densities as well as the spatial design of transport and communication infrastructure (Anderson *et al.*, 1996, p. 9).
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### Appendix I Descriptive Summary of Pre-Existing Spatial Measures

<table>
<thead>
<tr>
<th>Purpose of the Measure</th>
<th>Data Analyzed</th>
<th>Measure</th>
<th>Method</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landscape pattern Index</td>
<td>land use</td>
<td>Diversity (Shannon) Index</td>
<td>Landscape / Spatial Metrics</td>
<td>Geoghegan et al. (1997)</td>
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<td></td>
<td></td>
<td>Fragmentation Index</td>
<td>Landscape / Spatial Metrics</td>
<td></td>
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<tr>
<td>Measure recreational and scenic amenities</td>
<td>View Characteristics</td>
<td>Simpson’s Diversity Index</td>
<td>Landscape / Spatial Metrics</td>
<td>Bastian et al. (2002)</td>
</tr>
<tr>
<td>Spatial distribution of population and employment</td>
<td>Total Employment</td>
<td>Global Moran</td>
<td>Spatial Autocorrelation</td>
<td>Baumont et al. (2004)</td>
</tr>
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<td></td>
<td>Employment Density</td>
<td>Global Moran</td>
<td>Spatial Autocorrelation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Population Density</td>
<td>Global Moran</td>
<td>Spatial Autocorrelation</td>
<td></td>
</tr>
<tr>
<td>Analyze model outcomes</td>
<td>land use</td>
<td>Landscape composition</td>
<td>Landscape / Spatial Metrics</td>
<td>Parker and Meretsky (2004)</td>
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<td>Number of patches/mean patch size</td>
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<td>Area-weighted mean shape index</td>
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<td>Class area concentration</td>
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<td>Average product/average core area</td>
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<td>Contrasting edge density</td>
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<td>Total contrasting edge</td>
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<td></td>
<td>Mean nearest-neighbor distance</td>
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<tr>
<td>Measure urban landscape patterns</td>
<td>land use and land cover</td>
<td>Percent Land</td>
<td>Landscape / Spatial Metrics</td>
<td>Alberti (2005)</td>
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<td>Mean patch size</td>
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<td>Shannon index</td>
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<td>Aggregation index</td>
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<td>Percent of like adjacencies</td>
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<tr>
<td>Quantifying Urban Form</td>
<td>Employment or population</td>
<td>Shannon’s relative entropy</td>
<td>Entropy</td>
<td>Tsai (2005)</td>
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<td>Employment or population</td>
<td>Gini Coefficient</td>
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<td>Employment or population</td>
<td>Global Moran</td>
<td>Spatial Autocorrelation</td>
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<td>Employment or population</td>
<td>Global Geary</td>
<td>Spatial Autocorrelation</td>
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<tr>
<td>Measure urban sprawl</td>
<td>land use</td>
<td>Integrated Sprawl index</td>
<td>Factor analysis of Landscape / Spatial Metrics</td>
<td>Frenkel and Ashkenazi (2008a,b)</td>
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<td>Analysis of the evolution of urban structure</td>
<td>construction initiation; meters² by land use</td>
<td>Global Moran</td>
<td>Spatial Autocorrelation</td>
<td>Porat et al. (2008)</td>
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<tr>
<td>Urbanisation Indicators</td>
<td>land use</td>
<td>Total urbanised area</td>
<td>Landscape / Spatial Metrics</td>
<td>Van Eck and Koomen (2008)</td>
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<td>Urban population density</td>
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<td>urbanisation degree</td>
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<td>Number of urban areas</td>
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<td>Average urban area size</td>
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<td>Patch size distribution</td>
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<td>Avg. circularity ratio</td>
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</table>
### Appendix II Descriptive Statistics of Key Variables

<table>
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<tr>
<th>Building Values</th>
<th>Parcel Size</th>
<th>PSI</th>
<th>LE_EXP</th>
<th>RES</th>
<th>LEO</th>
<th>Rural Population</th>
<th>SE</th>
<th>Unemployment</th>
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<tbody>
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