

Consumers and Low-Carbon Mobility Technology Diffusion

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New Thinking Symposium

Canadian Museum of Nature

February 28, 2020

Outline

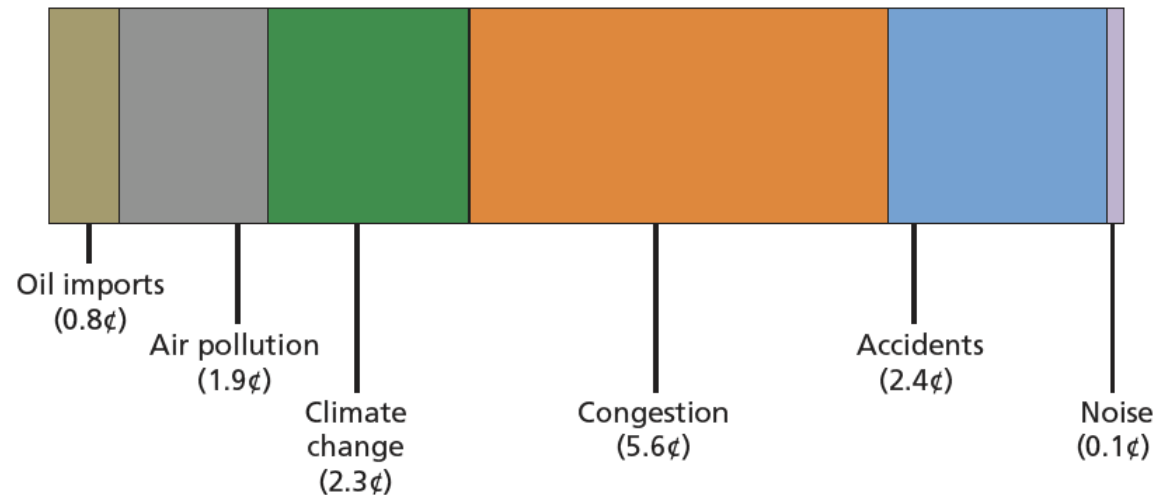
- The carbon uncertainty of mobility innovation
- Frameworks for adoption/diffusion of innovation
- Application to a consistent puzzle: the gender gap in PEV diffusion

The carbon uncertainty of
mobility innovation

Focus here on vehicles

- Positive aspects of motor vehicles
 - Commerce, independence, convenience...
- Negative aspects of motor vehicles

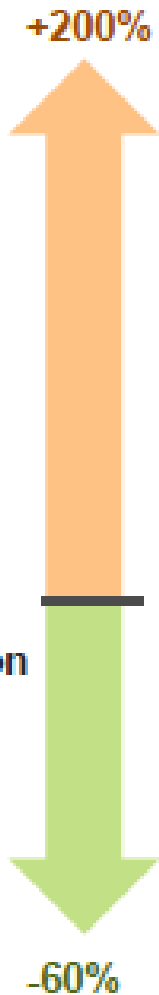
Rand estimate of the per-mile externalities associated with driving a motor vehicle



NOTE: Estimates are in 2010\$ and based on NHTSA (2012a) values. GHG emissions use the central value from the U.S. Interagency Working Group on the Social Cost of Carbon (2013). Emissions factors are well-to-wheel for a 24.8-mpg vehicle using data from Argonne National Laboratory (2012).

RAND RR443-2.1

Uncertain Energy Impacts: Automated Vehicles



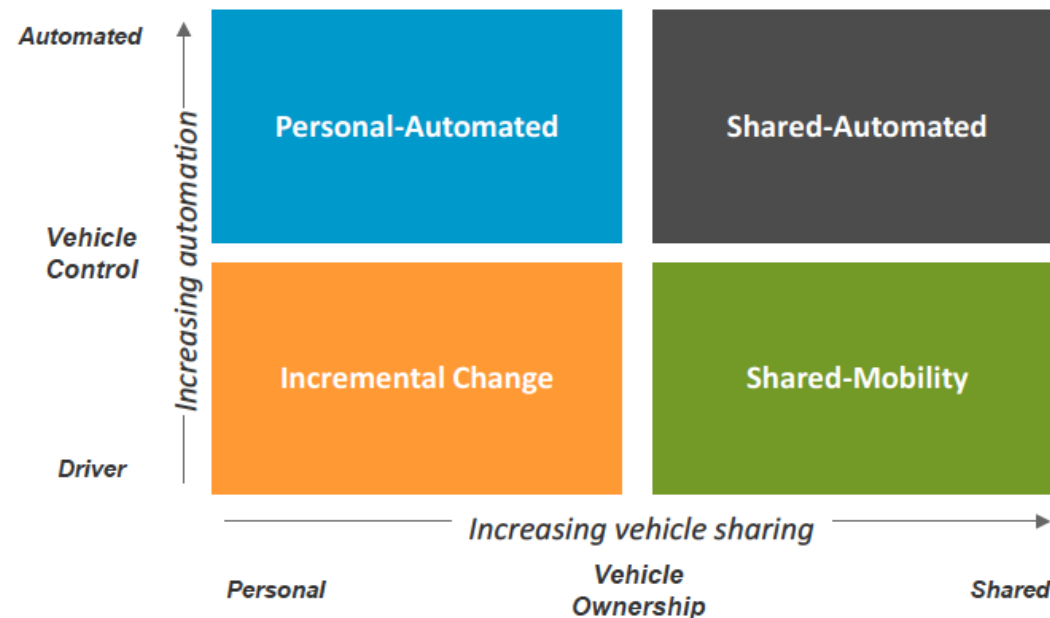
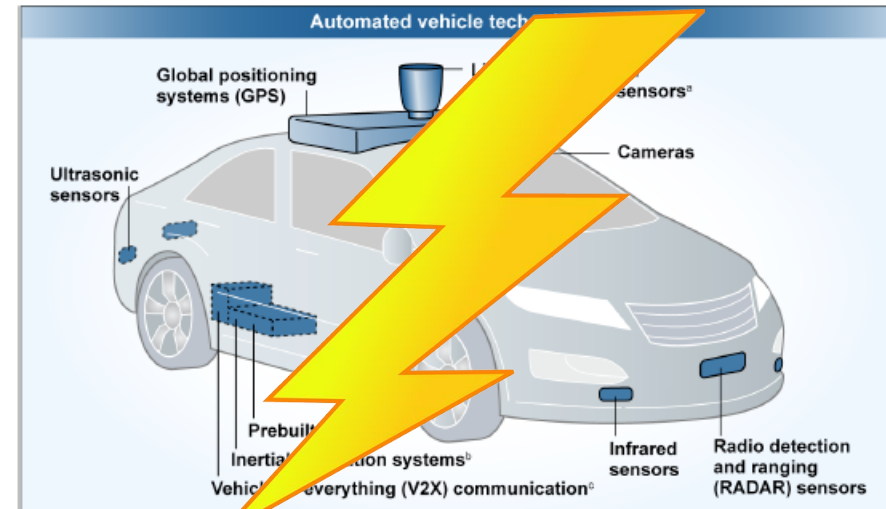
*Factors potentially contributing to an increase in energy consumption and associated emissions**:*

