An Integrated Framework for Estimating Long-Term Mobile Source Emissions: Linking Land Use, Transportation, and Economic Behavior

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Resources for the Future

Progress Review Meeting of EPA Global Change STAR Grantees

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"An Integrated Framework for Estimating Long-Term Mobile Source Emissions Linking Land Use, Transportation and Economic Behavior"

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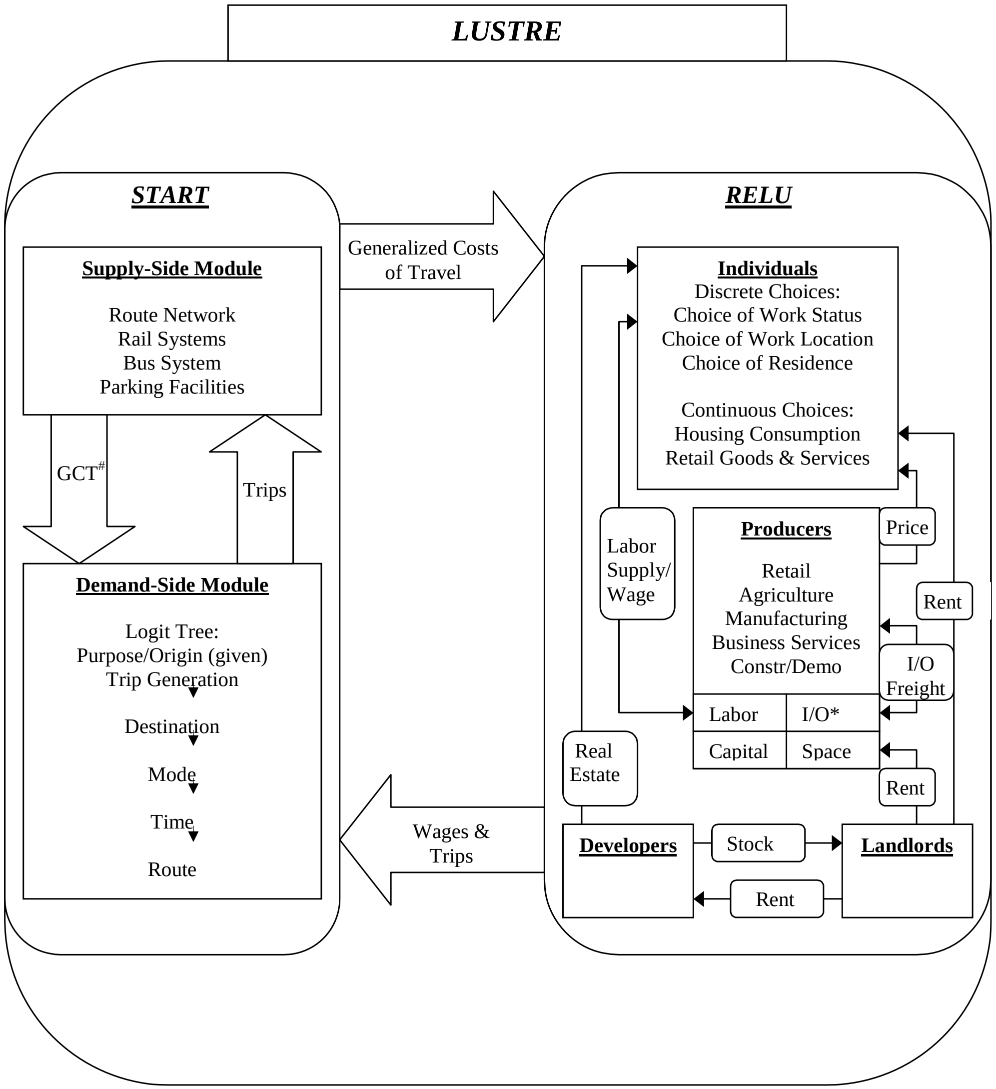
Outline

- LUSTRE Model Overview
  - Model Structure
  - Data Sources and Calibration
- Examples of Research Papers
  - Marginal Social Cost Pricing
  - Spatial Development and Energy Consumption
- Future Extensions and Work Underway

Land Use, Strategic Transport, Regional Economy (LUSTRE)

