An Agent-Based Model for Estimating Consumer Adoption of PHEV Technology

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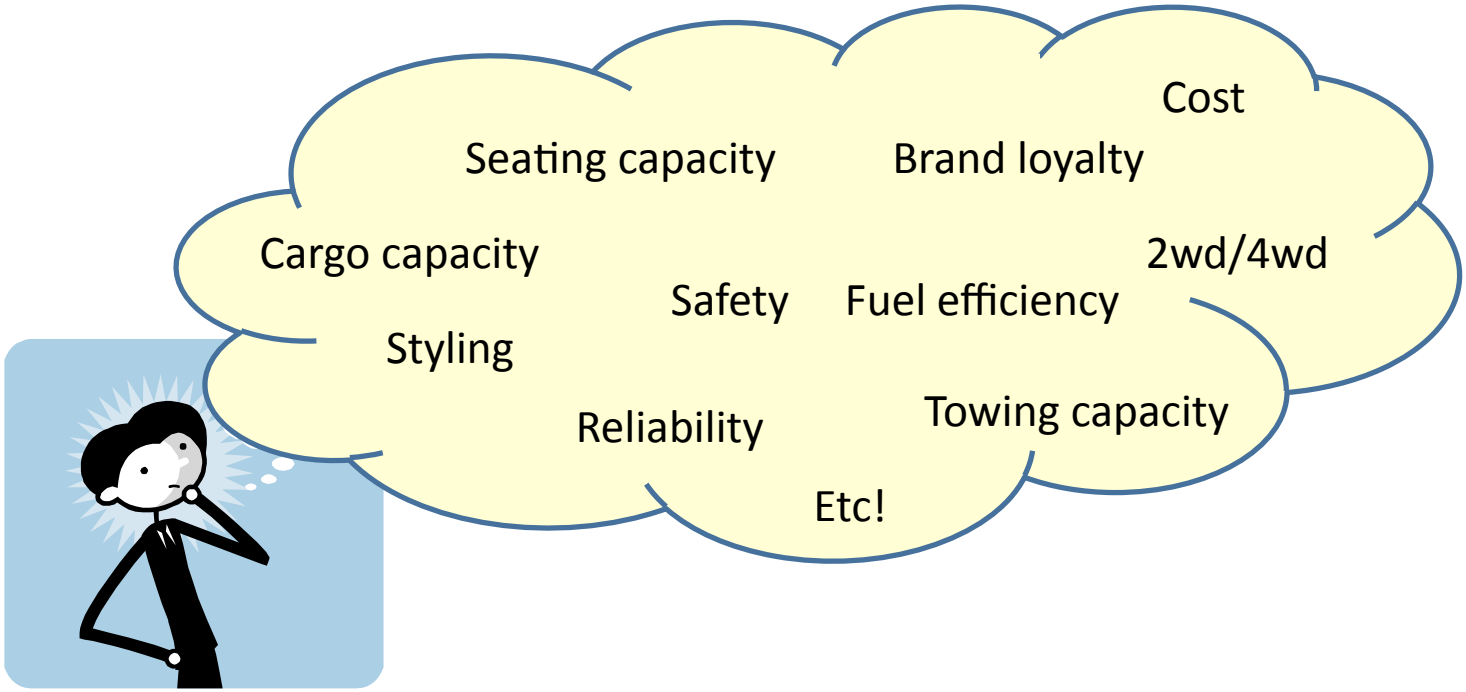
Vehicle consumers weigh the costs and benefits of many vehicle characteristics in determining which vehicle to purchase…



We assume that, in the future, many comparable vehicles will be available with and with-out a plug-in option, so **ultimately the choice will come down to whether or not to purchase the PHEV option.**

What are the primary factors that will affect a consumers decision to buy a PHEV option, assuming all other vehicle attributes are the same?

- Discomfort with new technology until its tried and tested
- Perceived Financial trade-offs:
  - Price premium of PHEV
  - Perceived relative fuel costs (projected fuel prices, relative fuel efficiency, accuracy of estimation)
- Perceived Environmental trade-offs
- "Greenness" (relative value of Environmental vs. Financial benefits)

Two forms of social influence in our Agent Based Model (ABM):

1) **Threshold model** (e.g., as in Granovetter 1978; Watts 2002)

The idea is that some people are not comfortable adopting new technologies until they see some level of adoption around them (their 'threshold').

In this case, agents assess the proportion of PHEVs in their "perceived fleet" – cars in their social + geographic neighborhood, and only if this is above their personal threshold of comfort will they even consider the PHEV.

Different agents have different thresholds.

2) **Social conformity** (e.g., as in Axelrod, 1997; Bednar & Page, 2007)

The idea is that people tend to be influenced by the attitudes and behaviors of those whose attributes are already similar to them.

In this case, agents have social networks of others with similar demographic attributes (age and salary), and certain attributes (G and Y) can be stochastically increased through these social networks.

Different agents have different susceptibilities to social influence.

In order to avoid having to:

•make up specifications for a wide range of hypothetical PHEVs, and

•make a host of other assumptions about vehicle model selection

in this proof-of-concept study **we opted to only model the subset of vehicle consumers who have already narrowed their selection to the only model for which we could obtain specifications with and without a PHEV option.**

Prius-like HEV:

45 mpg

$25K

Prius-like PHEV:

105 mpg for first 35 mi after charging

45 mpg thereafter until next charge

5kWh battery with 5.5 hr charging time

$0.11 per kWh (www.eig.gov, 2009)

$25K+plug-in premium

Plug-in premiums used in simulations:

