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Spatial Development and Energy Consumption

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RESOURCES FOR THE FUTURE

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Abstract

Previous literature has suggested that the urban form (i.e., city size, density, and center distribution pattern) influences urban energy consumption. It has been argued that more dense development is likely to result in more energy-efficient and sustainable cities. However, very little is known about the precise magnitude of possible energy savings from more compact urban form. Moreover, practically no research has been done to investigate which urban policies are likely to be effective in making cities more energy efficient and to quantify those potential energy savings.

In this paper we discuss the potential effectiveness of urban policies at improving energy efficiency. First, we analyze several abstract scenarios suggested by the literature to see whether making a previously dispersed city more compact would result in improved energy efficiency. Then we model realistic transportation and land-use policies and examine whether those policies are likely to reduce energy consumption in the urban context.

Key Words: energy consumption; urban form; general equilibrium; land use; transportation; government policy

JEL Classification Numbers: D58; H23; Q48; R13; R14; R40; R5

Contents

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Introduction

In recent years, American consumers spent over half a trillion dollars a year on energy. The consumption of energy in the United States in 2000 totaled about 98 quadrillion Btus, triple the consumption in 1949. Although over this time period the amount of energy used per real dollar of U.S. gross domestic product (GDP) fell from 20.6 thousand Btus to 10.6 thousand Btus, population growth (from 149 million in 1949 to 281 million in 2000) and per capita GDP growth caused energy consumption per household to grow 63 percent, from 215 million Btus in 1949 to 350 million Btus in 2000.

In the last two decades concerns about energy prices and energy security seemed to be of less importance, and other consequences of energy consumption, such as environmental protection, led the quest for conservation. More recently, issues of energy security are again on the front pages of the newspapers and in addition to them, concerns about climate change make the search for recipes to restrain energy consumption more urgent.

Recent evidence suggests that in the long run for each extra dollar earned, spending on energy amounts to 55–60 cents, so it is unsurprising to find the demand for energy to be rising with people's incomes.[1] Still, the demand for energy in most instances is a derived demand, that is, people do not demand energy per se, but like to consume goods and services that require energy. This provides some justification for the hope of reducing energy consumption while minimizing the impact on the welfare of consumers.

In this paper we consider one particular approach to reducing energy consumption: modifying urban spatial structure to reduce the demand for energy in transportation and space heating. At first glance this would appear to be a promising approach. Table 1 reports on energy consumption in the four broad sectors of the U.S. economy. As shown, growth in energy use in

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[1] See Gately and Huntington (2001) regarding long-term energy spending for each dollar earned.

the largest sector, industrial, has been stagnant for the past 30 years, while growth in the other three sectors has been steady and significant. These three sectors—transportation, residential, and commercial—are most likely to be affected by changes in urban form.

Table 1. Annual U.S. Energy Use by Sector (quadrillion BTUs)

Year	Transportation	Industrial	Commercial	Residential	Total
1973	18.6	32.7	9.5	14.9	75.7
2006	28.4	32.1	18.0	21.1	99.7
			Rates of change (%)		
1973–2006	1.3	-0.1	2.0	1.1	0.8

Source: Oak Ridge National Laboratory (2007)

In general terms, urban form refers to the physical layout and design of a city. Urban form includes density, street layout, transportation, employment and other urban activity areas, and urban design characteristics. While existing urban form is a product of numerous factors such as regional economic factors, regional development trajectory, and a combination of policy and regulation factors, urban forms significantly vary over the world regions. Therefore, there is a strong hope that urban form can be affected by government policies and other factors.

Theory and Empirical Research

The relationship between urban form and energy consumption was actively studied during the early 1970s, when concerns about the security of the energy supply gave rise to a wave of research aimed at evaluating the efficiency of the current state of energy consumption. Interest waned in the 1980s after the price of crude oil collapsed, but several events in the last decade or so have put the relationship between urban form and energy use back on the research agenda, including a renewed concern about energy security and new concerns about global climate change. In addition, the policy prescriptions of the energy–urban form link seemed to point toward more compact cities, something that dovetailed nicely with local environmental concerns, as evidenced by the Smart Growth movement and the battle in some areas over rapid growth and suburban sprawl.

The main link between energy use and urban form, of course, is urban transportation, where abundant evidence has linked the spatial density of economic activities to the demand for vehicle use. While making adjustments to urban form doesn't constitute direct energy conservation, it serves as a facilitating strategy that makes a variety of conservation activities possible.[2] Armed with this idea, several research studies in the mid 1970s attempted to estimate potential impacts of land-use planning on energy consumption. The studies assumed either hypothetical cities or a hypothetical growth pattern of existing cities. The forecast reductions in total energy consumption ranged between 0.35 percent according to Keyes (1977) and 46.3 percent according to the Council on Environmental Quality (1975).[3] Although those studies provided some valuable insights, their major drawback is that they did not explicitly model behavioral responses of individual households to changes in price signals.

A secondary link is found in space heating requirements. Large multifamily dwellings, usually found in dense urban areas, have a lower ratio of exterior surface area to interior square footage, thus reducing the rate of heat or cooling loss. This link has received much less attention, especially from policy analysts. The majority of research on the relationship between urban form and energy consumption that followed those early studies focused on transportation-related energy consumption with very little attention paid to building-specific energy consumption. In this paper we review those strands of literature separately.

Transportation-Related Studies

It is usually perceived that the most significant impact of the built environment on energy consumption is made through travel. On the other hand, the research into the relationship between auto travel and built environment might address some issues different from energy consumption, such as emissions, other environmental concerns, and urban sprawl as a general phenomenon. Therefore, in this section we review the literature that addresses the relationship between the amount of auto travel and characteristics of urban form in general.

Researchers of the effect of the built environment on travel demand have analyzed the impact of density, city size, and mixed land use in human settlements of different scales as well as the supply of public transit and the structure of the urban system.[4] The most extensive and frequently cited studies on the impact of density on travel demand are by Newman and

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[2] Keyes (1977).

[3] The studies include those of Keyes (1977); Council on Environmental Quality (1975); Roberts (1977); Carrol (1977); and Edwards (1977). A detailed review of these studies can be found in Anderson et al. (1996).

[4] For more comprehensive reviews, see Anderson et al. (1996); Badoe and Miller (2000); Crane (2000); Ewing and Cervero (2001); Handy (1996); Steiner (1994); and Stead et al. (2000).

Kenworthy (1989, 1999) and Kenworthy and Newman (1990) on energy use by cars in 32 large cities in Europe, the United States, Australia, Asia, and Canada.[5] Based on some simple regression analyses, Kenworthy and Newman concluded that differences in gasoline price, income, and vehicle fleet efficiency explained only about 40 percent of the variation in the gasoline demand. However, they found that a large portion of the remaining variation can be explained by a simple measure of population density. They concluded that urban population density is the single most important factor and called for policies of "reurbanization" to reduce transport energy demand and the associated environmental problems.

Higher densities may be expected to reduce the need to travel longer distances. The literature of this hypothesis is ambiguous. Steiner (1994) in her literature review concludes that, in aggregate, studies suggest that residents in high-density areas travel longer distances than residents in low-density areas.[6] Levinson and Kumar (1997), however, studied cities in the United States with more than 1 million inhabitants and came to another conclusion.[7] After controlling for available opportunities, transport infrastructure, and the socioeconomic and sociodemographic characteristics of the residents, they found a positive relationship for auto and transit commuters between metropolitan residential density and average commuting distance.

These ambiguous results could be related to metropolitan area size. Levinson and Kumar (1997) suggest that metropolitan residential density is a proxy for metropolitan area size.[8] Because large metropolitan areas offer more services and facilities than smaller ones, they may be associated with shorter travel distances and use of public transit. On the other hand, a dispersion of urban land use over a large area may lead to longer travel distances and a higher share of car trips. The complex interactions between metropolitan area size and travel distances have been extensively studied by Gordon and colleagues (1989).[9] They analyze the relationship between metropolitan area size and distances traveled for both commuting and discretionary purposes in the United States. They find that the travel behavior is significantly different for central city and suburban residents. In particular, for central city residents, commuting trips increase with city size. In contrast, for nonwork trips travel distances decrease for cities with up

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[5] Newman and Kenworthy (1989, 1999); Kenworthy and Newman (1990).

[6] Steiner (1994).

[7] Levinson and Kumar (1997).

[8] Levinson and Kumar (1997).

[9] Gordon et al. (1989).

to 1 million residents and increase for larger cities. At the same time, suburban residents have longer travel distances for both work and nonwork purposes, and their travel behavior is less affected by the size of the metropolitan area where they live.

One of the important leitmotifs in the literature on the relationship between urban form and travel is the provision of public transit and its role in reducing auto travel. At the same time, in the empirical analysis it has proven difficult to control for other variables that affect automobile ownership and mode choice. For example, several studies used the distance of a household residence from public transit or from the central business district as a measure of availability of public transportation.[10] Bento and colleagues (2005) attempted to rectify this problem by measuring transit supply by route miles in public transit networks normalized by the city area.[11] They found that the probability of driving to work decreases when population centrality and rail miles increase and road density decreases. They also found that moving sample households from a city with characteristics of Atlanta to a city with characteristics of Boston reduces annual vehicle miles traveled (VMT) by 25 percent.

Quantifying the benefits of compact and dense development might be a more difficult task than initially thought. For one thing, people with different demographic and socioeconomic characteristics might have strong preferences for a particular lifestyle. Dieleman and colleagues (2002) have found that personal attributes of households and characteristics of their residential environment are very important determinants of modal choice and travel distance.[12] Early studies did not take this determinant into account at all and were later criticized for that omission.[13] Aggregate studies often failed to control for socioeconomic and demographic characteristics among households in different areas as well as for differences in transportation infrastructure and the cultural, political, historical, and economic differences among the areas.[14] However, many disaggregate studies have not effectively accounted for the possibility that residential location is both a cause and an effect of residential density and vehicle usage. Golob and Brownstone (2005) pointed out that the use of city- or metropolitan area–wide data on urban form together with disaggregate travel data often does not solve the problem since that approach ignores

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[10] Train (1980); Boarnet and Sarmiento (1998); Crane and Crepeau (1998); Boarnet and Crane (2001).

[11] Bento et al. (2005).

[12] Dieleman et al. (2002).

[13] Handy (1996); Steiner (1994).

[14] Gomez-Ibañez (1991).

potentially important influences on travel of differences in urban form between neighborhoods or larger geographic zones within a metropolitan area.[15] Golob and Brownstone (2005) have used a model in which residential density, vehicle usage, and fuel consumption are jointly determined within the model. Analyzing data from Southern California, they found that a lower density of 1,000 housing units per square mile implies a positive difference of almost 1,200 miles per year and about 65 more gallons of fuel per household. Moreover, the contribution of vehicle choice to this number is about 20 gallons per year.