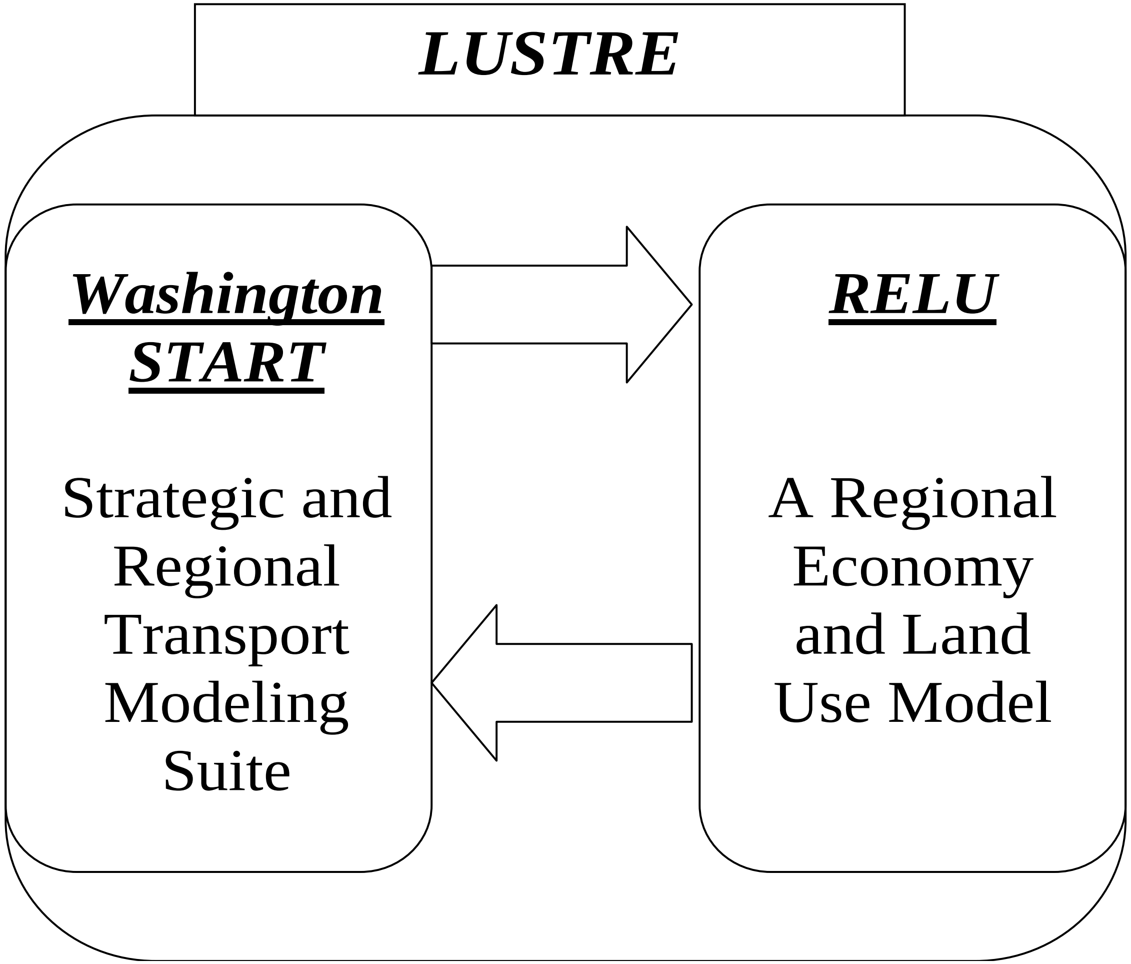


[#] Generalized Costs of Travel
*Intermediate demand for finished goods and services, also referred as Input/Output (I/O) tables.

LUSTRE features

- Consistent spatial disaggregation
- Non-monocentricity
- Agent heterogeneity
- Unemployment
- Frictions
  - Income and real estate taxes
  - Congestible alternative modes

LUSTRE Overview



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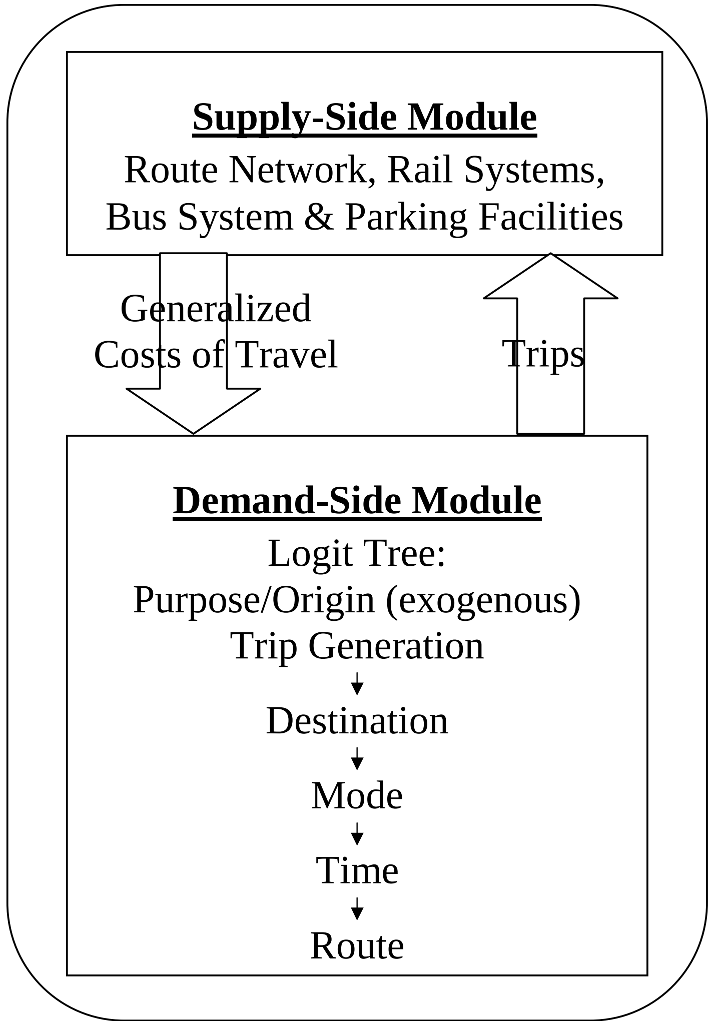
Washington-START Model

- Transportation simulation model
- Developed by RFF researchers using START modeling suite
- Designed for quick policy analysis
- Evaluation of policies using a consistent economic framework
- Not politically constrained
- Calibrated for Washington, DC metro area

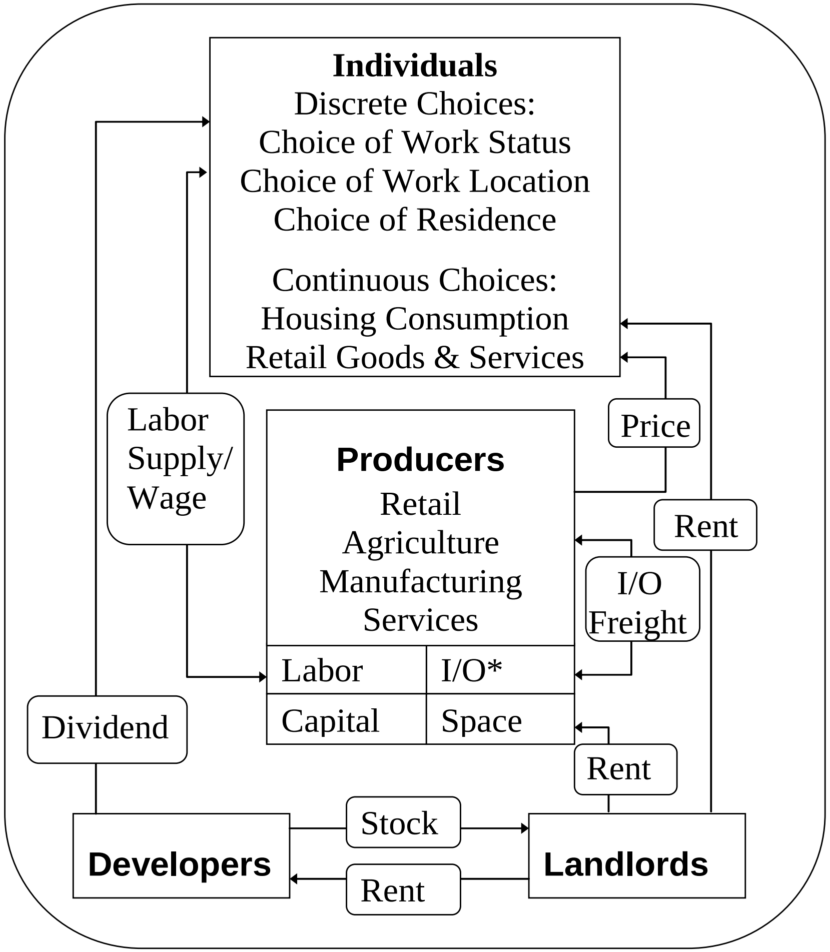
Washington-START Model



RELU Model Features

- Spatially disaggregated general equilibrium model of economic activity without predetermined location of residents and firms
- Some extras
  - 4 income classes
  - Employed and unemployed
  - Explicit modeling of housing
  - Developers' and landlords' decisions
  - Income and property taxes