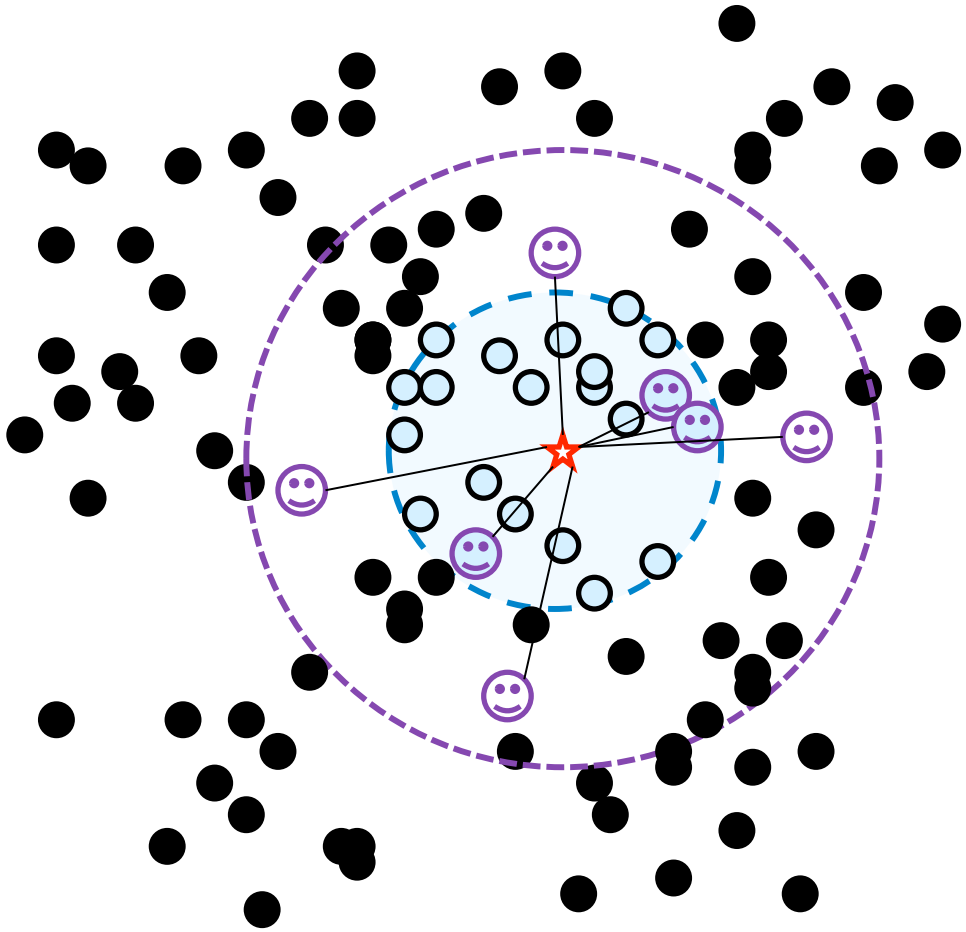
- high: $10,400 (current cost of conversion kit)
- low: $5,000 (possibly subsidized)

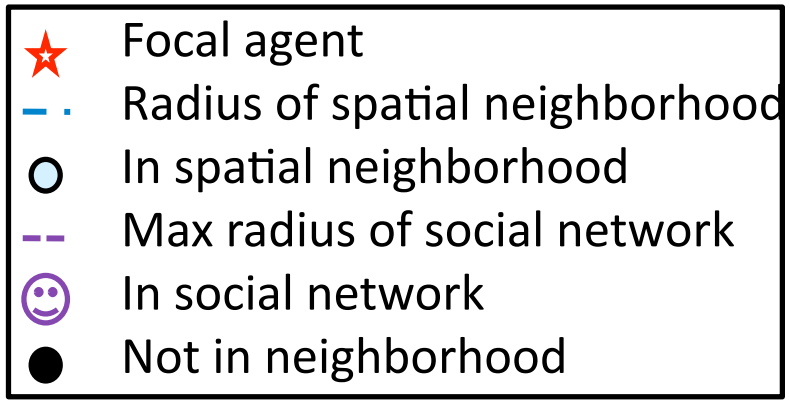
(specifications from www.hymotion.com assuming 50/50 city/hwy).

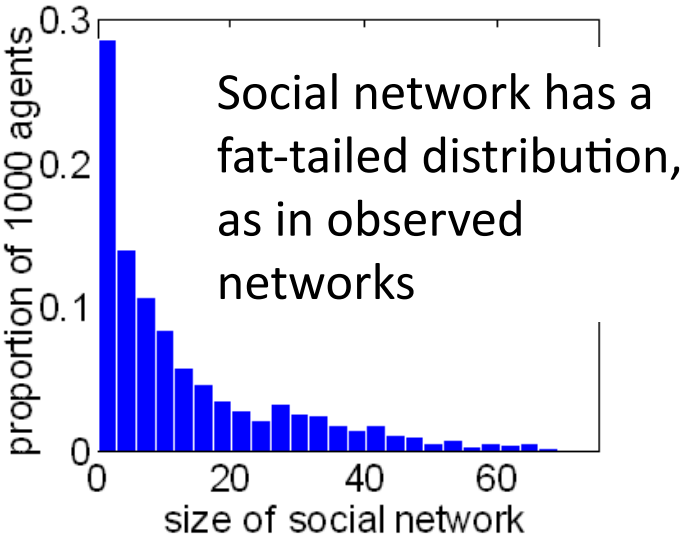
"Agents" are potential new-vehicle consumers with the following heterogeneous attributes:

- Age
- Salary
- Residential location (2-D coordinates)
- Expected number of years they own a car before buying a new one
- Annual vehicle miles traveled (VMT)
  (round trip daily commute assumed to be VMT/365/2)
- Comfort Threshold for considering the new PHEV technology
- Susceptibility to Social Influence (0 to 1)
- Greenness (**G**)
- Years (**Y**) that they look-ahead in estimating relative fuel costs
  (ternary: 0 yrs, 1 yr, all yrs of expected duration of ownership)
- Current vehicle age
- Current vehicle mpg
- Geographic 'neighborhood'
- Social 'neighborhood'

- Radii of spatial neighborhoods are linear functions of VMT
  (median spatial radius ~4 miles)
- Radii of social neighborhoods uniformly distributed (0 to 5 mi)
- Social network: in social radius, similar salary (±$10K) and age (±5 yrs)