Finally, some researchers have suggested that dispersed development might lead to less automobile use than a monocentric city. They have argued that efficient travel patterns emerge as firms and households follow one another during the course of employment decentralization.[16] The literature on this topic primarily addresses auto-based commuting, although decentralization would affect nonwork travel as well. At the same time, several authors have shown that polycentric urban form tends to be associated with higher levels of auto dependence and solo driving.[17] Some evidence suggests that mode effects could partially be explained by insufficient transit connectivity between residences and workplaces.[18] Overall, the literature on the effect of polycentric form is inconclusive with respect to the aggregate effect of polycentricity on the amount of travel in urban areas.

Studies of Energy Consumption in Buildings

Energy consumption in buildings is another component that contributes to the overall metropolitan energy consumption. In the United States, buildings account for 36 percent of all energy consumed, compared with 41 percent in the European Union and more than 50 percent in the United Kingdom.[19] City comparisons with respect to this particular type of energy consumption are even harder to make in a meaningful way since such factors as climate, preexisting housing stock, and idiosyncratic population habits can make the overall picture even more complex. Nevertheless, energy use in buildings is rarely mentioned in the discussions of the relationship between urban form and energy use. For example, a detailed review of

[15] Golob and Brownstone (2005). For use of city/metrowide data on urban form together with disaggregate travel data, refer to Levinson and Kumar (1997) and Bento et al. (2005).

[16] Gordon and Richardson (1997); Levinson (1998); Schwanen et al. (2004).

[17] Cervero and Wu (1997, 1998).

[18] Modarres (2003).

[19] Steemers (2003).

interactions among land use, transportation, and environmental issues done by the Environmental Protection Agency (2001) discussed energy only in terms of energy use for transportation.[20]

At the same time, there is an existing literature on the relationship between building energy use and urban form that provides its own prospective on urban planning trade-offs.

In the earlier literature Steadman (1979) concluded that high-density linear development along transport routes would be more energy efficient than compact central development because buildings can be more energy efficient.[21] (A linear pattern better permits natural lighting, ventilation, and passive solar gain, and infrastructure can be shared.)

More recent studies are inconclusive. Some authors suggest that higher building densities reduce energy demand.[22] Others believe that increasing density can increase energy demand due to restricting light and thus lowering the opportunity for solar gain.[23] In a review of the issues related to housing, Steemers (2003) concludes that the energy argument for and against densification is finely balanced and will depend on infrastructure issues (e.g., opportunities for buildings to share water and energy networks).[24] Although more detailed analysis goes beyond the capabilities of our modeling framework, these issues should be kept in mind for further analysis.

Energy Consumption and Public Policy

Although much of the literature reviewed in the previous section focused on the concept of a compact city that seems to be characterized by a smaller energy- and emissions-related footprint, several important questions remain. One of them is whether the energy burden even in principle can be significantly reduced if the urban form becomes more compact. As we have seen above, both theory and empirical evidence are inconclusive, and direct numerical comparison of the effects involved might be required to find the answer. The most important question that we are trying to address here is whether land-use changes alone can make a significant difference for energy consumption. In order to test this hypothesis, we conducted a series of experiments to make the urban form more compact. In what follows, we call such experiments "Urban

[20] U.S. EPA (2001).

[21] Steadman (1979).

[22] For examples, see Holden and Norland (2005); Mindali et al. (2004).

[23] For examples, see Hui (2001) and Larivière and Lafrance (1999).

[24] Steemers (2003).

Scenarios." However, there are two important caveats. First, scenarios are not policies, and we don't know how to achieve what is described in a particular scenario. Second, achieving the state of affairs described in a particular scenario might require either very high and hard-to-estimate costs or significant changes in the internal preferences of the city residents that would be difficult or impossible to effect.

We also would like to determine which policies can achieve outcomes preferable to the status quo. It is one thing to say that cities of different urban form have different patterns of energy consumption and a quite different thing to assume that realistic policies can turn an inefficient city into an efficient one. We will call the second type of experiments "Urban Policies." An important difference between the policies and the scenarios is that policies are direct instruments that come with implementation recipes. People's preferences under a policy stay the same as in the status quo, and therefore we can conduct cost–benefit analyses of different policy instruments and compare policies based on the net benefits they are likely to bring.[25]

Anderson and colleagues (1996) suggested that the most efficient way to further study the relationship between the urban form and urban energy efficiency would be through a comprehensive study of possible outcomes of alternative policies.[26] In particular, they said that the current (circa 1995) generation of land-use and transportation models should be extended in two ways—by incorporating a range of policy instruments as exogenous variables, that is, as model parameters that can be easily changed, and by building modeling blocks that would translate travel demand and land-use changes into energy and emissions. In this paper, we took their suggestion and developed a methodology to analyze how urban policies might affect metropolitan energy consumption.

The main benefit of using a land-use and transportation framework to evaluate urban policies and scenarios is that transportation and land use in urban areas are very much intertwined. Likewise, scenarios and policies that affect either transportation or land-use decisions directly will indirectly affect the other component. Therefore, it is hard to predict which policies—predominantly land-use policies or predominantly transportation policies—

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[25] In this framework, costs of the policies can include tangible items such as implementation costs as well as other costs, such as political costs. Although harder to estimate, political costs sometimes serve as a major impediment to policy adoption and implementation.

[26] Anderson et al. (1996).

would be more effective at reducing energy consumption unless such a complex methodology is employed.

The motivation of the rest of this paper is to (1) evaluate to what extent an ideal compact urban form leads to energy savings and (2) investigate how much savings can be achieved through policy intervention.

The remainder of the paper is structured as follows. The following section outlines our methodology and model. We then briefly describe the scenarios and policies that we simulate using the model. Next we discuss an array of other urban policies that cannot be accurately simulated using our model but whose effects can be compared to those of the policies we are able to simulate. The paper concludes by discussing the limitations of our approach and sketches a roadmap for future research.

Methodology

In this section we briefly describe the structure and main features of the modeling framework used to conduct policy simulations. Also, we state energy-related assumptions made in this study and describe the energy-related status quo for the Washington, DC metropolitan area that we use as a baseline for policy simulations.

Model Overview

The model we use in this paper is an integrated model of land use, economic activity, and transportation. The model provides an attractive tool for the evaluation of urban policies that affect the residential and transportation decisions of inhabitants of urban areas. Because both local travel and the locational decisions of firms and residents in the metropolitan area are modeled explicitly, scenarios and policies that affect such decisions can be represented, evaluated, and compared. An important element of the model is that it automatically computes the changes in the residents' economic welfare caused by a particular policy. The computation of welfare serves as a basis for cost–benefit analysis, an evaluation of the economic efficiency of a particular policy. Finally, the model reveals the actual policy mechanism. In other words, the simulations demonstrate how exactly the decisions of the economic actors are changed due to policy and therefore eliminates the impression that policies operate within black boxes.

At the same time, our model in its current form has only 40 land-use zones and about 350 transportation links. Although such structure leads to fast run times and enables quick analysis of multiple policies, it also poses some limitations. First of all, not all policies can be meaningfully represented in the model. This especially concerns policies implemented at a microscale in areas much smaller than the existing modeling zones. Another limitation is that the model does not explicitly consider what determines vehicle ownership choices and therefore is not able to reflect a shift to smaller, more efficient cars as a result of higher fuel prices. Finally, the model only shows the effects of the policies in the long run; it cannot demonstrate what intermediate changes will occur in the urban area before all policy effects take place. Consequently, although our model provides a detailed model of the entire regional economy, it is not equally good at predicting the consequences of all policies.

Details of Energy Modeling

This section presents the methodology used to produce annual estimates of vehicular and residential energy use with our model.[27]

Vehicular Energy Use

The transportation simulation component of our model computes the costs of travel, which consist of monetary costs and time costs. The monetary costs of driving include fuel costs, fuel tax, vehicle depreciation, wear and tear, maintenance, and insurance. The model predicts fuel use, which varies by speed and VMT. Fuel use is measured in gallons and corresponds to a combination of gasoline and diesel products. Our methodology does not include fuel used by buses in the public transit system. Our model simulates transport for an average weekday of the year. The annual estimate of fuel use thus corresponds to a working year (250 days).[28] For the purposes of easy comparison with residential energy use, we convert gallons of gasoline into Btus.

Residential Energy Use

To estimate residential energy usage, we combine population distribution numbers from our model with energy consumption data from the Energy Information Administration's (EIA) residential energy consumption surveys.[29] In particular, we use annual energy consumption (end-use only) data disaggregated by household members and by the following four building types: single-family housing units detached (SFD), single-family housing units attached (SFA),

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[27] More details on modeling assumptions and a brief description of the baseline (status quo) energy profile can be found in the Appendix, sections A2 and A3, respectively.

[28] Because we model traffic for an average weekday, we consider only working days to compute annual vehicular energy use. Therefore, we underestimate the total effect.

[29] EIA (2001).

apartments in multifamily housing buildings of two to four units (MF24), and apartments in multifamily housing buildings of five units or more (MF5). These consumption data correspond to national averages, but we adjust them for the Washington metropolitan area's climate, considering the difference between the average national consumption per household and the average consumption per household for a climate zone of fewer than 2,000 cooling-degree days and between 4,000 and 5,999 heating-degree days.

Our methodology of producing energy use estimates will capture energy savings in residential use obtained by two sources. First, energy savings/losses from substitution between single-family and multifamily housing will be included. Second, different population distributions by income class across the region will also affect energy outcomes.

Modeled Urban Scenarios and Policies

Our simulations are divided into two categories. We first model three urban scenarios that consist of changes to the urban forms of our modeling region. In other words, we assume that drastic changes in the urban form simply occur and they consequently change the energy footprint of the metropolitan area, but we do not attempt to determine what policies might lead to such outcomes and don't even try to see how difficult or costly such changes might be. These scenarios show, respectively, how changes in individual preferences, building density, and road capacity, consistent with denser urban forms, affect energy use.

For the second category of simulations, we consider policies commonly discussed in the context of urban sprawl and energy. Each of them aims to induce behavioral responses of the same nature as the ones observed under the three urban scenarios. For the policies, the urban forms respond to the design of the policies and are not changed based on ad hoc assumptions. We model three policies. The first one is the so-called Live Near Your Work (LNYW) program, which is a policy that provides a monetary incentive to live closer to the work location. Like the scenario of a change in preferences in favor of higher density, this policy would be expected to induce residents to move toward the center of the region. Second, we model an Inclusionary Zoning (IZ) program, which is a policy that requires developers to provide affordable housing and denser development. This policy induces an effect similar to that of the scenario in which building density increases. Finally, we consider a VMT tax; this policy, like a change in road capacity, directly affects the cost of driving. The rest of this section further describes each of the simulations.