RELU Model



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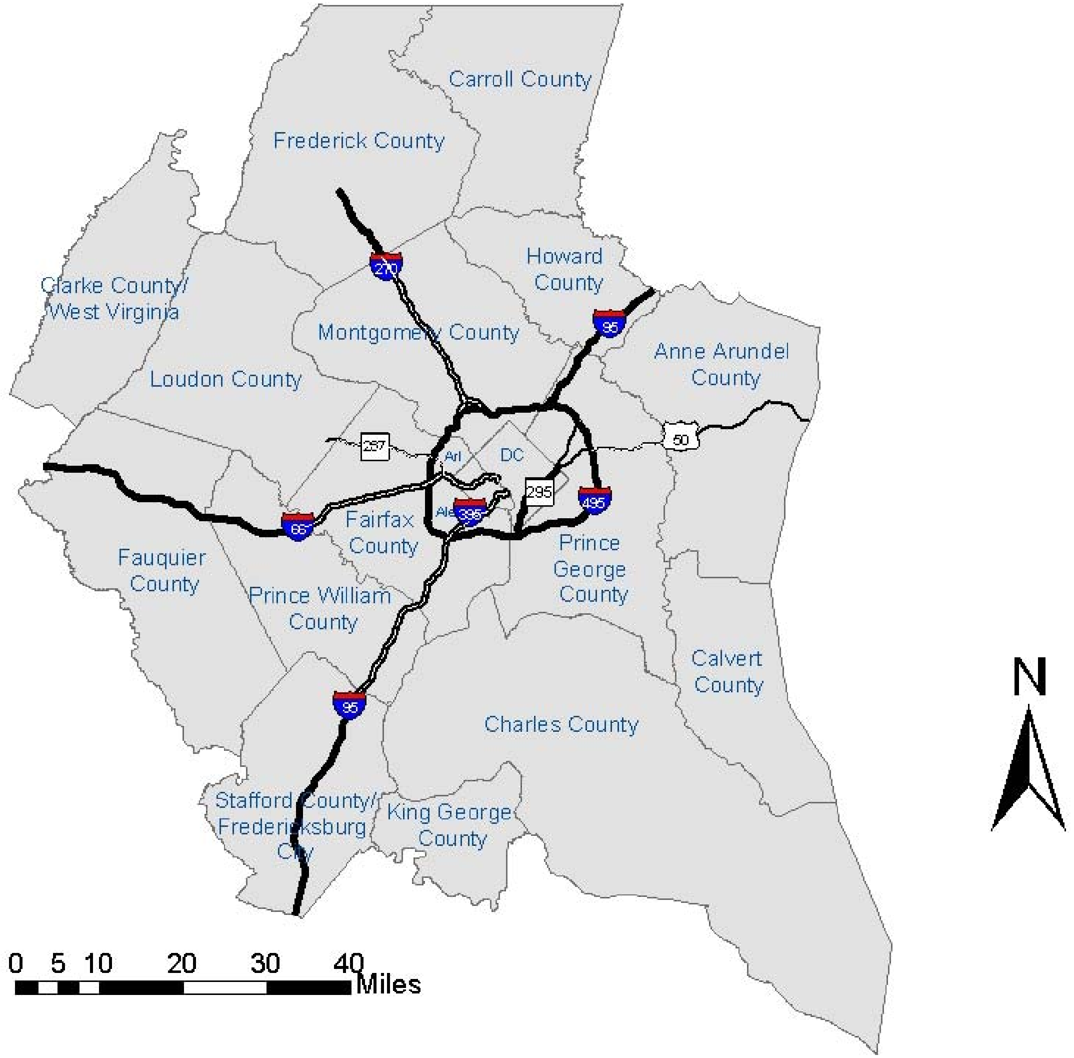
LUSTRE Modeling Region



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Data Sources

- 2000 Census
  - SF1A & SF3A
  - CTPP
- BEA production data
- Consumer Expenditure Survey
- MWCOG transportation data

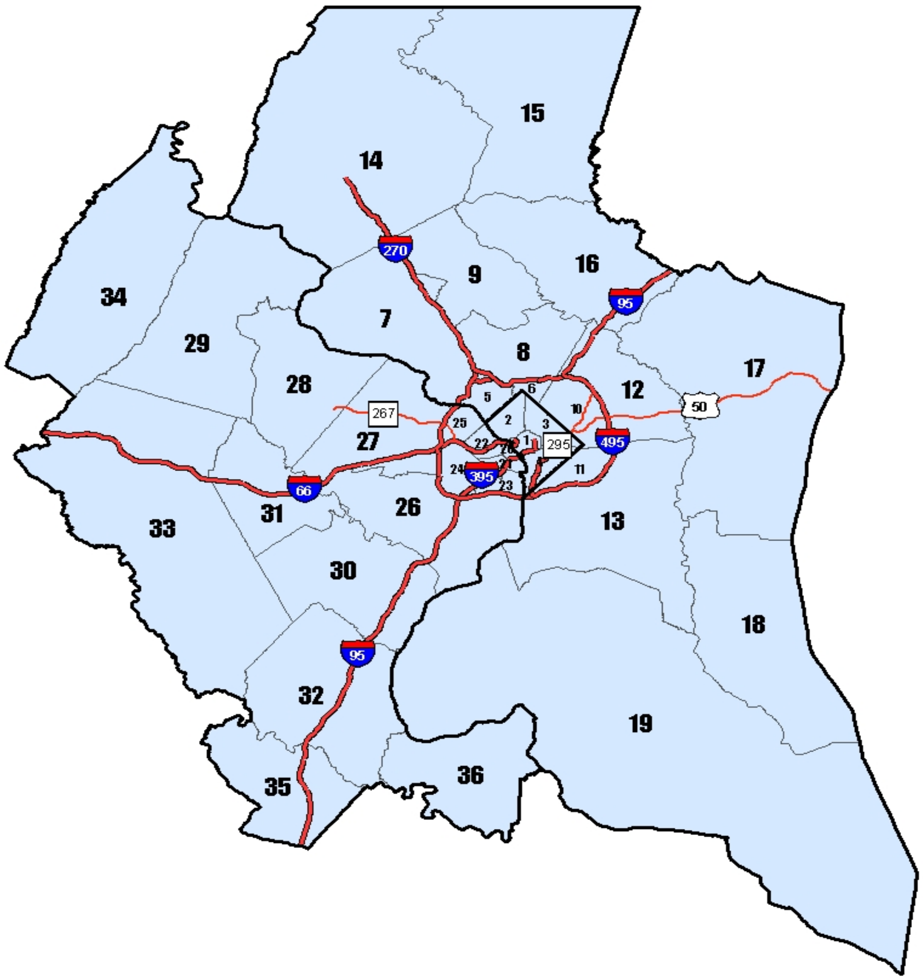
Literature on Marginal Social Costs of Transportation