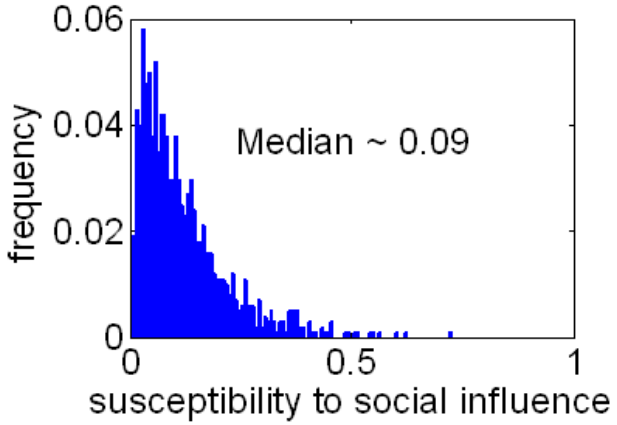
Each year, potentially increase agent attributes G and Y, based on social conformity

For each agent (in random order):

Randomly select one 'neighbor' from my social neighborhood (similar age, salary, and residential location group) with probability inversely proportional to Euclidean distance between our Greenness values G)

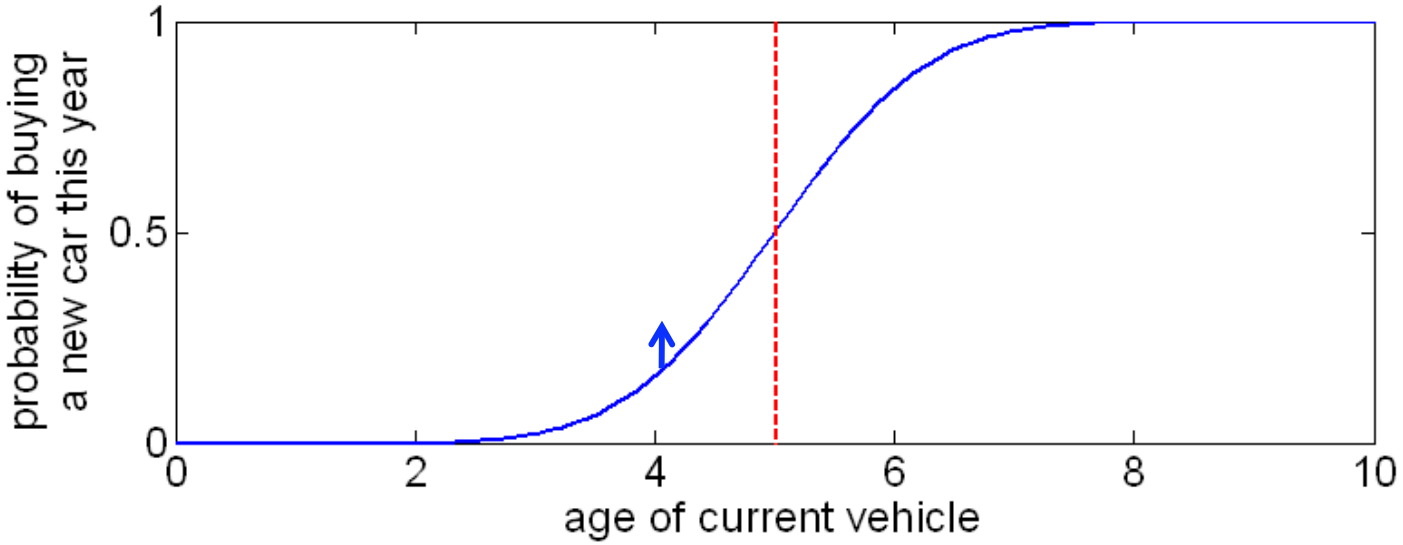
Select a Uniform random number 0-1
If the number is less than my social susceptibility
  If my G < neighbor's G
    my G ← neighbor's G
  End If
Endif if

Select a Uniform random number 0-1
If the number is less than my social susceptibility
  If my Y < neighbor's Y
    my Y ← neighbor's Y
  End If
Endif if



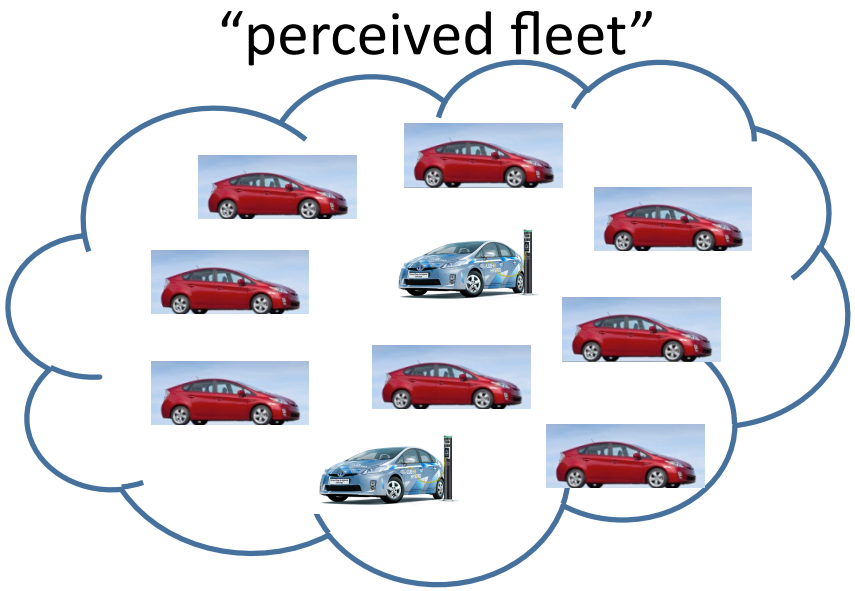
Each year, each agent (in random order) stochastically determines whether or not to buy a new car.