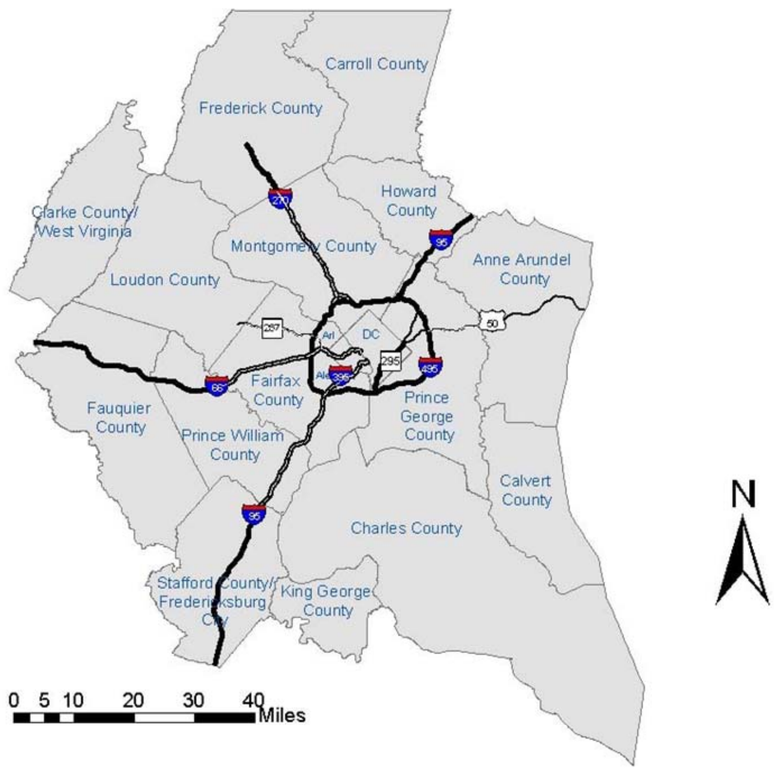
Urban Scenarios

Individual Preferences

Individuals in our model choose where to work and where and in what type of housing to live. In addition to the dollar benefits, each choice of work location and housing type has a relative inherent attractiveness associated with it. In our model the inherent attractiveness is characterized by a fixed parameter and is calibrated to match the observed data. With such characterization, it is relatively simple to consider a scenario where the relative attractiveness of the choices bundles changes in a way consistent with preferences to live in a denser area. More specifically, we consider a scenario where living inside the Beltway, the ring road freeway surrounding the District of Columbia (Interstate 495 and part of Interstate 95, shown in Figure 1), is considered 25 percent more attractive than it was before. Under this assumption our model predicts that 124,000 residents move to the area.

Figure 1. Metropolitan Washington, DC, with Zones Used in the Model

Zone Number	Description
1	DC Downtown
2	DC Northwest
3	DC Northeast
4	DC Southeast
5	Montgomery Co. Southwest
6	Montgomery Co. Southeast
7	Montgomery Co. West
8	Montgomery Co. East
9	Montgomery Co. Northeast
10	Prince George Co. Northwest
11	Prince George Co. Southwest
12	Prince George Co. Northeast
13	Prince George Co. Southeast
14	Frederick Co.
15	Carroll Co.
16	Howard Co.
17	Anne Arundel Co.
18	Calvert Co.
19	Charles Co.
20	Arlington East
21	Arlington South
22	Arlington West
23	Alexandria
24	Fairfax Co. East
25	Fairfax Co. Northeast
26	Fairfax Co. South
27	Fairfax Co. Northwest
28	Loudon Co. East
29	Loudon Co. West
30	Prince William Co. South
31	Prince William Co. North
32	Stafford/Fredericksburg Co. North
33	Fauquier Co.
34	Clarke Co.
35	Stafford/Fredericksburg Co. South
36	King George Co.
37	External Zone, South
38	External Zone Southwest
39	External Zone, Northwest
40	External Zone, East



Building Density

In our model, each residential building type (single family and multifamily) is associated with a structural density (square feet of floor space per acre). The structural density varies by zone to capture the fact that urban development in downtown Washington, DC, is denser than in the far suburbs of Frederick County, Maryland, for example. For this urban scenario, we consider that all residential urban development inside the Beltway is 20 percent denser and the increase in density comes only from additional SFA and MF5 housing units.

Road Capacity

Our model describes in a stylized but disaggregated manner the transportation network of metropolitan Washington. Capacities of arterial roads and freeways are determined by a nonlinear relationship between the speed and VMT on that road.[30] By scaling these relationships, it is possible to simulate changes in road capacity. Lower road capacity is consistent with denser urban area. On the other hand, a reduction in road capacity will increase congestion, ceteris paribus. And the converse is true for higher road capacity. In the model, an increase in congestion might have an ambiguous effect on residential pattern. In response to higher congestion costs, people can switch not only routes, time of travel, and mode, but also residence and work location. If this latter type of response is significant, lower road capacity could lead to a more dispersed city. To focus on this complicated series of effects, we model two scenarios. In the first one we increase the road capacity of the transportation network situated inside the Beltway by 25 percent. In the second simulation we consider a 25 percent decrease in road capacity.

Urban Policies

Live Near Your Work Program

In the Washington metropolitan area LNYW programs have already been established.[31] In this region and elsewhere, LNYW programs usually provide a closing-cost assistance grant to first-time homebuyers who choose a property within a certain distance from their work location. For our simulations, we modeled an LNYW program that provides a closing-cost assistance

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[30] In START this relationship is described by speed/flow●distance curves. See Houde et al. (2007).

[31] See Table A2 in the Appendix.

grant of $8,000, which is in the higher range of the existing programs.[32] To provide an illustrative example that fits the requirements of the model, we relax some of the eligibility criteria. For example, because the exact geographic locations of the buildings within the model's zones are not defined, it is not possible to consider eligibility criteria based on a specific distance from residence to workplace. For our simulation, we consider an LNYW program that provides a grant to the residents living and working inside the Beltway. Unlike existing programs, we assume that both residents meeting this location criterion prior to the start of the policy and the ones moving to meet the criteria receive the grant. Our version of LNYW is therefore more generous, but also more consistent with an economy in long-run equilibrium.[33]

Inclusionary Zoning Program

Montgomery County, Maryland, implemented the first IZ program in the United States in 1973. Since then, 135 cities and counties have adopted similar programs.[34] Different IZ programs are quite similar in their design. In a nutshell, they require any new development exceeding a certain threshold in the number of units to set aside affordable housing units. To make building affordable housing more attractive, a bonus density is assigned to the project.[35] This bonus allows developers to increase the density in excess of the existing zoning and land-use laws. Different criteria of eligibility exist. In addition to income, such factors as age, disabilities, place of work, and household size are also considered. Given that the supply of affordable housing units is most likely below the demand, the units are usually assigned by a lottery. Once occupied, the units have a control period during which the units cannot be sold or rented at the market rate.

[32] In our model, individuals make decisions based on their annual income, not permanent income. To be consistent with the model assumptions, the LNYW grants must then be converted into annual payments. For the conversion, we assume that the grant corresponds to the net present value of an ordinary annuity (i.e., an annuity payable at the end of each period) payable over 30 years at a 5 percent interest rate. Under these assumptions, the grant corresponds to an annual payment of approximately $520.

[33] Our version of the LNYW program is notably more generous because it is not restricted to first time homebuyers. This is due to the fact that homeownership is not modeled explicitly. Considering that residents meeting the location criterion before the start of the policy also benefit from the grant is consistent with our assumption that the prediction of the model is a long-run equilibrium. It implicitly assumes that the grant is capitalized in the value of the land/property and thus also accrued to these existing residents, not only the new ones. This is a realistic assumption since we have perfect competition, low elasticity for the supply of land, and a permanent policy.

[34] Smart Growth Network (1995).

[35] In practice, both mandatory and voluntary IZ programs are used.

To better understand the effects of IZ programs on energy use, we simulate such a program in a counterfactual way. In the present case, we create a counterfactual scenario of a world where an IZ program has been implemented over the entire area inside the Beltway for all past developments and has been fully successful. Therefore, under this scenario there is a stock of affordable housing units corresponding to the one specified by the program, and simultaneously the urban density over the county is increased by the full percentage corresponding to the bonus provided.[36] Appendix Table A3 provides more details about the assumptions of our simulated IZ program.

Vehicle Mile Traveled Tax

As our principal policy target is transportation, we simulate a tax of 10 cents per VMT in the metropolitan area.[37] The revenues collected are redistributed equally and as a single payment to all residents. The current gasoline tax, which is about 40 cents per gallon, is unaffected by this VMT tax. In LUSTRE this VMT tax is implemented as a change in the price of fuel. Since fuel economy depends on link speed, our tax, strictly speaking, is not a pure distance tax, but it is very close to one in its effects.

Discussion of Results

Based on the simulation results, we can draw important conclusions. First, except for the urban scenarios where road capacity is changed, all other scenarios induce energy savings and all policies improve economic welfare of the residents. Second, for all scenarios and policies, the overall changes in vehicular energy use are more significant than the changes in residential energy use. This is true both in absolute and in percentage terms. The total energy savings observed are primarily a consequence of a reduction of vehicle fuel consumption. Third, except for the VMT tax, the potential for energy savings of all scenarios and policies is low, under 1 percent. However, albeit overall changes in residential energy savings are small, in some cases it is not due to a lack of substitution between building types.

[36] In a sense, since we assume that the program is fully successful, the results represent an upper bound on the effectiveness of an IZ program.

[37] This VMT tax is set at the optimal level; it maximizes residents' welfare in terms of congestion reduction and redistribution of the tax revenues to the residents. It should be noted that the welfare function does not take into account the benefits of other outcomes, including the effect on energy conservation.

We refer readers to Tables 2 through 4 for more details. Table 2 presents the changes in residential and vehicular energy use for the different urban scenarios and policies. For the three policies, the welfare changes are also reported. Tables 3 and 4 separate vehicular energy use from residential energy use to show which sector is more responsive. In the rest of this section, we further investigate the source of these results for each scenario and policy.