- + Reduced Travel Costs
- + Increased Vehicle Miles Traveled (VMT)
- + Zero-Occupancy Vehicles
- + Access for New User Groups
- + Faster Driving Speeds
- + Shipment of Goods
- + Increased Features

*Factors potentially contributing to a decrease in energy consumption and associated emissions**:*

- Platooning or Drafting
- Eco-Driving
- Congestion Mitigation
- De-emphasized Performance
- Emerging Mobility Service Models
- Improved Crash Avoidance
- Power Train Efficiencies
- Zero Emission Vehicles (ZEVs)**
- Less Hunting for Parking
- Vehicle Right Sizing

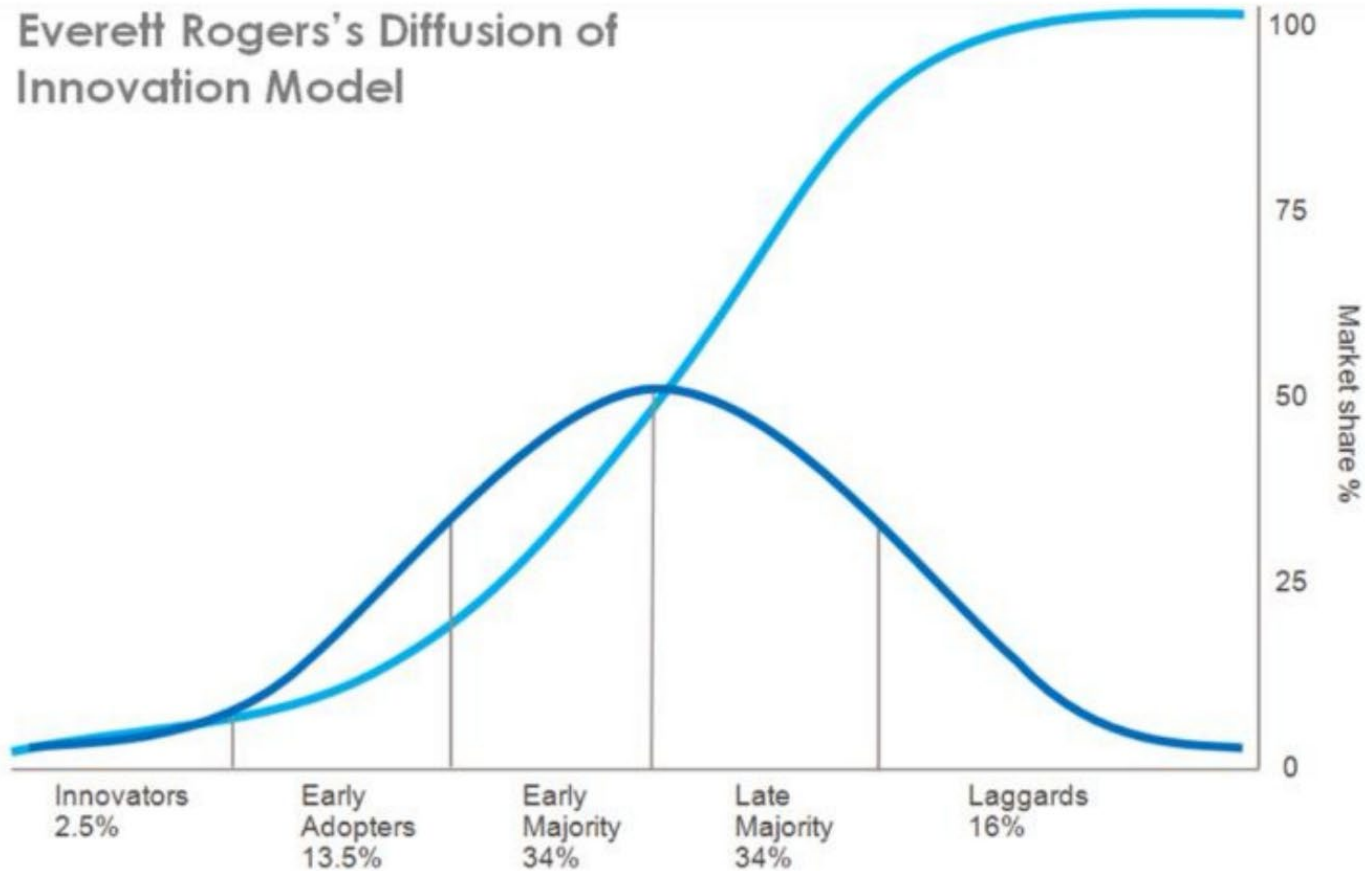
Current Energy Consumption Levels*



Source: The Transforming Mobility Ecosystem: Enabling an Energy Efficient Future (DOE 2017)

Frameworks for
adoption/diffusion of innovation

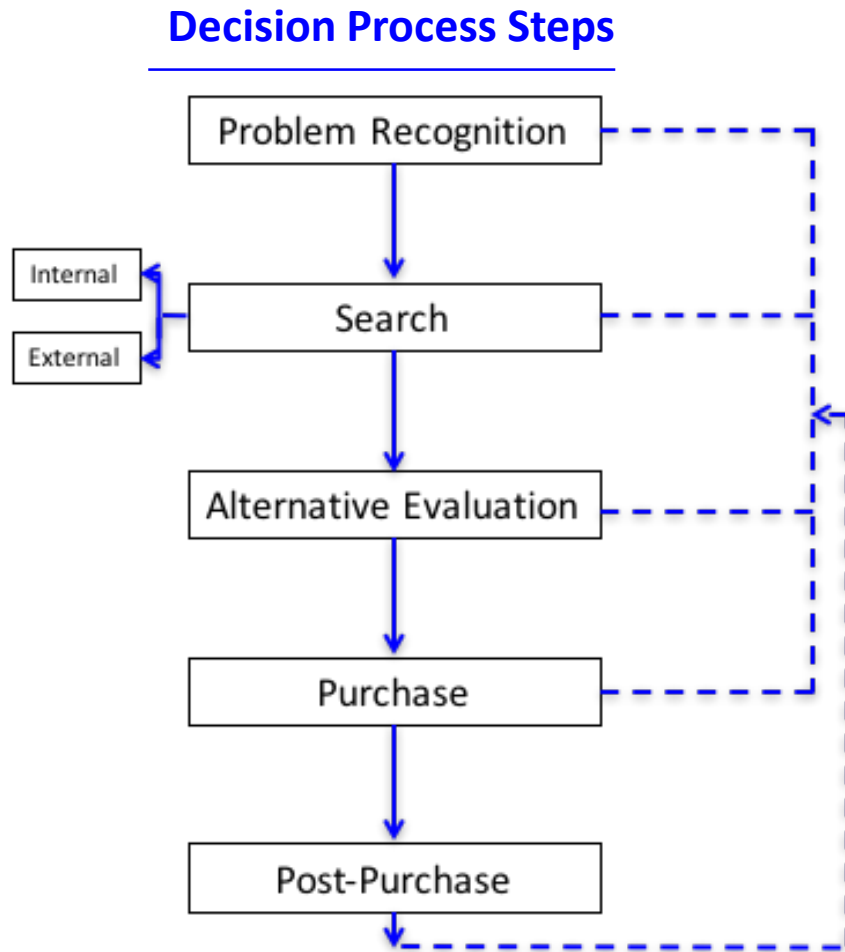
Most common framework for diffusion



Thinking about consumers...

- Transportation sector
 - Owners of vehicles (if multiple vehicles, purchase through procurement)
 - Users of transit systems
 - Customers of TNCs (e.g., Uber, Lyft)
 - Customers of oil companies (e.g., Shell, Exxon, etc.)
- Electricity sector
 - Rate-payers of utilities (traditionally natural monopoly)
- Building sector
 - Owners (deal with operating costs)
 - Renters

Perhaps more Leverageable for Policy: The EKB Model of the Purchase Decision Process



Influences

• **Internal factors**

- Long-term
 - Demographic, psychological, and behavioral attributes
 - Consumer experience with product/brand
 - Switching costs
 - Brand attitude, loyalty
- Short-term
 - Affect throughout the process
 - Impulse triggers

• **External factors**

- Perception of risk
 - Negative consequences of a poor purchase decision
 - Probability of negative consequences
 - Prospect theory
 - Search, experience, credence goods
- Risk management/consumer involvement in purchase
 - Constraints regarding purchase context
 - Too little time
 - Rapidly changing products
- Role of third parties

Application to a consistent puzzle:

The gender gap in plug-in electric vehicle (PEV)
diffusion

The PEV Gender Gap & the Whole Traveler Survey

- Women are:
 - Half of U.S. drivers
 - Involved in 85% of purchase decisions of all product types
 - Involved in the majority of vehicle purchase decisions
- Fewer women than men express interest in or adopt plug-in electric vehicles (PEV) across regions, countries, and time
- The Whole Traveler (WT) survey addresses transportation preferences and behaviors of 1,045 San Francisco Bay Area respondents. It covers:
 - Past, present, and future use of or interest in emerging transportation technologies and services, including PEVs, shared mobility, and AVs
 - Questions get at many internal and external factors from the EKB slide
 - From the make/model/year of respondents' cars, we added vehicle-specific data (e.g., seats, cargo space, safety rating, MSRP)
- WT gender gap for PEV interest/ownership is 14.7% (63.5% of men and 48.8% of women)
 - There are also significant gender differences across demographic, personality, and preference variables

Hypotheses on the Gender Gap

Group	Hypothesis
H1: Risk	H1a: Monetary risk aversion mediates the gender gap (+)
	H1b: Concern for physical safety mediates the gender gap (+)
H2: Personality	H2a: Openness suppresses the gender gap (-)
	H2b: Neuroticism mediates the gender gap (+)
	H2c: Extraversion suppresses the gender gap (-)
	H2d: Agreeableness suppresses the gender gap (-)
	H2e: Conscientiousness mediates the gender gap (+)
H3: Willingness and/or ability to pay mediates the gender gap (+)	
H4: Transportation Preferences	H4a: Factors related to household responsibility for transporting family members and household goods mediate the gender gap (+)
	H4b: Factors related to commute habits suppress the gender gap (-)

Hypotheses, as Operationalized

Group	Hypothesis	Key Variable(s)	% mediated (+) or suppressed (-)
			By individual variable
H1: Risk	H1A: Monetary risk	Risk averse identifier	- 2.38**
	H1B: Certainty of timing	Predictable time index	- 1.36**
		Short travel time index	- 1.12**
H1C: Safety	Safety importance index Vehicle safety rating †	3.23** 0.41***†	
H2: Personality	H2A: Openness	Openness score	- 1.2**
	H2B: Agreeableness	Agreeableness score	- 4.71**
	H2C: Extraversion	Extraversion score	- 0.39**
	H2D: Neuroticism	Neuroticism score	0.81**
	H2E: Conscientiousness	Conscientiousness score	6.53**
H3: Willingness and/or Ability to Pay		Income level Low cost index Discount factor Predictable cost index Vehicle purchase price †	10.28** 0.74** 0.28** 1.66** 0.12***†
H4: Transportation Preferences	H4A: Moving people and things	Child(ren) in household	0.28**
		Child transport index	1.57**
Vehicle seats (#) †		3.17***†	
Multiple stops index		7.28**	
Low hassle index		0.6**	
Vehicle cargo capacity †		3.05***†	
	H4B: Commute habits	Primary commute distance‡	0.3**
H5: Environmental preferences		Environmental index	-1.17**

Key mediating and suppressing variables

Mediator Variables	% of WT Gender Gap Explained
Income level	10.28
Multiple stops index	7.28
Conscientiousness score	6.53
Safety importance index	3.23
Vehicle seats (#) †	3.17
Vehicle cargo capacity †	3.05
Predictable cost index	1.66
Child transport index	1.57
Neuroticism score	0.81
Low cost index	0.74
Low hassle index	0.6
Vehicle safety rating †	0.41
Primary commute distance‡	0.3
Discount factor	0.28
Child(ren) in household	0.28
Vehicle purchase price †	0.12
Total Explained: 30.7% (PEV gap from 14.7 to 10.2%)	

Suppressor Variables	% of WT Gender Gap Explained
Agreeableness score	-4.71
Risk averse identifier	-2.38
Predictable time index	-1.36
Openness score	-1.20
Environmental index	-1.17
Short travel time index	-1.12
Extraversion score	-0.39
Total Explained: 11.7% (PEV gap from 14.7 to 16.4%)	

Prompts policy ideas beyond rebates...

Mediator Variables	% of WT Gender Gap Explained
Income level	10.28
Multiple stops index	7.28
Conscientiousness score	6.53
Safety importance index	3.23
Vehicle seats (#) †	3.17
Vehicle cargo capacity †	3.05
Predictable cost index	1.66
Child transport index	1.57
Neuroticism score	0.81
Low cost index	0.74
Low hassle index	0.6
Vehicle safety rating †	0.41
Primary commute distance‡	0.3
Discount factor	0.28
Child(ren) in household	0.28
Vehicle purchase price †	0.12
Total Explained: 30.7% (PEV gap from 14.7 to 10.2%)	

Implications for charger locations

Suppressor Variables	% of WT Gender Gap Explained
Agreeableness score	-4.71
Risk averse identifier	-2.38
Predictable time index	-1.36
Openness score	-1.20
Environmental index	-1.17
Short travel time index	-1.12
Extraversion score	-0.39
Total Explained: 11.7% (PEV gap from 14.7 to 16.4%)	

Implications for carpool lane access

Thank you!
Questions?