Select a Uniform random number 0-1
If the number is less than blue line
(normal cdf centered on preferred age to sell current car)
then continue on to **assess which car to buy**
Otherwise
don't buy a car this year, and increase age of current car by 1 year
End If



NOTE: if the age of current vehicle is less than preferred age to sell (dotted red line), and there is a vehicle available that is sufficiently more efficient, relative to your salary and projected gas prices, then blue line is shifted upwards slightly.

Assess which car to buy: Am I even willing to consider the PHEV?



e.g., 2 PHEVs out of 10 vehicles

If proportion of PHEVs in my perceived fleet is > my personal threshold
    Then **I will consider the PHEV**
Otherwise
    I will buy the HEV
End If

Assess which car to buy: Relative costs of HEV *vs.* PHEV?

Determine Financial Costs C of the two vehicles as follows:

If Y == 0 (no fuel cost lookahead)
  Operating Costs = 0
Else assess for 1 yr (Y==1) or all years of anticipated ownership (Y==2)
  Gasoline costs are projected annually using slope of last 3 years
  Operating Costs for HEV are just VMT*yrs/mpg*annualProjectedGasPrices
  Operating Costs for PHEV also take into account
    proportion of miles driven within PHEV battery range
    (based on daily roundtrip commuting distance),
    different mpg when within PHEV battery range, and
    recharging frequency and costs
End If

Total Costs = Initial Cost + Operating Costs (for both C_{HEV} and C_{PHEV})

Determine Relative perceived costs of the two vehicles: RC = $(C_{PHEV} - C_{HEV}) / C_{PHEV}$

Note: RC <1 if HEV perceived cheaper, RC > 1 if PHEV is perceived cheaper; the lower RC is, the better the HEV is perceived

Assess which car to buy: Relative environmental costs of HEV *vs.* PHEV?

Determine amount of Gas Per Year GPY (GPY_{HEV} and GPY_{PHEV}) , accounting for the proportion of miles the PHEV is run within PHEV battery range

Determine the perceived Relative Environmental Benefits based on relative gas used per year: REB = ($GPY_{HEV} - GPY_{PHEV}$) / GPY_{HEV}

NOTE: REB is always < 1; the lower REB, is the better the PHEV is perceived

Assess which car to buy:
Based on Relative Financial Costs and Environmental Benefits

Weigh relative environmental benefits REB and relative financial costs RC based on "greenness" **G**:

Desirability D = **G** × REB − **(1 − G)** × RC

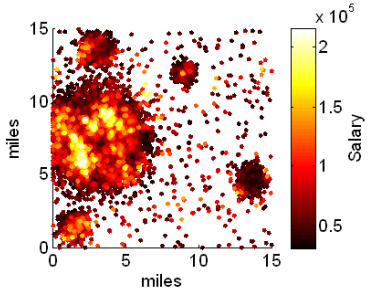
If D > 0
  buy the PHEV 
Elseif D < 0
  buy the HEV 
Else
  chose between HEV and PHEV randomly
End If

RECALL: REB is always < 1; the lower REB, is the better environmentally the PHEV is perceived relative to the HEV
RECALL: RC <1 if HEV perceived cheaper, RC > 1 if PHEV is perceived cheaper;
the lower RC is, the better financially the HEV is perceived relative to the PHEV

If RC > 1, agent will buy the PHEV based on cost-considerations alone, regardless of their greenness G.

Preliminary simulations

Simulated a 15 mi^2 region with 1 larger city and 4 smaller towns
Demographics of agents created randomly based on data where possible



1) Representative Simulation to illustrate system dynamics:

- 10,000 agents
- A low (possibly subsidized) PHEV price premium of $5K
- Moderately increasing gas prices (max of $4.87 in year 14)
- Uniform initial distribution of Y between ternary flags 0,1,2
- Median susceptibility to social influence only 0.09

2) 12 simulations with 1000 agents each, to illustrate sensitivity to gas prices, PHEV premiums, and ability of agents to accurately estimate relative fuel savings:

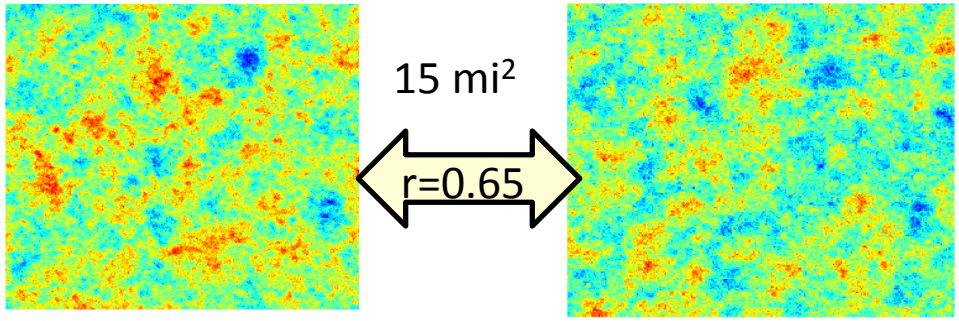
All combinations of:

- 2 PHEV price premiums ($5000, $10,400)
- 3 gas price projection scenarios ($2.84, $4.87, $6.89 at yr 14)
- 2 extremes of fuel cost projections (0 years, all years of expected ownership)

3) Many simulations varying lots of conditions to test up-scaling (see next talk!)