Table 2: Welfare Gains and Energy Savings

	Overall Welfare Gains	**Annual Change in Residential Energy Use (End Use)**		**Annual Change in Vehicular Energy Use (gasoline converted to Btus)**		**Total Change in Energy Use**	
	Millions of Dollars	Billions of Btus	% Change	Billions of Btus	% Change	Billions of Btus	% Change
Urban Scenarios							
High Preferences to Live inside the Beltway	–	–115.7	–0.07	–1704.4	–0.78	–1820.1	–0.49
Increase in Residential Housing Density inside the Beltway	–	–194.1	–0.12	–618.1	–0.28	–812.2	–0.22
Increase in Road Capacity: 25 % Increase inside the Beltway	–	118.7	0.01	428.3	0.20	440.1	0.12
Decrease in Road Capacity: 25% Decrease inside the Beltway	–	–208.2	–0.01	–634.6	–0.29	–655.4	–0.18
Policies							
Live Near Your Work Program Enacted inside the Beltway	94	6.9	–0.004	–226.4	–0.10	–233.3	0.06
Inclusionary Zoning Program Enacted inside the Beltway	1051	9.5	–0.01	–737.4	–0.34	–746.9	0.20
VMT Tax 10¢/mile	305	133.7	–0.09	–35,139.7	–16.10	–35.273.4	10.39

Source: Authors' analysis.

Table 3: Annual Percentage Change in Vehicular Energy Use

	Daily Fuel Consumption (Gasoline)	Annual (250 days) Fuel Consumption (Gasoline)		Annual Change in Fuel Consumption		
	Millions of Gallons	Millions of Gallons	Billions of Btus (1 gallon = 126,000 Btus)	% Change	Annual Changes in Millions of Gallons	Annual Changes in Billions of Btus
Model Baseline	6.93	1,732	218,253	–	–	–
Urban Scenarios						
High Preferences to Live inside the Beltway	6.87	1,719	216,549	–0.78	–14	–1,704
Increase in Residential Housing Density inside the Beltway	6.91	1,727	217,635	–0.28	–5	–618
Increase in Road Capacity: 25% Increase inside the Beltway	6.94	1,736	218,682	0.20	3	428
Decrease in Road Capacity: 25% Decrease inside the Beltway	6.91	1,727	217,619	–0.29	–5	–634
Policies						
Live Near Your Work Program Implemented inside the Beltway	6.92	1,730	218,027	–0.10	–2	–226
Inclusionary Zoning Program Enacted inside the Beltway	6.91	1,726	217,516	–0.34	–6	–737
VMT tax 10¢/mile	5.81	1,453	183,114	–16.10	–279	–35,139

Source: Authors' analysis.

Table 4: Annual Change in Residential Energy Use per Housing Type

		Single-Family Detached	Single-Family Attached	Apartment in Multifamily Housing of 2–4 Units	Apartment in Multifamily Housing of 5 Units or More	All Types
Model Baseline	Billions of Btus	103,488	39,524	3007	10,638	156672
Urban Scenarios						
High Preferences to Live inside the Beltway in Multifamily Housing	% Change	–0.75	0.44	1.57	2.63	–0.17
Increase in Residential Housing Density inside the Beltway	% Change	–1.81	4.55	–4.27	0.62	–0.12
Increase in Road Capacity: 25% Increase inside the Beltway	% Change	–0.01	0.02	–0.004	0.004	0.01
Decrease in Road Capacity: 25% Decrease inside the Beltway	% Change	0.01	–0.03	0.01	–0.01	–0.01
Policies						
Live Near Your Work Program Implemented inside the Beltway	% Change	–0.06	0.14	–0.01	0.04	–0.004
Inclusionary Zoning Program Enacted inside the Beltway	% Change	–1.83	5.00	–5.02	–0.08	–0.01
VMT tax 10¢/mile	% Change	–0.11	0.30	–0.27	–0.01	–0.09

Source: Authors' analysis.

Table 5: Change in Population

		Area	
		Inside the Beltway	**Outside the Beltway**
Model Baseline	Number of Residents	1,164,632	2,974,502
Urban Scenarios			
High Preferences to Live inside the Beltway	% Change	10.69	–4.19
Increase in Residential Housing Density inside the Beltway		4.22	–1.65
Increase in Road Capacity: 25% Increase inside the Beltway		0.10	–0.04
Decrease in Road Capacity: 25% Decrease inside the Beltway		–0.18	0.07
Policies			
Live Near Your Work Program Implemented inside the Beltway	% Change	0.79	–0.31
Inclusionary Zoning Program Enacted inside the Beltway		5.62	–2.20
VMT tax 10¢/mile		0.66	-0.26

Source: Authors' analysis.

High Preferences to Live inside the Beltway Area

As noted earlier, the exogenous increase in the inherent attractiveness to live inside the Beltway induces 124,000 individuals to move to the area. This corresponds to approximately a 10 percent increase in the population. On the other hand, the population living in the periphery outside the Beltway decreases by more than 4 percent (Table 5). This scenario thus significantly increases the density of the population distribution in the Washington metropolitan area.

Under this scenario, there are few individuals who substitute from single-family to multifamily housing. On the other hand, residents moving inside the Beltway are now more likely to live in SFA rather than SFD housing. Similarly, individuals choosing to live in multifamily housing who move inside the Beltway are now more likely to be in an MF5 than an MF24 apartment.[38] The reduction in residential energy use comes from the latter substitution. Even though residential energy use increases by 1.92 percent and 0.62 percent, respectively, in SFA and MF5 units, the reductions of 0.88 percent and 0.47 percent in SFD and MF24 units, correspondingly, lead to an overall decrease (Table 3).

On the transportation side, the movement of the population affects VMT (Table 6), mode choice, and congestion. People living inside the Beltway have better access to public transit and thus make a greater use of it (Table 7). They also have shorter travel distances for both commuting and shopping trips, which decrease the average trip distance (Table 8). On the other hand, the significant increase in population contributes to congestion of the road and transit networks. The increase in congestion can be seen from the lower average speeds of travel on the roads. For the present scenario, it decreases inside the Beltway by 0.67 percent (Table 2). Changes in speeds also affect vehicle fuel consumption rates, but unlike VMT, the relationship is not straightforward.[39]

Increase of Residential Housing Density inside the Beltway Area

Under this scenario, we have simulated a 20 percent increase in the density of the urban development inside the Beltway and further stipulated that the increase was from additional SFA and MF5 housing units only. This simulation is equivalent to an increase of 20 percent in the supply of such units. We first observe that this increase in supply lowers the market rents in the area. As result, they attract a number of individuals to live there. Around 49,000 individuals move, which corresponds to a 4.22 percent population increase inside the Beltway and a 1.65 percent population decrease outside the Beltway (Table 5). Compared with the previous scenario, fewer individuals move, but there is a greater decrease in residential energy use (Table 4). This is due to the fact the increase in housing density comes from only new SFA and MF5 units, which are associated with lower energy use.

[38] As described in the Appendix, Section A2, the disaggregation of the population distribution from single-family housing into SFA and SFD categories and from multifamily housing into MF24 and MF5 is based on exogenous coefficients, which are indexed by zones. Table A1 shows that in the central zones, the proportion of SFA relative to SFD is higher. The same is true for MF5 relative to MF24.

[39] In our model, the relationship between speed and fuel consumption is a characterized by a fourth-degree polynomial.

Even if the movement in population has a similar pattern to the preceding scenario, the nature of the transportation effects are different. The reduction in VMT is basically nil (Table 6). The reduction in average trip distance is noticeable (Table 8). Unlike the preceding scenario, the movement of population inside the Beltway does not induce congestion; in the present scenario, average speeds on the roads inside and outside the Beltway increase (Table 8). Transit usage increases, but so do the number of car trips (Table 8). In sum, on average trips are shorter, faster, and more likely to be done by transit. However, the overall number of trips increases, explaining why the VMT remains almost unchanged.

Table 6: Daily Changes in Vehicle Miles Traveled (VMT)

	Daily VMT (Thousands of Vehicle Miles)	**Daily Change in VMT**	
		Thousands of Vehicle Miles	% Change
Model Baseline	172,461	–	–
Urban Scenarios			
High Preferences to Live inside the Beltway	171,620	–841	–0.49
Increase in Residential Housing Density inside the Beltway	172,390	–71	–0.04
Increase in Road Capacity: 25 percent Increase inside the Beltway	173,175	713	0.41
Decrease in Road Capacity: 25 Percent Decrease inside the Beltway	172,002	–459	–0.27
Policies			
Live Near Your Work Program Implemented inside the Beltway	172,594	132	0.08
Inclusionary Zoning Program Enacted inside the Beltway	172,297	–163	–0.09
VMT tax 10¢/mile	147,430	–25,031	–14.51

Source: Authors' analysis.

Table 7: Changes in Travel Mode

		Modes				
		Single-Occupancy Vehicle	**High-Occupancy Vehicle**	**Bus**	**Train**	**Walking/ Biking**
LUSTRE Baseline	Trips/Day	11,705,440	10,092,421	515,198	646,105	1,689,457
Urban Scenarios						
High Preferences to Live inside the Beltway	% Change	–0.21	0.25	2.70	3.55	3.65
Increase in Residential Housing Density inside the Beltway	% Change	0.043	0.79	3.52	4.96	1.99
Increase in Road Capacity: 25 percent Increase inside the Beltway	% Change	0.23	0.036	–0.19	–2.17	–0.62
Decrease in Road Capacity: 25 Percent Decrease inside the Beltway	% Change	–0.39	–0.087	0.48	3.70	1.11
Policies						
Live Near Your Work Program Implemented inside the Beltway	% Change	0.024	0.14	0.85	1.19	0.72
Inclusionary Zoning Program Enacted inside the Beltway	% Change	–0.024	0.66	3.46	4.69	2.13
VMT tax 10¢/mile	% Change	–17.80	16.41	16.41	20.21	21.71

Source: Authors' analysis.

Table 8: Changes in Average Trip Distance and Average Speed of Travel over the Road Network

		Average Trip Distance (Car Only)			Average Speed (Car Only)		
		Road Network inside the Beltway	Road Network outside the Beltway	All Road Networks	Road Network inside the Beltway	Road Network outside the Beltway	All Road Networks
LUSTRE Baseline		7.92 miles	12.27 miles	11.02 miles	42.49 m/h	45.84 m/h	44.98 m/h
Urban Scenarios							
High Preferences to Live inside the Beltway	% Change	–0.16	–0.01	–0.65	–0.67	0.28	–0.01
Increase in Residential Housing Density inside the Beltway	% Change	–0.18	–0.29	–0.42	0.26	0.37	0.33
Increase in Road Capacity: 25 percent Increase inside the Beltway	% Change	0.05	–0.03	0.001	1.37	–0.07	0.27
Decrease in Road Capacity: 25 Percent Decrease inside the Beltway	% Change	–0.08	0.06	0.003	–2.04	0.17	–0.34
Policies							
Live Near Your Work Program Implemented inside the Beltway	% Change	–0.03	–0.25	–0.13	–0.04	0.09	0.05
Inclusionary Zoning Program Carried out inside the Beltway	% Change	–0.14	–0.18	–0.40	0.14	0.32	0.26
VMT tax 10¢/mile	% Change	–2.11	–2.42	–2.30	0.56	0.80	0.71

Source: Authors' analysis.