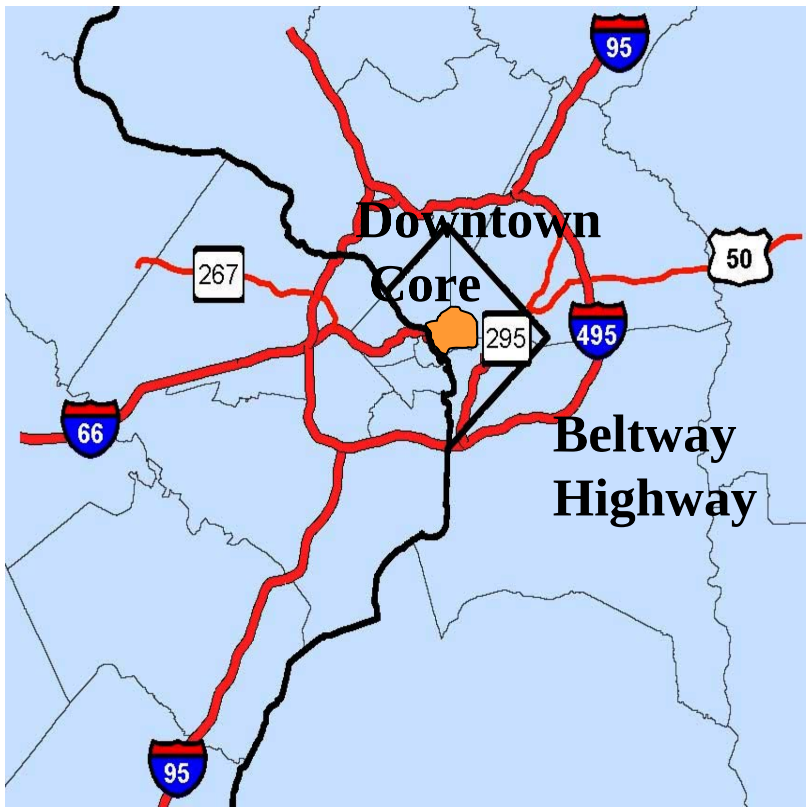
- Quinet (2004), Delucchi (2000), Lee (1993), Litman (2003)
- Most common externalities
  - Congestion
  - Traffic Accidents
  - Local Air Pollution
  - Global Air Pollution
  - Oil Dependency
  - Noise

Central Values for MEC (Parry et al. 2006)

External Costs	Cents/mile (2000)	Studies Reviewed
Air Pollution	2.02	Small and Kazimi (1995) McCubbin and Delucchi (1999) US Federal Highway Administration (FHWA) (2000)
Accidents	2.64	US FHWA 1997, Miller et al. 1998, Parry 2004
Climate Change	0.35	Nordhaus and Boyer (2000) Tol (2005) Pearce (2005)
Oil Dependency	0.53	Leiby et al. (1997) NRC 2002 CEC 2003
Noise	0.053	Delucchi and Shi-Lang (1998) US FHWA (1997)
Congestion	3.08	Small and Parry (2005) US FHWA (1997, 2000)

Modeling area





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Second-best road pricing schemes

- Downtown Cordon
- Beltway Cordon
- Double Cordon
- Freeway Tolls
- Comprehensive Tolls
- Gasoline Tax

Research Questions

- How effective are the second-best road pricing schemes at internalizing (even if partially) social costs?
- What trade-offs are involved?

Methodology

- Cordon tolls: second-best is determined by the highest gain in consumer surplus
- Road tolls: $MCC_k = \left(\frac{1}{S_{k1}} - \frac{1}{S_{k0}} \right) \times FD_k \times VOT_k$
- Gas tax: highest gain in consumer surplus
- All other externalities: assumes to be proportional to VMT (5.6 cents per mile)

Results

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Optimal Fees and Effect on VMT

		Congestion Pricing			*Social Cost Pricing*		
Policy	Percent of VMT affected	Toll/Tax rates, where charged	Average cost per VMT (¢/mi)	Total estimated VMT (million miles per day)	Toll/Tax rates, where charged	Average cost per VMT (¢/mi)	Total estimated VMT (million miles per day)
Base Case	-	-	-	172.7	-	-	172.7
Gas Tax	100%	2.74 $/gal	9.00	-18.8	4.24 $/gal	14.59	-26.2
Comprehensive Tolls	100%	Variable	3.04	-6.9	Variable	9.30	-19.4
Freeway Tolls	26%	Variable	0.67	-2.1	Variable	2.02	-6.3
Double Cordon	7%a	D: $3.43 B: $2.18	0.35	-1.2	D: $4.29 B: $2.57	0.37	-1.4
Beltway Cordon	7%a	Beltway 2.84	0.29	-0.9	Beltway 3.34	0.30	-1.0
Downtown Cordon	1.1%a	Downtown 4.70	0.14	-0.7	Downtown 5.80	0.14	-0.8

Consumer Surplus, Social Welfare and Externalities

	Change in Consumer Surplus, Only Congestion Internalized (millions of 2000$)	Change in Social Welfare with Additional External Costs (millions of 2000$)	Congestion Costs (millions of 2000$)	Average MCC (¢/mi)	Air Pollution Costs (millions of 2000$)	Accident Costs (millions of 2000$)	Climate Change Costs (millions of 2000$)	Oil Depen-dency Costs (millions of 2000$)	Noise Costs (millions of 2000$)
Base Case	-	-	3182.2	7.45	874.0	1139.9	152.0	228.0	22.8
Gas Tax (Congestion Pricing)	333.6	788.4	2281.0	6.59	709.5	925.4	123.4	185.1	18.5
Gas Tax (Social Cost Pricing)	250.0	883.5	1877.0	5.96	644.9	841.1	112.2	168.2	16.8
Comprehensive Toll (Congestion Pricing)	391.5	557.6	1353.1	3.42	813.9	1061.6	141.5	212.3	21.2
Comprehensive Toll (Social Cost Pricing)	452.0	919.9	1155.5	3.37	704.7	919.2	122.6	183.8	18.4
Freeway Toll (Congestion Pricing)	174.8	225.3	2436.4	5.82	855.7	1116.1	148.8	223.2	22.3
Freeway Toll (Social Cost Pricing)	243.7	395.0	2378.9	5.94	819.2	1068.6	142.5	213.7	21.4
Double Cordon (Congestion Pricing)	86.3	116.5	3003.3	7.12	863.0	1125.7	150.1	225.1	22.5
Double Cordon (Social Cost Pricing)	85.0	118.1	2985.2	7.08	862.0	1124.3	149.9	224.9	22.5
Beltway Cordon (Congestion Pricing)	59.0	82.7	3020.7	7.16	865.4	1128.8	150.5	225.8	22.6
Beltway Cordon (Social Cost Pricing)	60.0	81.7	3033.8	7.14	866.1	1129.7	150.6	225.9	22.6
Downtown Cordon (Congestion Pricing)	51.5	68.9	3087.8	7.45	867.7	1131.7	150.9	226.3	22.6
Downtown Cordon (Social Cost Pricing)	50.6	69.8	3077.4	7.45	867.0	1130.9	150.8	226.2	22.6