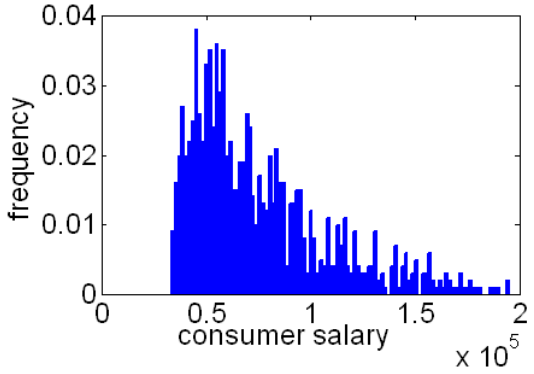
The Turning-Bands method was used to create 2 spatially-correlated fields

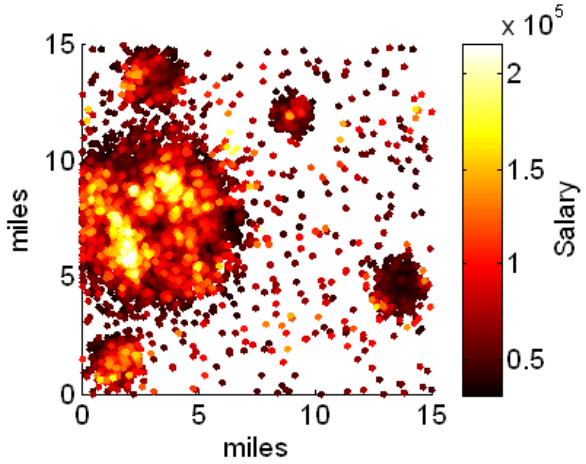
Salary
Pseudo-β Transform:
Min = $30K
Max = $250K
Median ~ $65K

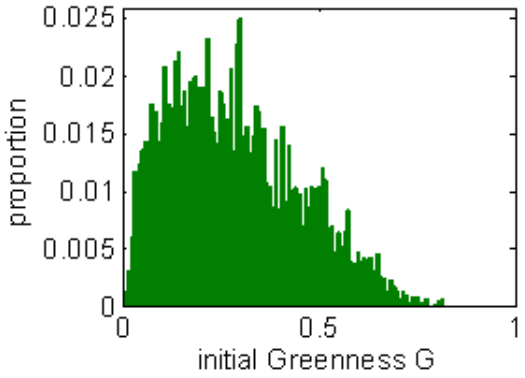


Greenness
Pseudo-β Transform:
Min = 0
Max = 1
Median ~ 0.17

X,Y agent locations using Gaussian kernels for towns

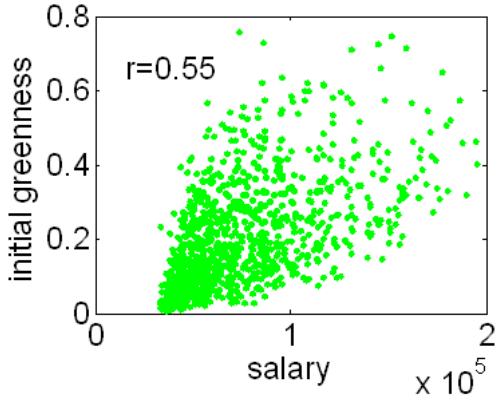






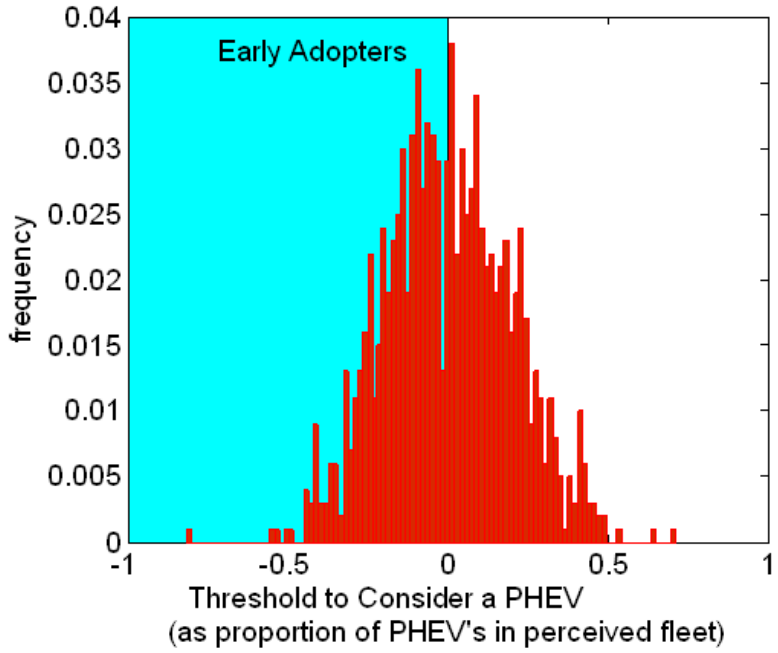
Salary and Greenness are thus spatially-correlated, β-distributed, and mildly cross-correlated.

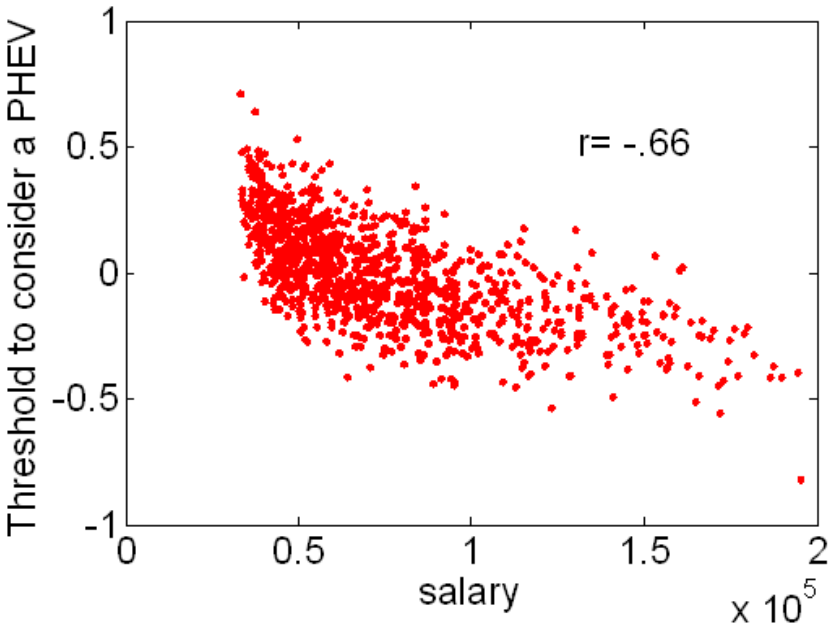
Other agent attributes were then randomly generated using multivariate normal distributions with loose correlations to salary, then transformed to appropriate distributions as needed.