Changes in Road Capacity

As mentioned above in "Details of Energy Modeling," lower road capacity is associated with denser urban development, but also with congestion, which could have the perverse effect of leading to a more dispersed urban landscape. For example, in our scenarios, a 25 percent decrease in the road capacity inside the Beltway induces individuals and firms to relocate to the peripheral zones. The effect is, however, small: only 2,000 individuals move (Table 5), and the increases in production in the different zones and economic sectors never exceed 0.15 percent. For an increase in road capacity, the nature of the effects is the same, but of the opposite sign. Furthermore, the movement is even smaller: 1,200 individuals move inside the Beltway and there is a slight bias toward single-family housing (Table 5). For these two scenarios, theses small changes in population distribution have few effects on residential energy use.

The transportation effects are, however, more important. Interestingly, even though higher road capacity decreases congestion (Table 8), overall it leads to higher VMT (Table 6). Part of the reason is that travelers abandon public transit and opt for cars as a means of transportation (Table 7). Therefore, car fuel consumption increases. Given the small changes in residential energy use, this scenario leads to higher energy consumption. The opposite is true for a reduction in road capacity.

Live Near Your Work Program inside the Beltway

Under a Beltway-wide LNYW program, 9,250 individuals decide to move from outside to inside the Beltway (Table 5). Furthermore, economic activity is relocated, to a certain extent, to this area. This displacement has two causes. First, there is the movement of the population. Second, the additional income from the LNYW grant is spent primarily at shopping destinations inside the Beltway. As result, the Beltway LNYW program not only induces the workforce to move, but also leads to relocation of the firms that benefit from both the increase in the labor supply and demand for goods and services in the area. Although people move inside the Beltway, the magnitude of the change is too small to significantly affect residential energy use.

The policy leads to an overall increase in VMT of 0.08 percent. It is particularly interesting to note that under the Beltway LNYW program the influx of population inside the Beltway does not reduce VMT. Overall the average speed slightly increases (Table 8), which is the only cause for the small reduction in vehicle fuel consumption (Table 3). This policy is still successful in achieving what it has been primarily designed for: reducing commuting distance. For commuting trips only, we observe a reduction of 0.21 percent in the average trip distance, which results in a reduction of 0.44 percent in VMT. It is the increase in consumption inside the

Beltway, fueled by the LNYW grant, that has the unintended consequence of more shopping trips (and more trips overall; Table 7) and thus mitigated the decrease in the overall VMT achieved by commuters. Therefore, this policy also has a small effect on vehicle energy consumption.

Inclusionary Zoning Program Enacted inside the Beltway

The IZ program has an important effect on the population distribution. More than 65,000 individuals move inside the Beltway; this is around 15,000 more than under the urban scenario where only the housing density increases by 20 percent. The requirement for affordable housing is therefore an effective way to attract new residents. Interestingly, the overall change in residential energy use under the IZ is smaller than under the urban scenario with higher density. The reason for such a result is that the IZ program creates a greater incentive to move to an SFA rather than an MF5. Our assumptions regarding the design of the policy are an important factor. A higher average rent or lower set-aside requirement for the affordable single-family housing units could lead to different results. The present policy has been modeled in accordance with existing IZ programs, but the results are sensitive to the details of program rules.

If the movement in population has little effect on the overall residential energy use, it is not true on the transportation side. VMT decreases by 0.09 percent partly as a result of shorter average trip distance (Table 8). Coupled with the substitution in mode choices toward public transit (Table 7), it is enough to relieve congestion, as shown by the higher average speeds of travel (Table 8).

Vehicle Miles Traveled Tax

The VMT tax is the policy that achieves the largest reduction in energy use. As expected, the bulk of the reduction comes from transportation, but interestingly, the VMT tax is effective at reducing residential energy use. For example, it does better than the infill policies.

The VMT tax also induces individuals to move to the center of the region. Almost 11,000 people move inside the Beltway. The increase is particularly concentrated in the District of Columbia and Arlington County. These are the two places where the share of SFDs relative to SFAs and the ratio of MF5s relative to MF24s are the highest over all the study area. It explains why the decrease in residential energy use in those areas is significant. The VMT tax and the substantial decrease of travel that it induces are an effective way to increase urban density.

On the transportation side, the decrease in fuel use is drastic. This is due to the important decrease in VMT, which has three causes. First, as people move to the center of the economic activity, the average trip distance to work and shopping locations is consequently reduced (Table 8). Second, there is an important switch to public transit and nonmotorized modes of travel (Table 7). Both of these effects contribute to congestion relief (Table 8). The third and more subtle cause of VMT reduction comes from the fact that the VMT tax causes some people to stop working and, therefore, to stop commuting. The model assumes that the vast amount of revenue collected from the VMT tax—nearly $1.18 billion per year—is distributed equally among all residents of the metropolitan area. Some workers facing high commuting costs and simultaneously receiving a generous tax rebate would simply prefer not to work because their commuting costs are so high and because the tax rebate is large enough to enable them to afford not to work. This is particularly true for low-income individuals for whom commuting costs represent a larger share of their budget and to whom the tax rebate is more valuable.[40]

Other Potential Urban Policies

The list of policies that could affect energy use in urban areas is very long. Here we do not intend to cover a comprehensive list of policies, but will try to discuss three large groups of potentially relevant ones.

Congestion Pricing

A set of policies that is likely to affect the urban energy footprint are various transportation policies that are often called congestion pricing policies. Although particular policy schemes may significantly vary, the best-known real-world example of such policies is the London Area Pricing Scheme that was first implemented in 2003, considered a success, and since then has doubled its charge area.[41] Although congestion pricing is still facing significant opposition, pricing experiments are planned or underway in many U.S. metropolitan areas.

Our previous research has shown that congestion pricing schemes promise to reduce road congestion and improve the well-being of urban travelers. At the same time, those policies are likely to have much less impact on energy consumption. In another study, we analyzed five

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[40] The assumption of lump sum distribution, i.e., that the tax rebate is distributed equally to all residents, is highly unrealistic. It is more likely that the funds will be given over to reductions of existing taxes, new public works spending, or some combination of the two. For example, some of those who now support taxing automobile use, especially those in the environmental community, condition their support on the use of a substantial portion of the revenues for investment in transit. Others try to earmark the funds for new road construction.

[41] The City of New York proposed a similar scheme in 2007 and received federal funding for this project.

distinct congestion-pricing schemes with the same level of VMT tax as the one used in this paper. In particular, we modeled a comprehensive toll (congestion pricing on all roads), a freeway toll (the same as comprehensive, but with pricing only on highways), and three different cordon-type pricing schemes (where entering a particular area of the city incurs a toll) covering central parts of urban areas (Table 9). It should be noted that these modeled policies are more extensive than any such policies currently in place anywhere in the United States and thus provide a fair indicator of the potential for such policies to achieve both congestion reductions and welfare gains. We found that, although a comprehensive toll yielded the highest welfare gains ($660 million annually), it turned out to be less effective at reducing total VMT in the urban area than the VMT tax (7.1 percent versus 14.6 percent). At the same time, from Table 2 and Table 3 we know that the VMT tax policy appears to be effective primarily because it succeeds at significantly reducing the VMT. To the extent that other transportation policies are less effective at reducing VMT, they will yield only a fraction of reduction in energy use. The same logic will apply to policies, including the VMT tax, imposed at levels much lower than the optimal. For example, it should not be surprising that a VMT tax of 1 cent per mile would reduce total VMT and therefore energy consumption by only a fraction of the amount that a 10-cent VMT tax would.

Table 9. Six Second-best Transportation Policies: Optimum Fees and Effects on Vehicle Miles Traveled (VMT)

Policy	Percent of VMT Affected	Toll Rates, Where Charged	Average Cost/ VMT (¢/mi)	Total Estimated VMT	
				(Millions/Day)	% Change
Base Case				172.7	
VMT Tax	100%	10¢/mile	7.9	147.4	–14.6
Comprehensive Toll	100%	Variable	3.3	160.5	–7.1
Freeway Toll	26%	Variable	0.7	169.0	–2.1
Double Cordon	7%[a]	Downtown : $2.18 Beltway: $3.43	0.4	170.5	–1.3
Beltway Cordon	7%[a]	Beltway $2.77	0.3	171.1	–0.9
Downtown Cordon	1.1%[a]	Downtown $4.70	0.2	171.3	–0.8

[a]Percent of trips, not VMT.

Source: Harrington et al.[42]

Nonurban Policies

Many of policies that could affect urban structure, perhaps most, are not designed to do so, but they could have unintended consequences. This would very likely be true of most federal policies, which may be concerned with energy use at the national level but not at the local level. Consider, for example two prominent federal policies, the Corporate Average Fuel Economy (CAFE) Standards and the home mortgage interest deduction. CAFE standards may reduce fuel

42 Harrington et al (2007).

use in vehicles by improving fuel economy, but they also reduce the fuel costs of driving, potentially increasing demand.

Experiments with CAFE in our model showed that this so-called rebound effect will increase vehicle use by about 8 percent and presumably accidents and traffic congestion as well.[43] The mortgage interest deduction has not been modeled by us, but it is possible that its effects would be important. By reducing the cost of housing, this tax break encourages consumers to build larger houses on larger lots, increasing the demand for both local travel and space heating/cooling.

Local Policies

Many local policies also have the potential to affect energy use, of which we mention two. One is increased transit use. We have used our model to estimate the benefits of the local transit system in Washington. We find that its benefits are very large.[44] However, we have not looked in any detail at the question of whether enhanced transit can reduce energy use in the metropolitan area. We think it is unlikely, mainly because even with very vigorous policies to encourage transit use, the overwhelming majority of trips in the metropolitan area will continue to be made by car. Transit is very effective for certain kinds of trips, in particular rush-hour trips into downtown Washington and Northern Virginia. For trips to other locations and at other times, its mode share is very low. Nonetheless, transit provides valuable services at all times to the poor and disabled.