For more information:

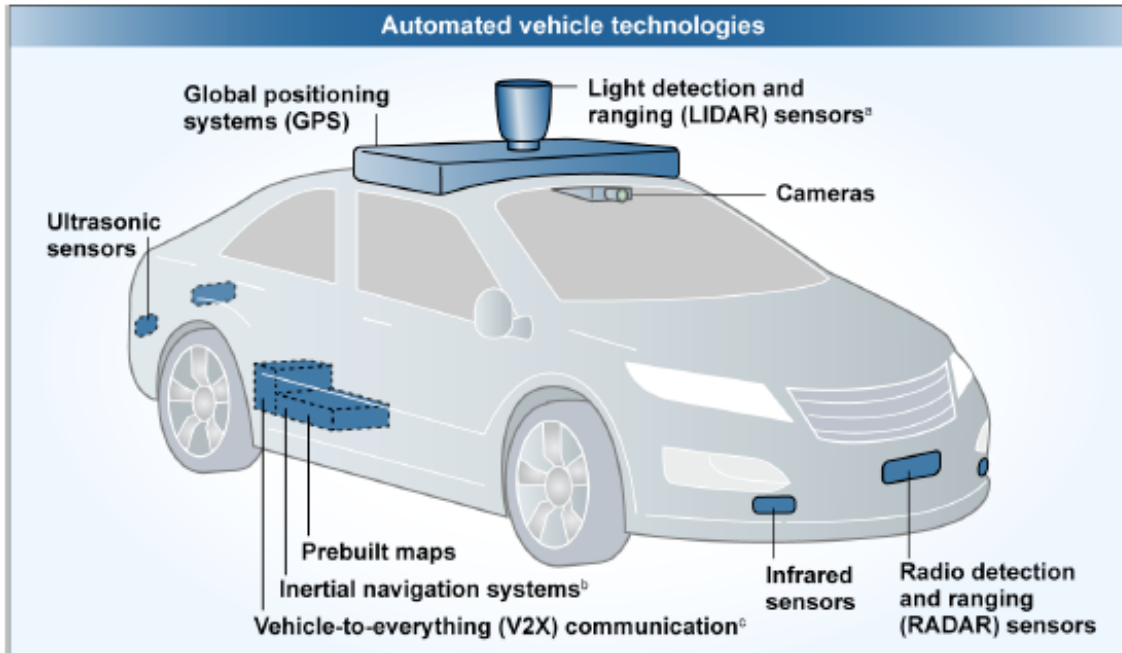
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Back-Up Slides

Group	Hypothesis	Key Variable(s)	% mediated (+) or suppressed (-)		
			By individual variable	Mediate / suppress by hypothesis group	All hypothesis group variables
H1: Risk	H1A: Monetary risk	Risk averse identifier	- 2.38**	-3.80	-0.05
	H1B: Certainty of timing	Predictable time index Short travel time index	- 1.36** - 1.12**		
	H1C: Safety	Safety importance index Vehicle safety rating †	3.23** 0.41***†	4.98	
H2: Personality	H2A: Openness	Openness score	- 1.2**	-5.69	-0.40
	H2B: Agreeableness	Agreeableness score	- 4.71**		
	H2C: Extraversion	Extraversion score	- 0.39**		
	H2D: Neuroticism	Neuroticism score	0.81**	8.97	
	H2E: Conscientiousness	Conscientiousness score	6.53**		
H3: Willingness and/or Ability to Pay		Income level Low cost index Discount factor Predictable cost index Vehicle purchase price †	10.28** 0.74** 0.28** 1.66** 0.12***†	10.27	10.27
H4: Transportation Preferences	H4A: Moving people and things	Child(ren) in household	0.28**	10.17	9.99
		Child transport index	1.57**		
Vehicle seats (#) †		3.17***†			
Multiple stops index		7.28**			
Low hassle index		0.6**			
		Vehicle cargo capacity †	3.05***†		
	H4B: Commute habits	Primary commute distance‡	0.3**	0.3**	
H5: Environmental preferences		Environmental index	-1.17**	-1.17	-1.17

Technology Developments - 1



^aLIDAR is a technology that uses laser remote sensing to map the vehicle's surroundings.

^bInertial navigation systems consist of gyroscopes and accelerometers to constantly track the vehicle's position and help improve the accuracy of the GPS

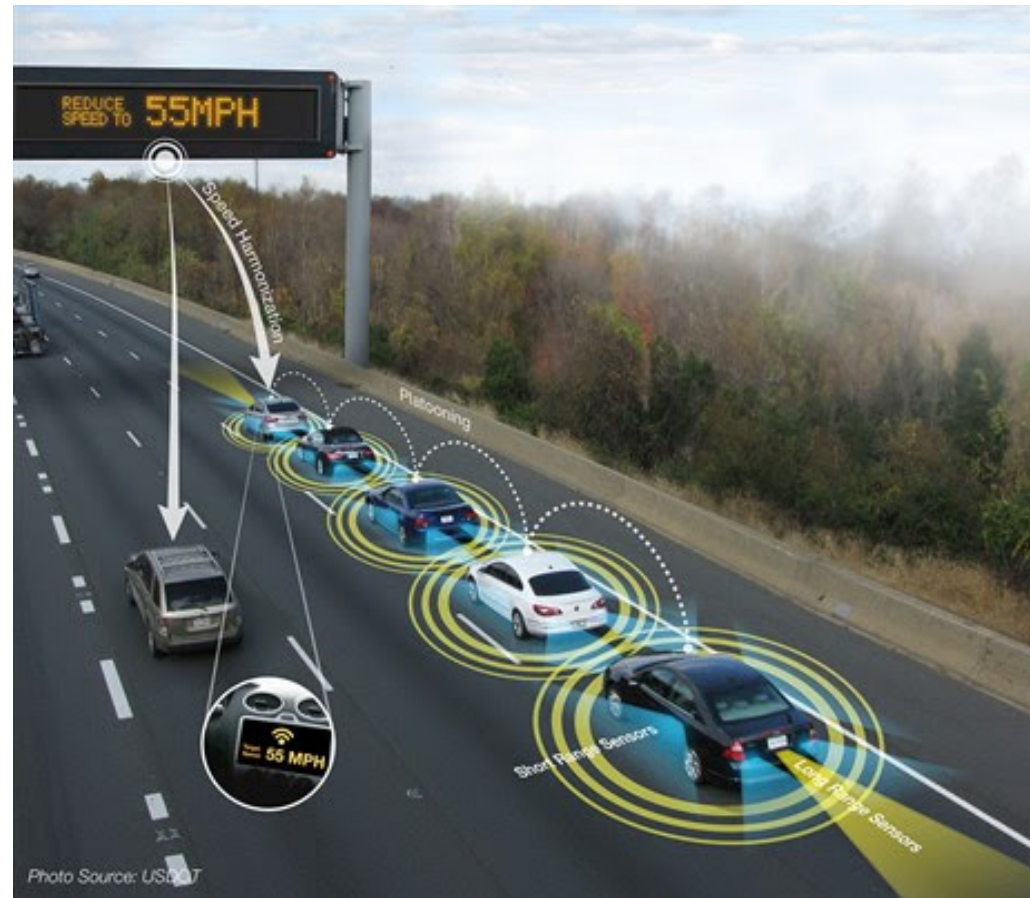
^cV2X encompasses communication between other vehicles or other permanently installed infrastructure.