•Threshold of proportion of perceived fleet that is a PHEV over which vehicle consumers would even consider buying a PHEV was normally distributed with a mean of 0, meaning that roughly half of consumers are willing to be 'early-adopters' of this technology.

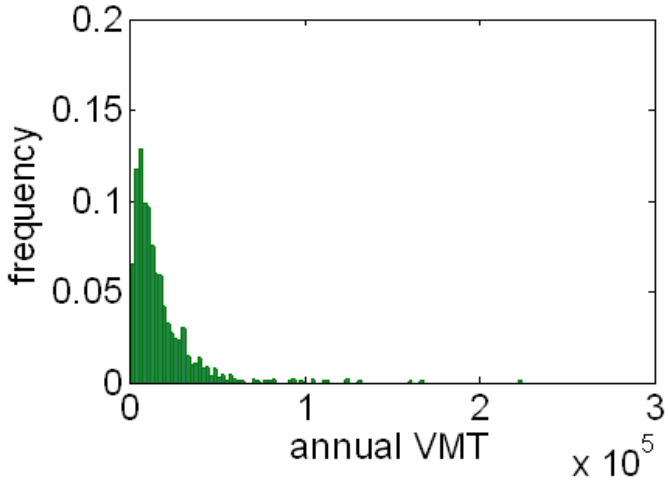
•This is consistent with the 2009 UM/Reuters Survey of Consumers indicating that about 1/2 of consumers would consider a PHEV if the price premium were low enough.

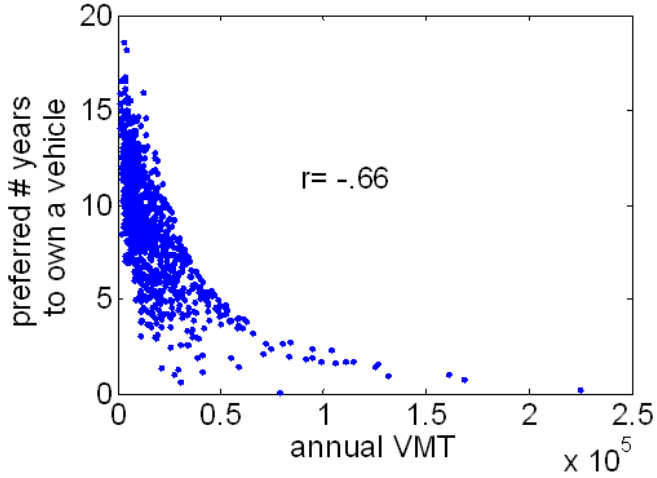




Richer people have a slightly greater tendency to be early adopters.

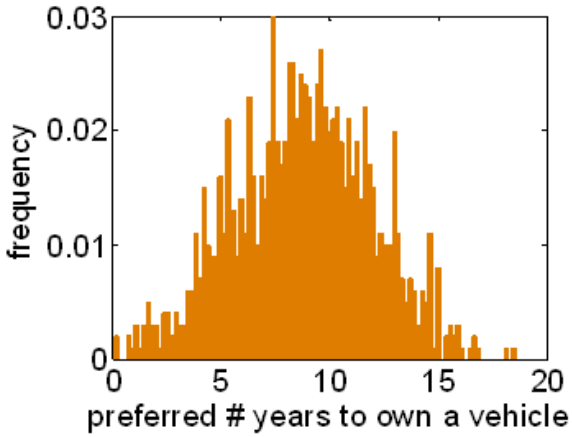
Annual VMT is log-normally distributed with median of ~12K miles (2001 NHTS)