Impact on Emissions

	Reduction in Vehicular Emissions (Ton Per Day)		
	VOC	CO	NOx
Base Case	173.5	2154.5	393.4
Gas Tax (Congestion Pricing)	-17.8%	-17.8%	-18.5%
Gas Tax (Social Cost Pricing)	-25.1%	-25.0%	-25.8%
Comprehensive Toll (Congestion Pricing)	-7.7%	-4.9%	-5.6%
Comprehensive Toll (Social Cost Pricing)	-18.7%	-16.8%	-17.7%
Freeway Toll (Congestion Pricing)	-2.2%	-1.1%	-1.4%
Freeway Toll (Social Cost Pricing)	-5.7%	-5.8%	-6.4%
Double Cordon (Congestion Pricing)	-1.5%	-1.0%	-1.1%
Double Cordon (Social Cost Pricing)	-1.6%	-1.1%	-1.2%
Beltway Cordon (Congestion Pricing)	-1.0%	-0.7%	-0.8%
Beltway Cordon (Social Cost Pricing)	-1.1%	-0.7%	-0.7%
Downtown Cordon (Congestion Pricing)	-0.9%	-0.6%	-0.7%
Downtown Cordon (Social Cost Pricing)	-1.0%	-0.6%	-0.7%

Sources of VMT reductions

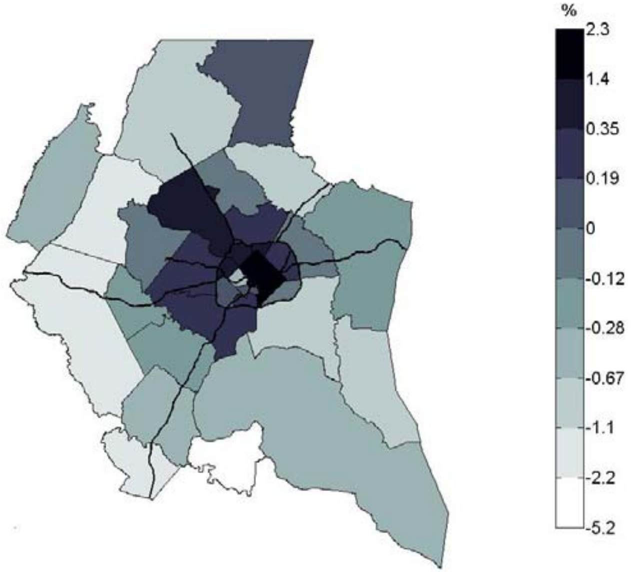
Comprehensive toll

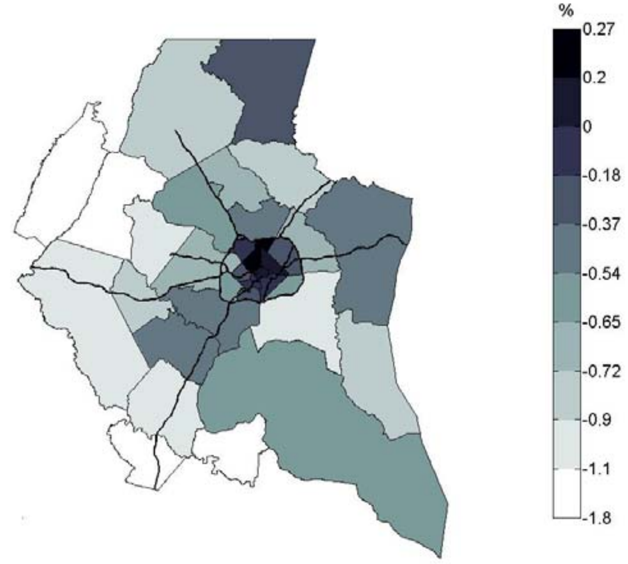
- Route Substitution 0.6 mln VMT
- Modal Shift 31.5 mln VMT
- Location choice 0.9 mln VMT
- Increase in voluntary

long-term unemployment 0.4 mln VMT

Total 33.4 min VMT

Residential and Employment Location





Conclusions

- Cordon tolls are significantly less efficient at reducing both congestion and a broader set of externalities
- Comprehensive toll is a more sophisticated policy that allows to achieve greater efficiency at a lower VMT reduction
- Even with comprehensive tolls, aggregate charges seem to be prohibitively high

Caveats

- Particular metropolitan area
- Particular road pricing scheme
- Particular revenue redistribution schemes
- No implementation costs
- No explicit modeling of vehicle choice

Energy Consumption

- US Energy consumption:
  - 1949: ~ 98 quadrillion Btu
  - 2000: ~300 quadrillion Btu
- Energy per real dollar of US GDP:
  - 1949: 20.6 thousand Btu
  - 2000: 10.6 thousand Btu
- Per capita annual energy consumption
  - 1949: 215 million Btu
  - 2000: 350 million Btu

Literature Review

Early Literature

- Hypothetical Cities or Hypothetical Growth Patterns
  - Council of Environmental Quality (1975)
  - Roberts (1977)
  - Carrol (1977)
  - Edwards (1977)
  - Keyes (1977)
- Most studies included both residential and transportation sectors
- Forecast reductions in total energy consumption between 0.35% (Keyes 1977) and 46.3% (Council of Environmental Quality 1975)

Literature Review

Transportation-Related Studies (1)

- Impact of density on travel demand
  - Newman and Kenworthy (1989, 1999)
  - Kenworthy and Newman (1990)
  - Steiner (1994)
  - Levinson & Kumar (1997)
- The effect of the settlement size
  - Levinson & Kumar (1997)
  - Gordon et al. (1987, 1989)
- The role of public transit
  - Crane & Crepeau (1998)
  - Boarnet & Crane (2001)