Levels of driving automation adopted by Department of Transportation

Level	Name	Definition
0	No automation	Human driver controls all aspects of dynamic driving tasks, even when enhanced by warning system
1	Driver assistance	Automation controls one vehicle function (e.g., steering or speed)
2	Partial automation	Automation controls both steering and speed with driver responsible for monitoring and immediate reengagement
3	Conditional automation	Automation controls both steering and speed and monitors environment; driver may be notified to reengage
4	High automation	Automation performs all aspects of dynamic driving tasks in some driving modes; driver not required to reengage
5	Full	Automation performs all aspects of dynamic driving tasks under all

Technology Developments - 2

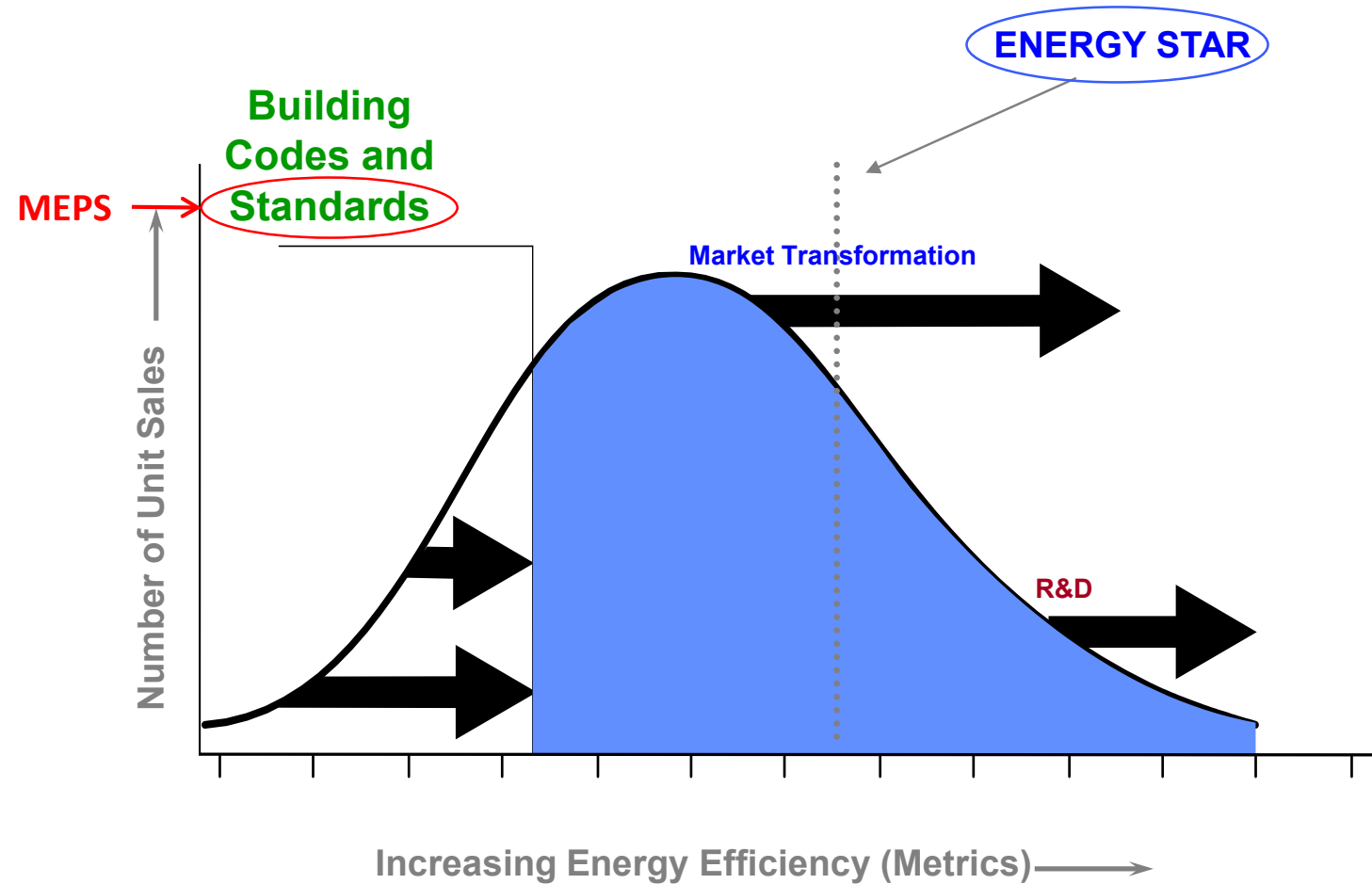
- Infrastructure issues
 - Sensors
 - Radio-frequency spectrum
 - Parking