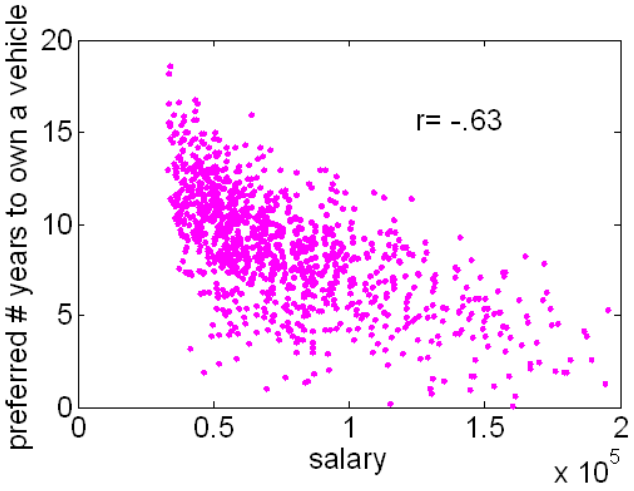




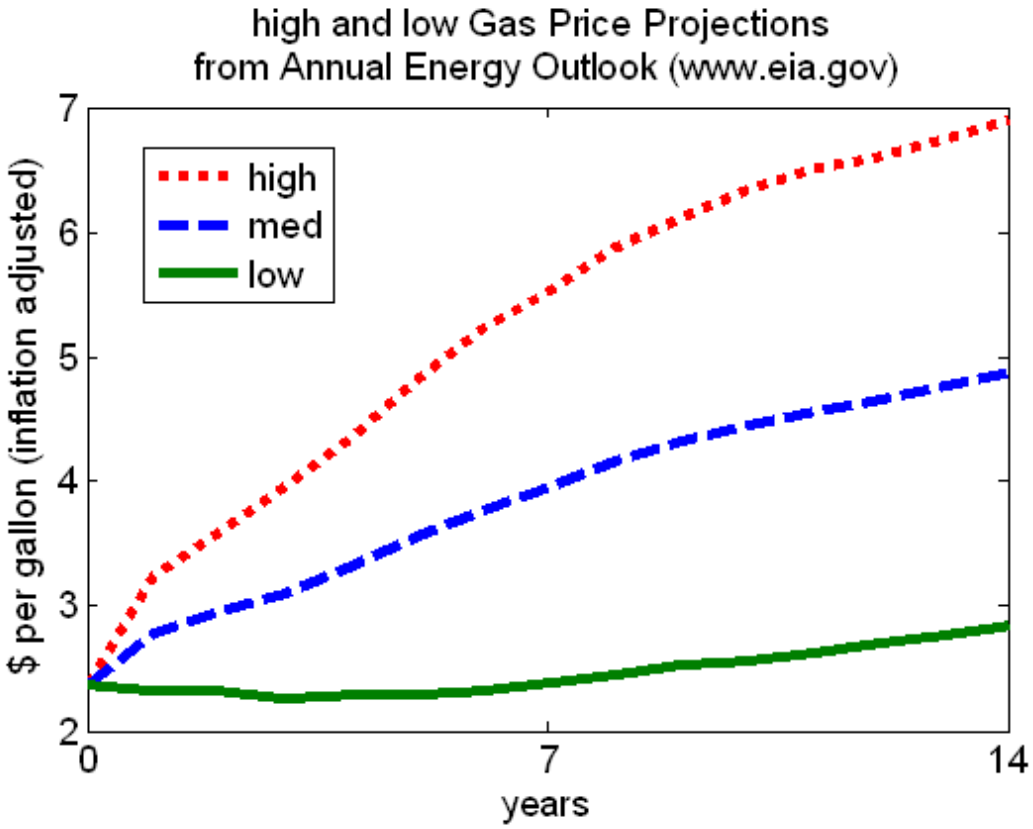
People with higher VMT buy cars more often.

Average number of years consumers own a car is normally distributed with mean of ~9 years (2001 NHTS)





Richer people tend to buy cars more often.



When calculating relative fuel costs of vehicles, agents estimate future gas prices by estimating slope of gas prices over a sliding window (3 yrs previous), then extrapolating ahead using that slope.

Average age of vehicle in initial fleet is 5 years
Average mpg of initial fleet is normally-distributed with mean =25.1
(RITA Bur. Trans. Stats. 2009)

epresentative Simulation to Illustrate System Dynamics:
Annual HEV and PHEV purchases show

When PHEV is first introduced, lots of people consider buying a car earlier than they would otherwise.

due to l
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ahead;
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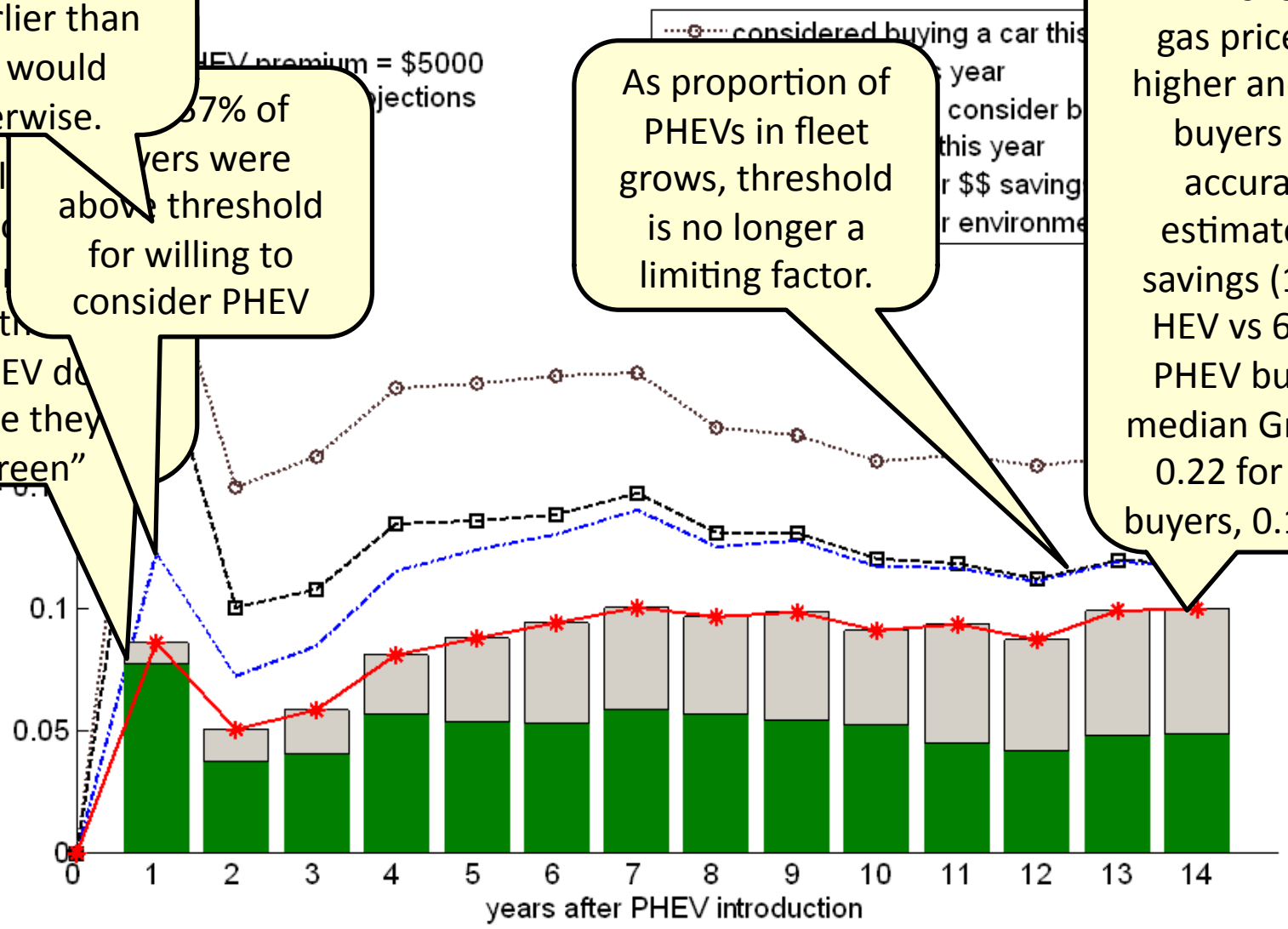
the PHEV d
because they
“”Green”