Literature Review

Transportation-Related Studies (2)

- Self-selection
  - Handy (1996)
  - Steiner (1994)
- Role of individual and socio-economic characteristics
  - Dieleman et al. (2002)
  - Gomez-Ibanez (1991)
- Varying residential density and vehicle choice
  - Golub & Brownstone (2005)
- Co-location hypothesis & polycentricity
  - Gordon & Richardson (1997)
  - Cervero & Wu (1997, 1998)

Literature Review

Building Energy Consumption-Related Studies

- Great variation from country to country
  - US: 36% of energy consumed in buildings
  - EU: 41%
  - UK:50%
- Energy-efficient building design
  - Steadman (1979)
- Relationship between building energy demand and density
  - Holden et al. (2004)
  - Mindali et al. (2004)
  - Hui (2001)
  - Lavarette et al. (1999)

Literature Review

Energy Consumption and Public Policy

- Questions remain:
  - Can land use changes make a significant difference for energy consumption?
  - If so, are there public policies that can achieve such results?
- Anderson et al (1996):
  - The most efficient way to approach those two questions is to conduct a comprehensive study of possible outcomes of alternative policies in a LUTI framework

Research Questions

- To what extent an ideal compact urban form leads to energy savings?

- How much energy savings can be achieved through a policy intervention?

Residential Energy Use Modeling

- Energy use coefficients distinguished for four types of residential building:
  - *Single-Family Detached (SFD);*
  - *Single-Family Attached (SFA);*
  - *Apartments in Building with 2 to 4 Units (MF24); and*
  - *Apartments in Buildings with 5 or more Units (MF5).*
- Population shift between SF and MF endogenous
- Population shift between SFD-SFA and MF24 and MF5 exogenous
- SFD/SFA and MF24/MF5 proportions vary by zone

Annual Energy Consumption Coefficients per Household Member, by Residence Type

	Single-Family Detached (SFD)	*Single-Family Attached (SFA)*	*Apartments in Building with 2 to 4 Units (MF24)*	*Apartments in Buildings with 5 or more Units (MF5)*
Consumption per Household Member (millions of BTU)	40.89	38.72	35.42	21.17

Shares of Residents Living in Different Types of Housing, by Locality

		SFA / (SFA+SFD)	MF24 / (MF24+MF5)
District of Columbia		66.67%	79.53%
Inner Core	e.g. Arlington, Alexandria	37.98%	90.17%
Inner Suburbs	e.g. Montgomery, Prince George, Fairfax, Falls Church	27.13%	91.92%
Outer Suburbs	e.g. Calvert, Charles, Frederick, Loudoun, Prince William, Stafford, Manassas	24.95%	81.68%
Far Suburbs	e.g. Clarke County	6.62%	64.87%

Savings in Residential Energy Use

- Population shift from SF to MF building type
- Population shift toward zones with higher proportion of SFA building relatively to SFD, and more importantly higher proportion of MF5 relatively to MF24

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Annual Residential Energy Use, LUSTRE Baseline

	Single Family Detached	*Single Family Attached*	*Multi Family 2-4 Units*	*Multi Family 5 Units*	*Total*
LUSTRE Baseline (billions of Btu)	103489	39525	3007	10639	156672

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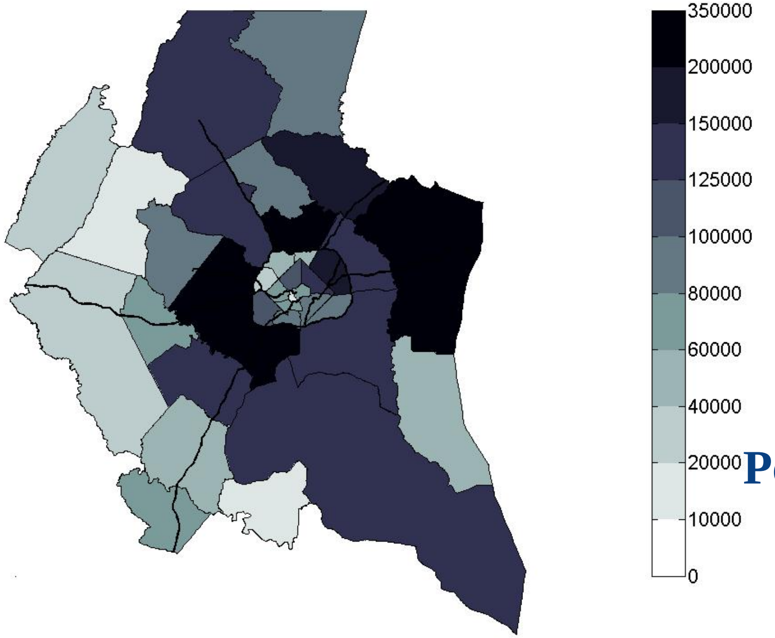
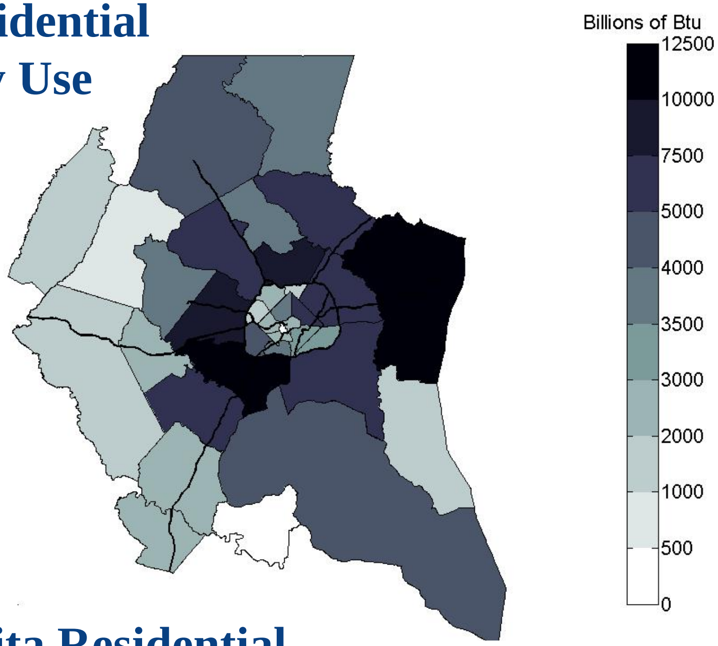
Population vs. Residential Energy Consumption by Zone