We also should mention transit-oriented development (TOD), a collection of policies to encourage economic development around rail transit stations. Locating housing and employment development within walking distance of transit stations will, according to the theory, reduce the demand for work trips and perhaps other types of trips as well, to the extent that such centers become magnets for other types of development. Unfortunately, our model's ability to analyze TOD is limited by the necessarily small number and large size of the spatial areas in the model. TOD is a policy that is focused on a small geographic area; in fact, the limit that people can be reliably induced to walk is between a quarter and a half mile. Because our model divides the Washington metropolitan area into fairly large geographic zones, we cannot model this policy effectively. On the other hand, we are skeptical about TOD's potential to significantly reduce

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[43] Parry et al. (forthcoming).

[44] Nelson et al. (2007).

energy consumption. The small size of the zones could put a limit on the overall scale of TOD, regardless of how successful it is in individual applications. After all, the number of transit stops, an essential ingredient to a TOD policy, is limited.

Concluding Remarks

In this paper we have simulated several urban scenarios and policies with the purpose of analyzing their comparative impact on energy consumption. Important novel features of the analysis include the interaction between land-use and transportation decisions built into our framework and an inclusion of both transportation-related and building heating/cooling–related effects. We find that a VMT tax of 10 cents per mile has a potential to substantially reduce energy consumption while all other policies, as well as the hypothetical scenarios, are likely to be much less effective. But even if the effects of the VMT tax are larger than the other policies examined, at a 10 percent reduction they are still modest, especially when compared to the scale of the intervention. After all, a tax of 10 cents for each mile traveled is a very large tax. The low sensitivity of travel to the costs of trips suggests that policies to reduce fuel use directly might be more promising approaches.

Trying to devise urban policies to reduce energy consumption is a dubious enterprise for another reason. As noted in the introduction, the two main reasons to be concerned about fuel consumption are global climate change and energy security. If there are any benefits from urban policy to reduce energy use, they will be enjoyed nationally, if not globally. The urban area implementing the policy cannot capture its benefits. If urban policy adopted for other reasons incidentally reduces energy consumption, that is all well and good. But policies with the main goal of reducing energy consumption should be national, not local. Localities, on the other hand, would do much better for themselves if they design urban policies to correct local externalities—congestion, local air pollution, provision of public open space—and leave the energy policy to federal and international entities.

References

Anas, A., and R. Xu. 1999. Congestion, Land Use and Job Dispersion: A General Equilibrium Model. *Journal of Urban Economics* 45: 451–73.

Anderson, W.P., P.S. Kanaroglou, and E.J. Miller. 1996. Urban Form, Energy and the Environment: A Review of Issues, Evidence, and Policy. *Urban Studies* 33(1): 7–35.

Badoe, D., and E.J. Miller. 2000. Transportation–Land Use Interaction: Empirical Findings in North America, and Their Implications for Modeling. *Transportation Research D* 5(4): 235–63.

Bento, A.M., M.L. Cropper, A.M. Mobarak, and K. Vinha. 2005. The Effects of Urban Spatial Structure on Travel Demand in the United States. *The Review of Economics and Statistics* 87(3): 466–78.

Boarnet, M., and R. Crane. 2001. The Influence of Land Use on Travel Behavior: Specification and Estimation Strategies. *Transportation Research A* 35: 823–845.

Boarnet, M.G., and S. Sarmiento. 1998. Can Land Use Policy Really Affect Travel Behavior? A Study of the Link between Non-work Travel and Land Use Characteristics. *Urban Studies* 35(7): 1155–1169.

Carrol, T.O. 1977. Calculating Community Energy Demand. In *Energy and the Community*, edited by R.J. Burby and A. Flemming Bell. Cambridge, MA: Ballinger.

Cervero, R., and K.-L Wu. 1997. Polycentrism, Commuting, and Residential Location in the San Francisco Bay Area. *Environment and Planning A* 29: 865–886.

———. 1998. Sub-centring and Commuting: Evidence from the San Francisco Bay Area, 1980–1990. *Urban Studies* 35: 1059–1076.

Council on Environmental Quality. 1975. The Costs of Sprawl on the USA. *Ekistics* 329: 266–72.

Crane, R. 2000. The Influence of Urban Form on Travel: An Interpretive Review. *Journal of Planning Literature* 15: 3–23.

Crane, R., and R. Crepeau. 1998. Does Neighborhood Design Influence Travel? A Behavioral Analysis of Travel Diary and GIS Data. *Transportation Research D* 3: 225–238.

Dieleman, F.M., M. Dijst, and G. Burghouwt. 2002. Urban Form and Travel Behavior: Micro-level Household Attributes and Residential Context. *Urban Studies* 39(3): 507–27.

Edwards, J.L. 1977. The Effect of Land Use on Transportation Energy Consumption. In *Energy and the Community*, edited by R.J. Burby and A. Flemming Bell. Cambridge, MA: Ballinger.

Energy Information Administration. 2001. *A Look at Residential Energy Consumption in 2001*. U.S. Department of Energy: Energy Information Administration.

Ewing, R., and R. Cervero. 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record* 1780: 87–114.

Gately, D., and H. Huntington. 2001. The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand. *Economic Research Reports 2001–01*. Chauncey V. Starr Center for Applied Economics, New York University.

Golob, T.F., and D. Brownstone. 2005. The Impact of Residential Density on Vehicle Usage and Energy Consumption. Working Paper 011. University of California Energy Institute.

Gomez-Ibañez, J.A. 1991. A Global View of Automobile Dependence: Review of *Cities and Automobile Dependence: An International Sourcebook*, by P.W.G. Newman and J.R. Kenworthy. *Journal of the American Planning Association* 57: 376–379.

Gordon, P., A. Kumar, and W.H. Richardson. 1989. Congestion, Changing Metropolitan Structure and City Size in the United States. *International Regional Science Review* 12: 45–56.

Gordon, P. and H. Richardson. 1997. Are Compact Cities a Desirable Planning Goal? *Journal of the American Planning Association* 63(1): 95-106

Handy, S.L. 1996. Methodologies for Exploring the Link between Urban Form and Travel Behavior. *Transportation Research D 1(2)*: 151–165.

Harrington, Winston, Sébastien Houde, and Elena Safirova. 2007. A Simulation of the Effects of Transportation Demand Management Policies on Motor Vehicle Emissions. Accepted for publication in Proceedings of the Transportation, Land Use Planning and Air Quality conference to be published by the American Society of Civil Engineers.

Holden, E., and I. Norland. 2005. Three Challenges for the Compact City as a Sustainable Urban Form: Household Consumption of Energy and Transport in Eight Residential Areas in the Greater Oslo Region. *Urban Studies* 42(12): 2145–2166.

Houde, S., E.Safirova, and W. Harrington. 2007. Washington START Transportation Model: Description and Documentation. Discussion paper 07-43. Washington, DC: Resources for the Future.

Hui, S.C.M. 2001. Low Energy Building Design in High Density Urban Cities. *Renewable Energy* 24: 627–240.

Kenworthy, J.R., and P.W.G. Newman. 1990. Cities and Transport Energy: Lessons from a Global Survey. *Ekistics* 34(4/5): 258–68.

Keyes, D.L. 1977. Land Use and Energy Conservation: Is There a Link to Exploit? In *Energy and the Community*, edited by R.J. Burby and A. Flemming Bell. Cambridge, MA: Ballinger.

Larivière, I., and G. Lafrance. 1999. Modeling the Electricity Consumption of Cities: Effect of Urban Density. *Energy Economics* 21: 53–66.

Levinson, D.M., and A. Kumar. 1997. Density and the Journey to Work. *Growth and Change* 28(2): 147–72.

Levinson, D.M. 1998. Accessibility and the Journey to Work. *Journal of Transport Geography* 6: 11–21.

May, A.D., M. Roberts, and P. Mason. 1992. The Development of Transport Strategies for Edinburgh. *Proceedings of the Institution of Civil Engineers: Transportation* 95: 51–59.

Mindali, O., A. Raveh, and I. Salomon. 2004. Urban Density and Energy Consumption: A New Look at Old Statistics. *Transportation Research A* 38: 143–162.

Modarres, A. 2003. Polycentricity and Transit Service. *Transportation Research A* 37: 841–864.

Nelson, Peter, A. Baglino, W. Harrington, E. Safirova, and D. Abram Lipman. 2007. Transit in Washington DC: Current Benefits and Optimal Level of Provision. *Journal of Urban Economics* 62(2): 231–51.

Newman, P., and J. Kenworthy. 1989. Gasoline Consumption and Cities: A Comparison of US Cities with a Global Survey. *Journal of the American Planning Association* 55: 24–37.

———. 1999. *The Costs of Automobile Dependence: A Global Survey of Cities.* Washington: Transportation Research Board.

Oak Ridge National Laboratory. 2007. Transportation Energy Data Book 2007. http://cta.ornl.gov/data/index.shtml (accessed November 16, 2007).

Parry, I., C. Fischer, and W. Harrington. Forthcoming. Do Market Failures Justify Tightening Corporate Average Fuel Economy (CAFE) Standards? *Energy Journal*.

Roberts, J.S. 1977. Energy Conservation and Land Use: Prospects and Procedures. In *Energy and the Community*, edited by R.J. Burby and A. Flemming Bell. Cambridge, MA: Ballinger.

Safirova, E., K. Gillingham, W. Harrington, P. Nelson, and D. Lipman. 2005. Choosing Congestion Pricing Policy: Cordon Tolls vs. Link-Based Tolls. *Transportation Research Record* 1932: 169–77.

Safirova, E., K. Gillingham, and S. Houde. 2007. Measuring Marginal Congestion Costs of Urban Transportation: Do Networks Matter? *Transportation Research A* 41(8): 734–49.

Safirova, E., W. Harrington, P. Nelson, I.W. Parry, K. Gillingham, and D. Mason. 2004. Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, DC. In *Road Pricing: Theory and Evidence*, edited by G. Santos. Amsterdam: Elsevier Science, 179–206.

Safirova, E., S. Houde, D. Lipman, W. Harrington, and A. Baglino. 2006a. Congestion Pricing: Long-Term Economic and Land Use Effects. Discussion paper 06-37. Washington, DC: Resources for the Future.

Safirova, E., S. Houde, C. Coleman, W. Harrington, and D. Lipman. 2006b. A Small Cordon in the Hand is Worth Two in the Bush: Long-Term Consequences of Road Pricing. Discussion paper 06-42. Washington, DC: Resources for the Future.

Schwanen, T., F.M. Dieleman, and M. Dijst. 2001. The Impact of Metropolitan Structure on Commute Behavior in the Netherlands: A Multilevel Approach. *Growth and Change* 35: 304–333.