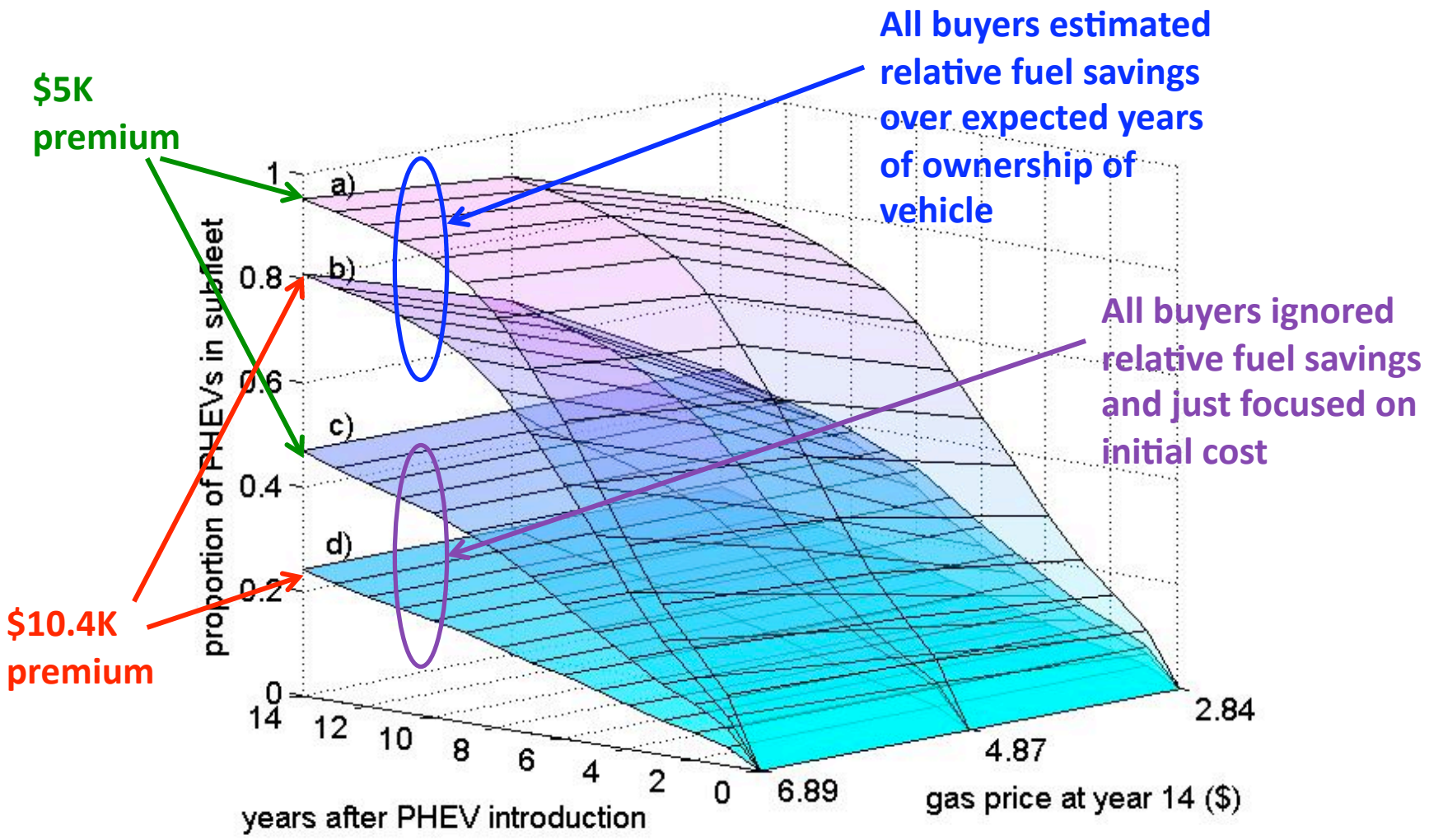
7% of
ers were
above threshold
for willing to
consider PHEV

As proportion of PHEVs in fleet grows, threshold is no longer a limiting factor.

By year 14, 80% of buyers select PHEV over HEV; gas prices are higher and more buyers now accurately estimate fuel savings (17% of HEV vs 67% of PHEV buyers); median Greeness 0.22 for PHEV buyers, 0.13 HEV)



Sensitivity Study



Note: As gas prices increase, potential gains in PHEV adoption are more strongly influenced by how accurately consumers estimate potential fuel savings than they are by the halving the PHEV price premium.

Conclusions

We have presented an agent-based modeling framework for simulating PHEV adoption

- accounts for social and spatial influences
- can extended to more vehicle types as specs become available

Such a model could be potentially useful to inform policy-makers and/or vehicle manufacturers; e.g.,

- Assess how much impact reducing price premium could have (e.g., through governmental incentives or improved battery manufacturing technology)
- Recognize that making it easy to accurately estimate relative lifetime fuel costs (under different gas price scenarios) could dramatically increase PHEV adoption (e.g., through simple web-based calculators and/or kiosks in dealerships)
- Assess potential effectiveness of spatially explicit marketing and distribution strategies

More data is needed to improve accuracy of agent-based rules, attitudes (such as greenness), and correlations in demographics.

This work was funded in part by the United States Department of Transportation through the University of Vermont Transportation Research Center.

We gratefully acknowledge computational resources and expertise provided by the Vermont Advanced Computing Center.

This work was in collaboration with the University of Vermont Complex Systems Center.