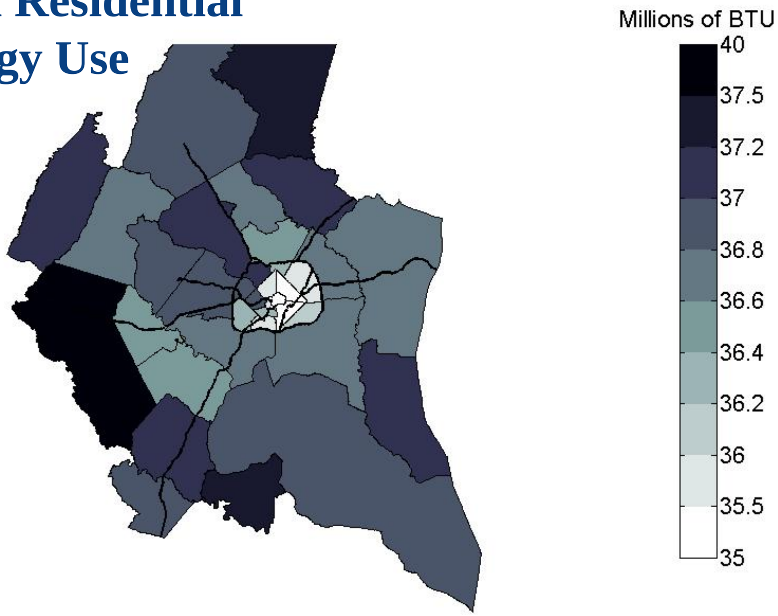
Population



Total Residential Energy Use



Per Capita Residential Energy Use



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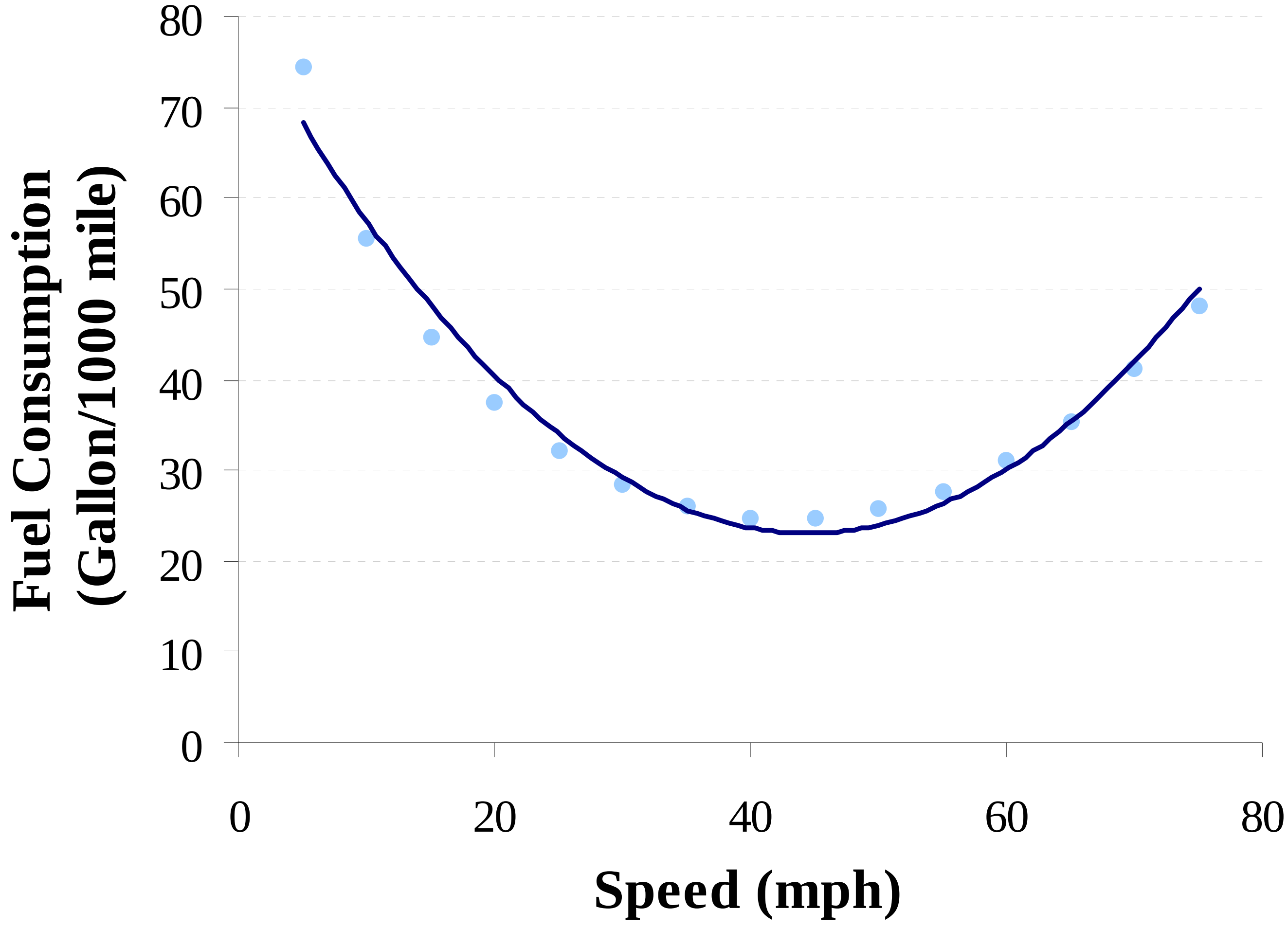
Vehicular Energy Use Modeling

- In START, car fuel consumption is a function of the speed.
  - This non-linear relationship is used to determine the monetary costs of driving
  - Here it is used to determine fuel consumption (in gallons).
  - Average for all type of cars (i.e. car size, age, gasoline type, etc…)
- *Fuel consumption by buses is not included

Relationship Between Vehicular Fuel Consumption and Speed in START



Vehicular Energy Use, LUSTRE Baseline

		Daily Vehicular Energy Consumption (Cars Only)	*Annual (250 days) Vehicular Energy Consumption (Cars Only)*
LUSTRE Baseline	Millions of Gallons	6.93	1732
	Billions of Btu	873	218254

Savings in Vehicular Energy Use

- Reduction in VMT=>
  - Trip distance
  - Number of car trips
- Change in speed of travel
  - Depends of the distribution of speeds at the baseline relatively to the "sweet spot" of the fuel consumption-speed curve (~45 mph)

Urban Scenarios and Policies

- Scenarios
  - Increased Preference to Live Inside the Beltway
  - Increased Building Density
  - Increased Road Capacity
  - Decreased Road Capacity
- Policies
  - Live Near Your Work (LNYW) Program
  - Inclusionary Zoning (IZ) Program
  - Increase in Gas Tax Rate