Smart Growth Network. 1995. *Getting to Smart Growth: 100 Policies for Implementation.* International City/County Management Association (http://www.smartgrowth.org/pdf/gettosg.pdf).

Stead, D., J. Williams, and H. Titheridge. 2000. Land Use, Transport and People: Identifying the Connections. In *Achieving Sustainable Urban Form*, edited by K. Williams, E. Burton, and M. Jenks. London: E& FN Spon, 174–186.

Steadman, J.P. 1979. Energy and Patterns of Land Use. In *Energy Conservation through Building Design*, edited by D. Watson. New York: McGraw-Hill, 246–260.

Steemers, K. 2003. Energy and the City: Density, Buildings and Transport. *Energy and Buildings* 35: 3–14.

Steiner, R. 1994. Residential Density and Travel Patterns: Review of the Literature. *Transportation Research Record* 1466: 37–43.

Train, K. 1980. A Structured Logit Model of Auto Ownership and Mode Choice. *Review of Economic Studies* 47(2): 357–370.

U.S. EPA (Environmental Protection Agency). 2001. *Our Built and Natural Environments: A Technical Review of the Interactions Between Land Use, Transportation and Environmental Quality*. U.S. EPA (www.epa.gov); available at www.smartgrowth.org/library/built.html.

Appendix

A1. Model Description

Our model, called LUSTRE, combines two preexisting models: the Regional Economy and Land Use (RELU) model and the Strategic and Regional Transport (START) modeling suite. The RELU model was developed by Alex Anas and Elena Safirova with the purpose of creating a theoretically sound modeling tool for the analysis of interactions between transportation, land use, and economic activity. The model is meant to be integrated with a detailed transportation model. The START modeling suite was developed by MVA Consultancy.[45] More recently, the START model was calibrated for the Washington, DC, metropolitan area (referred to as Washington START) and was used to conduct a wide range of policy simulations. LUSTRE is calibrated for the Washington, DC, metropolitan region of for the year 2000; the transportation network and characteristics of the economy both are specific to this region.

RELU Description

RELU is a spatially disaggregated static computable general equilibrium model that represents the long-term economic equilibrium in a regional economy. For this paper, the spatial representation corresponds to the Washington, DC, metropolitan area divided in 36 economic zones, plus four outer zones that act as sinks, that is, they attract economic activity but are not equilibrated together with the model zones. RELU follows the structure of Anas and Xu (1999) in its modeling philosophy, although several new features have been added.[46] For an exposition of the model in greater details, we refer the reader to Safirova and her colleagues (2006a).[47] The following description presents the salient features of the model.

RELU has seven types of economic agents that are explicitly represented. There are four types of individuals that correspond to a given skill level. These individuals are the consumers and the workforce in the regional economy; their total number is held fixed across simulations. The three other agent types are producers, landlords, and developers. Although the government is not explicitly modeled, income and property taxes are present.

[45] May et al. (1992).

[46] Anas and Xu (1999).

[47] Safirova et al. (2006a).

Individuals maximize their utility based on a series of discrete and continuous choices. After deciding whether to work or to be unemployed, individuals choose a triple corresponding to their residence, workplace, and type of housing. Conditional on these discrete choices, individuals decide how much housing to rent and how much retail goods and services to purchase at each available retail location. The costs of traveling to a given work or shopping destination are taken into account. Leisure is not represented in the model; aggregate labor supply is elastic because of voluntary unemployment and the variation in time spent traveling to shop.

The production sector consists of four basic industries: agriculture, manufacturing, business services, and retail; construction/demolition industries are represented as well. The producers are perfectly competitive profit-maximizing agents, with a Cobb–Douglas production function between four groups of inputs: labor, capital, buildings, and intermediate inputs. At the same time, within input groups, substitution is characterized by a constant elasticity of substitution function. All primary industries, except retail, provide intermediate inputs to other sectors. Retail output is consumed by individuals only or exported out of the economic region. Prices of intermediate inputs include freight costs; hence, firm reallocation is affected by the costs of shipping goods.

Landlords manage floor space in a profit-maximizing way in a perfectly competitive market. Rents and operating costs are taken as given. Landlords decide whether to offer a unit amount of floor space on the rental market. Floor space in buildings is disaggregated into four types: single-family housing, multifamily housing, commercial, and industrial.

Developers, like landlords, are profit-maximizing agents. They determine how much vacant land should be converted into buildings or vice versa. Construction and demolition prices and other costs are taken as given. Potential rents for the building also affect developers' decisions. Each individual owns a certain share of the real estate.

Washington START Description

START contains two submodels referred to as the supply-side and the demand-side. The supply-side consists of the transportation network disaggregated into 40 travel zones (START's travel zones correspond to RELU's 36 + 4 economic zones). Each zone has three stylized transportation links (inbound, outbound, and circumferential) and a number of other "special" links that represent the principal highway segments and bridges of the region. The traffic quality for each link is characterized by a speed-flow curve. The rail network of the region combines the Washington Metrorail system and suburban heavy rail systems (the Maryland Rail Commuter and the Virginia Railway Express). The three rail systems are modeled. A highly stylized route network represents bus travel, with bus accessibility in any zone determined by the density of stops, frequency of service, and reported bus travel times. Transit crowding costs and parking search costs are explicitly included in the model. The model also accounts for existing high-occupancy vehicle lanes. The supply-side computes the generalized cost of travel taking into account the time and monetary elements of traveling. Time components include the time spent traveling, transit waiting time, parking search time, and transit crowding penalties. Monetary components include car operating costs, car depreciation costs, parking fares, tolls, and transit fares. The value of time is a function of the travelers' wage rate and varies by trip purpose.

The demand-side is a strategic model centered on nested logit models. In START, trip purposes and origins are taken as given. Agents choose whether to generate a trip, destination, mode, time of day, and route (in LUSTRE, trip generation and destination are delegated to RELU). Nest order may be interchanged for different purposes. The model distinguishes four travel modes: single-occupancy vehicle, high-occupancy vehicle, transit (which has two submodes: bus and rail), and nonmotorized (walk and bike). It also represents three time periods: morning peak, afternoon peak, and off-peak. Travelers maximize their utility of travel based on a generalized cost of travel that combines time and money costs explicitly modeled in the supply module, as well as idiosyncratic preferences.

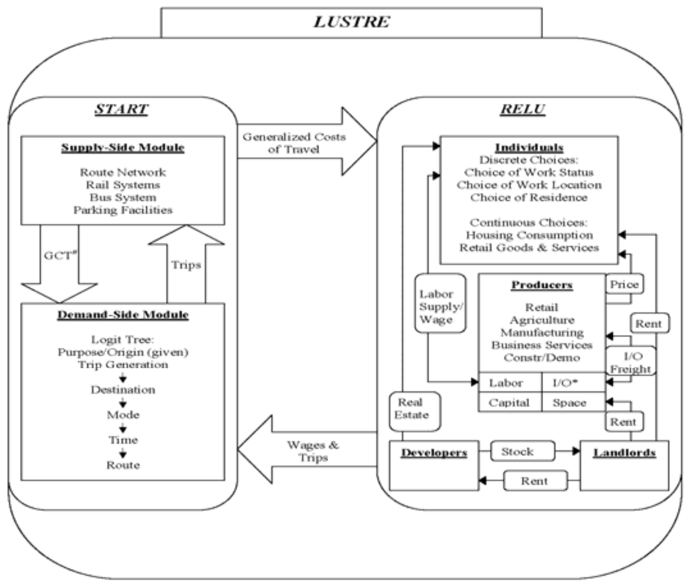
The overall structure of START is iterative. The trips computed in the demand-side are loaded into the supply-side network. The supply-side uses the loads to compute costs of travel, which are passed back to the demand module. This process iterates until the costs of travel converge to equilibrium values.

Model Integration

Figure A1 summarizes RELU and START and the integration procedure. First, RELU takes the time and monetary costs of travel as given. The RELU simulation yields (in addition to other land-use and economic effects) trip demands, disaggregated by purpose, origin/destination pairs, and wage rates. Trips are loaded into START, and RELU-determined wage rates translate into value of time for START. Thereafter, START computes the generalized costs of travel. Any transportation policies are taken into account in this step. Computed generalized costs are sent back to RELU. This iterative process between the two models continues until trip demands and costs converge.

Although the LUSTRE model has an intrinsically dynamic structure, in its present stage of development we exercise the model in its long-term equilibrium version. Therefore, when policy simulations are performed, we obtain results that correspond to changes in the long-term equilibrium of the urban area.

Figure A1. Flow Diagram of LUSTRE



#Generalized Costs of Travel

*Intermediate demand for finished goods and services, also referred as Input/Output (I/O) tables.

Welfare Measure

The strength of LUSTRE resides in its ability to compute welfare measures that account for the changes in transportation as economic variables. LUSTRE's welfare measures are provided by RELU based on utility function for individuals. We posit that the utility function of consumers is Cobb–Douglas between housing and aggregate consumption, while the subutility of all retail goods is a constant elasticity substitution function. Wages and prices of retail goods are net of travel costs. Individuals' utility is conditional to their discrete choice regarding their place of work, residence, and housing type. Each discrete choice bundle has an inherent attractiveness associated with it. Finally, individuals have idiosyncratic utility, which differs by consumers. Assuming that the various utilities are i.i.d. Gumbel with dispersion probability λ , this gives rise to a multinomial logit choice probability. The welfare measure for workers of skill class *f* in the model can then be expressed as a logsum:

$$W_f = \frac{1}{\lambda_f} \ln \sum_{ijk} e^{\lambda_f \tilde{U}_{ijk|f}} \qquad \text{(Equation A1)}$$

where λ_f is the dispersion parameter for the distribution of unobserved characteristics of workers of skill class *f* and $\tilde{U}_{ijk|f}$ is the indirect utility function for such workers conditional on residential location *i*, employment location *j*, and housing type *k*. See the mathematical appendix in Safirova and colleagues (2006a) for more details.[48]

A2. Energy Modeling Details

Because LUSTRE only considers two building types (single-family and multifamily housing), we use data from Census 2000 to further disaggregate LUSTRE population into the four categories of building types considered by the EIA.[49] Census 2000 provides the distribution of households within these four building types for different regions of the Washington, DC, metropolitan area. Therefore it is possible to split, exogenously, the number of household members living in single-family housing into SFD and SFA categories. Similarly, household members living in multifamily housing can be broken down into MF24 and MF5 categories. Because LUSTRE population corresponds to individuals, this disaggregation assumes that, for each zone, the ratio of individuals (household members) living in SFD units to the number of individuals living in SFA units is the same as for households. This is a realistic assumption given than the average household size is the same for the two building types.[50] We further assume that this ratio is constant across skill levels.[51] For household members living in multifamily housing units, we have adjusted the ratio to account for the fact that households living in MF5 are on

[48] Safirova et al. (2006a).