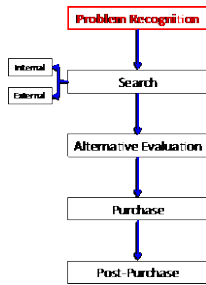


- we performed two aggregate analyses combining, across all hypotheses: 1) all consistent mediators, and 2) all suppressors (not included in Table 1). In the combined analysis, we estimate that the group of all consistent mediators together mediate 30.7% of the PEV gender gap ($p < 0.05$). That is, the gender gap in PEV interest observed in our dataset would be 30.7% smaller (i.e., a gap of 10.2% rather than 14.7%) were it not for gendered differences across the attributes captured by our set of mediating variables.
- In the combined analysis, we estimate that the group of all inconsistent mediators together suppress 11.7% of the PEV gender gap ($p = 0.15$). Suppressors can be counterintuitive to interpret. Our finding suggests that in the absence of the gendered differences across the suppressing variables (e.g., if women did not tend to have higher levels of environmental concern or higher levels of agreeability, etc.), we would expect the PEV gender gap to be 11.7% larger. That is, we would observe a gender gap of 16.4% rather than 14.7%.

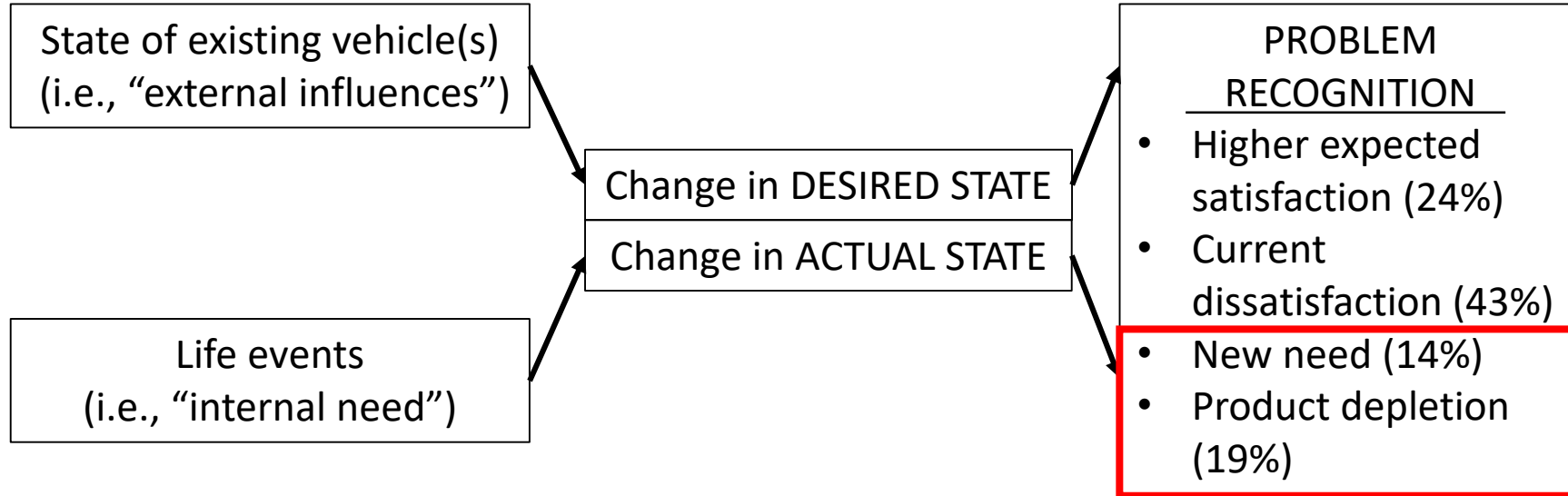
Concept Underlying Federal Policy

The Energy Star "Theory of criteria setting" Source: Karney (2004)



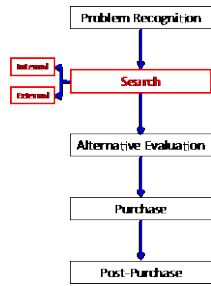


Problem Recognition Insight: Not all Consumer Segments will Approach Purchase in the Same Way



Source: Punj & Srinivasan (1992)

- **New need** segment (18% today?):
 - Shopped for the highest number of aggregate models across dealer visits
- **Product depletion** segment (30% today?):
 - Considered the smallest number of makes before visiting a dealership;
 - Made the smallest number of pre-decisions;
 - Shopped for the smallest number of aggregate models across dealership visits