Simulation Results

Energy Savings: Urban Scenarios

	Annual Change in Residential Energy use (End-Use) (million of BTU)	*Annual Change in Vehicular Energy use (gasoline converted in million of BTU)*	*Total Change in Energy Use*
High Preferences to Live Inside the Beltway Area	-115737 (-0.07%)	-1704423 (-0.78%)	-1820160 (-0.49%)
Increase in Residential Housing Density Inside the Beltway Area	-194127 (-0.12%)	-618073 (-0.28%)	-812199 (-0.22%)
Increase in Road Capacity: 25 Percent Increase Inside the Beltway	11868 (0.01%)	428311 (0.20%)	440179 (0.12%)
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-20815 (-0.01%)	-634605 (-0.29%)	-655419 (-0.18%)

Welfare Gains and Energy Savings: Policies

	Overall Welfare Gains (million of dollar)	Annual Change in Residential Energy use (End-Use) (million of BTU)	Annual Change in Vehicular Energy use (gasoline converted in million of BTU)	Total Change in Energy Use
Live Near Your Work Program Inside the Beltway	94	-6860 (-0.004%)	-226437 (-0.10%)	-233298 (-0.06%)
Inclusionary Zoning Program Inside the Beltway	1051	-9488 (-0.01%)	-737404 (-0.34%)	-746892 (-0.20%)
Gas Tax 2.02$/gallon	305	-133718 (-0.09%)	-35139718 (-16.10%)	-35273437 (-10.39%)

Changes in Population

	Inside the Beltway	Outside the Beltway
	% Change	
High Preferences to Live Inside the Beltway Area	10.69	-4.19
Increase in Residential Housing Density Inside the Beltway Area	4.22	-1.65
Increase in Road Capacity: 25 Percent Increase Inside the Beltway	0.10	-0.04
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-0.18	0.07
Live Near Your Work Program Inside the Beltway	0.79	-0.31
Inclusionary Zoning Program Inside the Beltway	5.62	-2.20
Gas Tax 2.02$/gallon	0.66	-0.26

Annual Percentage Change in Residential Energy Use by Housing Type: Urban Scenarios

	SFD	SFA	MF24	MF5	All Type
	% Change				
High Preferences to Live Inside the Beltway Area	-0.75	0.44	1.57	2.63	-0.17
Increase in Residential Housing Density Inside the Beltway Area	-1.81	4.55	-4.27	0.62	-0.12
Increase in Road Capacity: 25 Percent Increase Inside the Beltway	-0.01	0.02	-0.004	0.004	0.01
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	0.01	-0.03	0.01	-0.01	-0.01

Annual Percentage Change in Residential Energy Use by Housing Type: Policies

	SFD	SFA	MF24	MF5	All Type
	% Change				
Live Near Your Work Program Inside the Beltway	-0.06	0.14	-0.01	0.04	-0.004
Inclusionary Zoning Program Inside the Beltway	-1.83	5.00	-5.02	-0.08	-0.01
Gas Tax 2.02 $/gallon	-0.11	0.30	-0.27	-0.01	-0.09

Annual Percentage Change in Vehicular Energy Use

	% Change	Annual Changes (million of gallons)
High Preferences to Live Inside the Beltway Area	-0.78	-14
Increase in Residential Housing Density Inside the Beltway Area	-0.28	-5
Increase in Road Capacity: 25 Percent Increase Inside the Beltway	0.20	3
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-0.29	-5
Live Near Your Work Program Inside the Beltway	-0.10	-2
Inclusionary Zoning Program Inside the Beltway	-0.34	-6
Gas Tax 2.02$/gallon	-16.10	-279

Daily Changes in Vehicle Miles Traveled (VMT)

	Daily Changes (in miles)	% Change
High Preferences to Live Inside the Beltway Area	-841240	-0.49
Increase in Residential Housing Density Inside the Beltway Area	-71360	-0.04
Increase in Road Capacity: 25 percent Increase Inside the Beltway	713278	0.41
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-459707	-0.27
Live Near Your Work Program Inside the Beltway	132701	0.08
Inclusionary Zoning Program Inside the Beltway	-163774	-0.09
Gas Tax 2.02$/gallon	-25031828	-14.51

Shifts in Travel Mode

	SOV	HOV	BUS	TRAIN	Walk/ Bike
	% Change in Trip Numbers				
High Preferences to Live Inside the Beltway Area	-0.21	0.25	2.70	3.55	3.65
Increase in Residential Housing Density Inside the Beltway Area	0.043	0.79	3.52	4.96	1.99
Increase in Road Capacity: 25 percent Increase Inside the Beltway	0.23	0.036	-0.19	-2.17	-0.62
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-0.39	-0.087	0.48	3.70	1.11
Live Near Your Work Program Inside the Beltway	0.024	0.14	0.85	1.19	0.72
Inclusionary Zoning Program Inside the Beltway	-0.024	0.66	3.46	4.69	2.13
Gas Tax 2.02$/gallon	-17.80	16.41	16.41	20.21	21.71

Changes in Average Speed of Travel

	Road Network Inside the Beltway	Road Network Outside the Beltway	All Road Network
LUSTRE Baseline (mph)	42.49	45.84	44.98
High Preferences to Live Inside the Beltway Area	-0.67%	0.28%	-0.01%
Increase in Residential Housing Density Inside the Beltway Area	0.26%	0.37%	0.33%
Increase in Road Capacity: 25 percent Increase Inside the Beltway	1.37%	-0.07%	0.27%
Decrease in Road Capacity: 25 Percent Decrease Inside the Beltway	-2.04%	0.17%	-0.34%
Live Near Your Work Program Inside the Beltway	-0.04%	0.09%	0.05%
Inclusionary Zoning Program Inside the Beltway	0.14%	0.32%	0.26%
Gas Tax 2.02$/gallon	0.56%	0.80%	0.71%

Conclusions

- A draconian $2.02 gas tax has a potential to make a significant dent in energy consumption, but its political acceptability will not be high
- All other policies and scenarios are largely ineffective in reducing energy consumption
- For some policies, residential energy consumption can be more significant and may deserve a better representation

Important Caveats

- Energy totals do not include:
  - Buses
  - Commercial/Industry
- Simplifications in modeling of building stock and vehicle fleet:
  - Age
  - Maintenance
- Sources of energy saving missing:
  - Vehicle choice
  - Size of the residential units
  - Heterogeneity among individuals (e.g. income classes)
  - For the residential energy use, only “end-use” considered

Future Extensions

-Incorporate vehicle choice

- Make the model dynamic

- Better modeling of land use (zoning)

-Trade-off between local and regional effects (zoom-in methodology)

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