[49] EIA (2001).

[50] EIA (2001).

[51] Intuitively, one might think that there is a greater proportion of higher-income individuals living in SFD versus SFA units, particularly in the suburbs of Washington, DC. It might also be true for MF24 relative to MF5, but here this is less clear. Luxury apartments can be found in big structures in the region. The fact that we do not consider that the proportions of people living in SFD versus SFA and MF24 versus MF5 differ by income groups may cause some bias for policy simulations. Indeed, if the movement in population is not uniform across skill level, let’s say that only the less affluent are moving, a higher share of SFA units will be occupied, ceteris paribus. However, if the reverse is true, i.e., high-income individuals move more, more SFD units will be occupied.

average smaller than ones living in MF24 (2.0 versus 2.3; EIA 2001). Note that this disaggregation increases the accuracy of our scenarios. Yet the decision to live in SFA versus SFD, and analogously in MF24 versus MF5, is exogenous. In this context, one could think that this choice is imbedded in LUSTRE's individual decision making and characterized by a Leontief relationship.

Overall, the residential energy usage (REU) computed by LUSTRE is given by:

$$REU = \sum_{if} \begin{pmatrix} e^{SFA} \cdot r_i^{SFA} \cdot Pop_{i,f,SF} + e^{SFD}(1-r_i^{SFA}) \cdot Pop_{i,f,SF} + \\ e^{MF5} \cdot r_i^{MF5} \cdot Pop_{i,f,MF} + e^{MF24}(1-r_i^{MF5}) \cdot Pop_{i,f,MF} \end{pmatrix} \qquad \text{(Equation A2)}$$

where:

e : energy consumption coefficient (millions of BTUs/year) for each residential building type per household member.[52]

r^{SFA} : the ratio of number of household members living in SFA housing units to the total number of households living in single-family housing units, disaggregated by zone i , from Census 2000; see Table A1.

r^{MF5} : the ratio of number of households members living in MF5 units to the total number of households living in multifamily housing units, disaggregated by zone i , from Census 2000; see Table A1.

$Pop_{i,f,SF}$: Population of skill level f , living in zone i and in single-family housing units, from LUSTRE.

$Pop_{i,f,MF}$: Population of skill level f , living in zone i and in multifamily housing units, from LUSTRE.

[52] Energy consumption per household member amounted to 40.89 for SFD; 38.72 for SFA; 35.42 for MF24; and 21.17 for MF5 (in millions of Btus; EIA 2001).

Table A1. Share of Household Members Living in Different Housing Types for Different Regions of Washington Metropolitan Area

		Share (%) of Household Members Living in SFA Relative to Single-family Housing	Share (%) of Household Members Living in MF5 Relative to Multifamily Housing
District of Columbia		66.67	79.53
Inner Core		37.98	90.17
	Arlington County, VA	24.98	88.38
	Alexandria city, VA	58.74	92.52
Inner Suburbs		27.13	91.92
	Montgomery County, MD	25.93	92.92
	Prince George's County, MD	23.00	90.80
	Fairfax County, VA	31.35	92.02
	Fairfax city, VA	24.85	94.16%
	Falls Church city, VA	25.53	92.08
Outer Suburbs		24.95	81.68
	Calvert County, MD	4.53	70.96
	Charles County, MD	20.11	71.13
	Frederick County, MD	21.47	72.26
	Loudoun County, VA	32.49	90.31
	Prince William County, VA	33.23	87.45
	Stafford County, VA	12.87	73.64
	Manassas city, VA	43.67	86.99
	Manassas Park city, VA	33.52	47.86
Far Suburbs		6.62	64.87
	Clarke County, VA	4.55	58.26

Source: Census 2000.

A3. Baseline Energy Profile

In the baseline case, out of the total of 156.6 billion Btus of annual residential energy use, 103.5 billion are consumed by the residents of SFD homes. Energy consumption in the other three residential categories is 39.5, 3.0, and 10.6 billion Btus for SFA, MF24, and MF5, respectively. One can observe that less than 10 percent of residential energy in the Washington, DC, metropolitan area is consumed by residents of multifamily housing. At the same time, baseline vehicular energy use in the Washington, DC, metropolitan area is 218 billion Btus. In other words, in absolute terms residential energy consumption and consumption of energy in transportation are of the same order of magnitude in the baseline picture, and therefore a potential reduction in any of them can make a dent in the total amount of used energy.

Figures A2 and A3 show, respectively, the distributions of the population and residential energy consumption by zone. Although there are slight variations, one can see that overall residential energy consumption closely follows the population distribution.

Figure A2. Population by zone

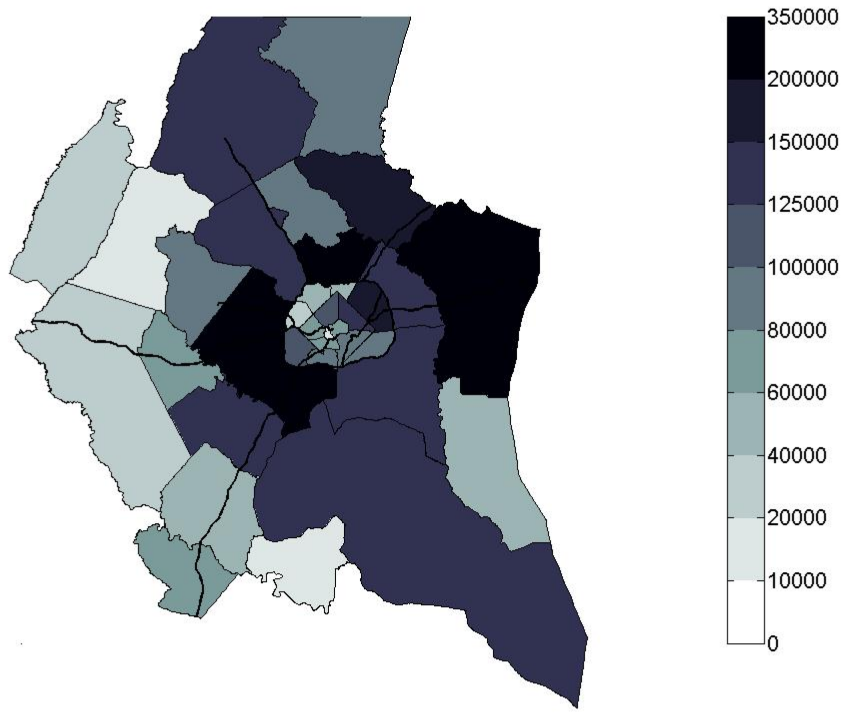
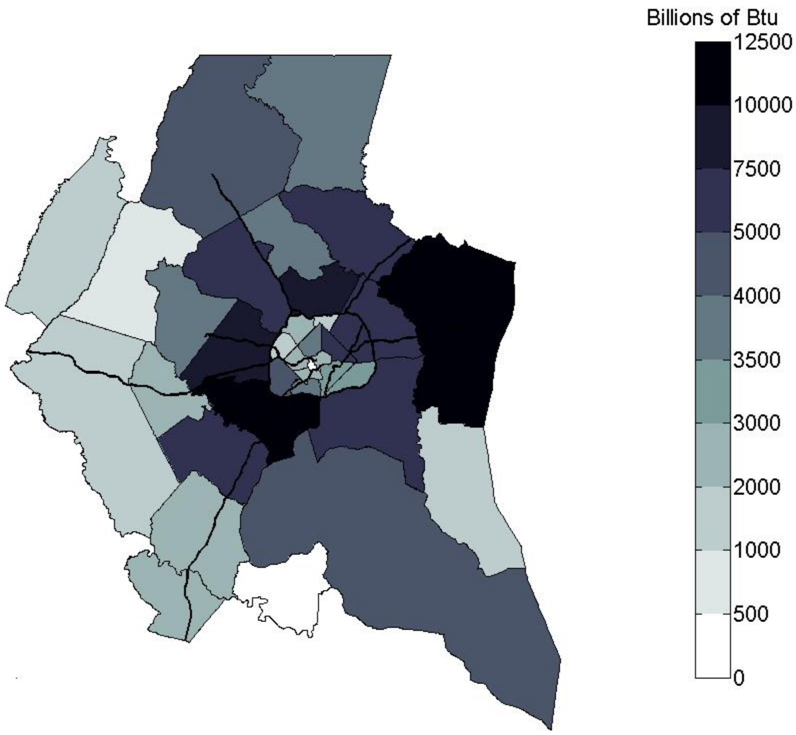


Figure A3. Annual Residential Energy Consumption



A4. Urban Policy Details

The descriptions of the existing LNYW programs in the Washington, DC, metropolitan area are presented in Table A2. The details of the simulated IZ program are given in Table A3.

Table A2: Live Near Your Work (LNYW) Programs in Washington Metropolitan Area

Program	Description
Maryland's LNYW Program Maryland Department of Housing and Community Development	Three percent closing cost–assistance grant to borrowers who are purchasing a home within 10 miles of their place of employment or within the boundaries of the local jurisdiction where they are employed. Available for first time homebuyers.
DC Employer-Assisted Housing Program (EAHP)	Grants and deferred loans of up to $11,500 to employees of the District of Columbia government who are first-time homebuyers in Washington, DC.
City of Alexandria Employee Homeownership Incentive Program	Deferred payment, 0% interest loans up to $5,000 for public employees who purchase homes in the City of Alexandria.
Arlington's LNYW Program	Forgivable Loan, forgiven at 1/36 per month. If borrower meets the eligibility criteria for three years, loan becomes a grant. At least one family member must be a permanent full-time worker employed by Arlington County or the Arlington School Board. Government employees receive LNYW assistance of $5,400. Schools employees: assistance is 1 percent of the purchase price, up to a maximum of $5,400.

Table A3: Inclusionary Zone (IZ) Program Simulated with LUSTRE

	IZ program
Area Covered	**Inside the Beltway**
Set-Aside Requirements for Affordable Housing	12% multifamily housing 15% single-family housing
Bonus Density	20% all provided as SFA and MF5 housing unit
Threshold Number of Units	No threshold
Eligibility Criteria	Below Median Income (Skill Level 1 and 2 in LUSTRE) Lottery determines the renters
Average Rent	$10/sq ft for multifamily housing $5/sq ft for single-family housing