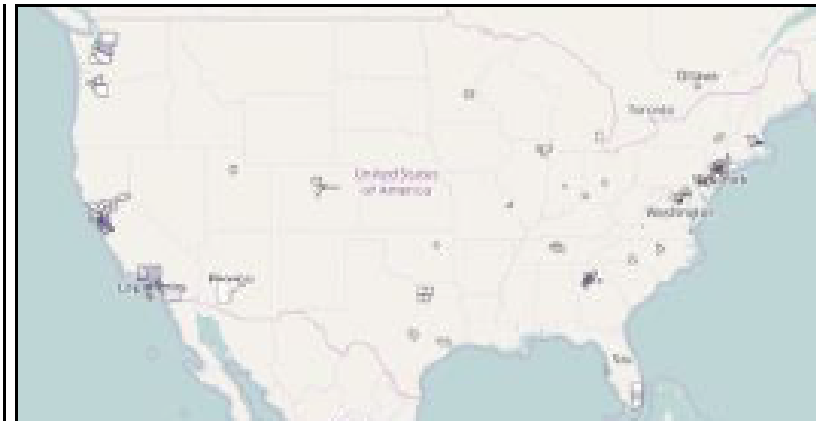


Search Insight: Uneven PEV + Infrastructure Distribution Matters

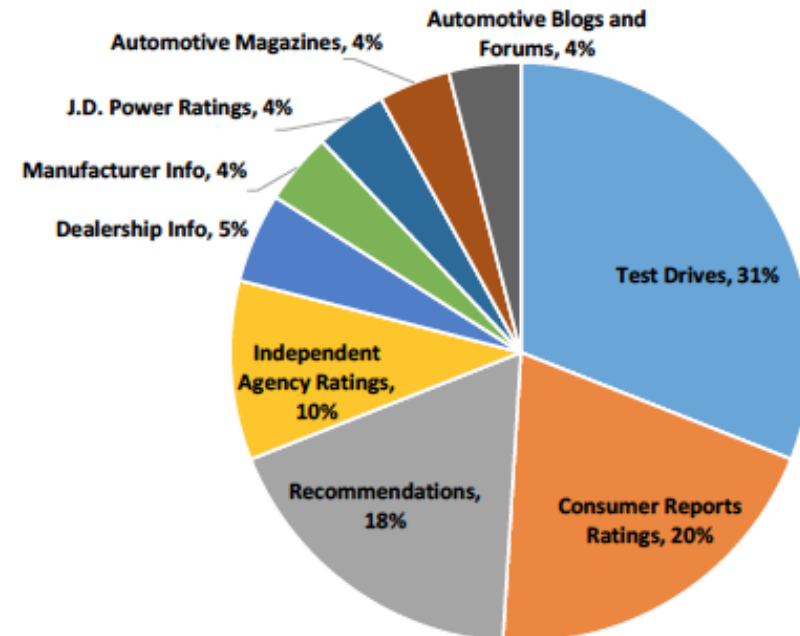
HEV Density

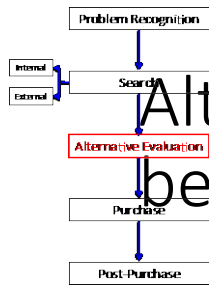


BEV Density



- Internal search heuristics
- External search mechanisms (e.g., test drives, personal recommendations)





Alternative Evaluation Insight: Match/Mismatch between Reasons to Purchase vs. Reject Purchase

Top reasons for LDV Purchase:

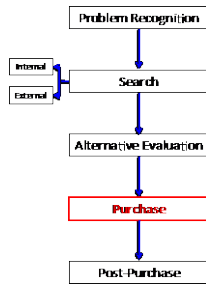
1. Reliability
2. Durability
3. Quality of workmanship
4. Values for the money
5. Manufacturer's reputation

Top reasons for PEV purchase (CA)

1. Save money on fuel cost
2. Reduce environmental impact
3. HOV lane access
4. Increase energy independence
5. Want a vehicle with new/better technology

Top reasons to reject PEV purchase

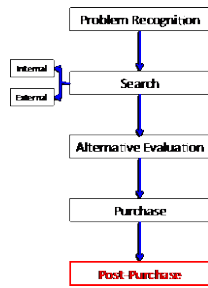
1. Too expensive
2. Not available in desired vehicle class
3. Technology not dependable
4. Poor performance
5. Other



Purchase Insight: Dealerships Matter

- Shrinking number of dealerships
- Distribution of product across dealerships
- Purchase complexity
 - Heterogeneous state incentives
 - Lease terms
 - Technical information

Year	Number of Franchised New LDV Dealerships
1970	30,800
1975	29,600
1980	27,900
1985	24,725
1990	24,825
1995	22,800
2000	22,250
2005	21,640
2010	18,460
2015	16,545



Post-Purchase Behavior-Relevant Insights

- PEV buyers vs ICE buyers:
 - More male, wealthy, married, professional, college-graduates...
- Distance between consumer expectations and actual satisfaction has a major effect on product evangelism – not much research on this
- Role of charging behavior is important and understudied
 - Physical issues (e.g., out-of-order chargers...)
 - Behavioral issues (e.g., occupied parking spaces, etiquette...)
 - Home charging most important
- Availability and affordability are issues (Axsen and Kurani 2012), especially as PEVs come off lease and enter secondary market (2/3 of vehicle sales)
- Visible public charging adds to sales, but how much is not clear enough to inform tradeoffs re: over-capacity issue for utilities
- Question if people (especially non-PEV owners) recognize a charger when they see one...