Behavior and the Diffusion of Innovations for Climate Goals: The Case of Electric Vehicle Adoption

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Tonight's Talk

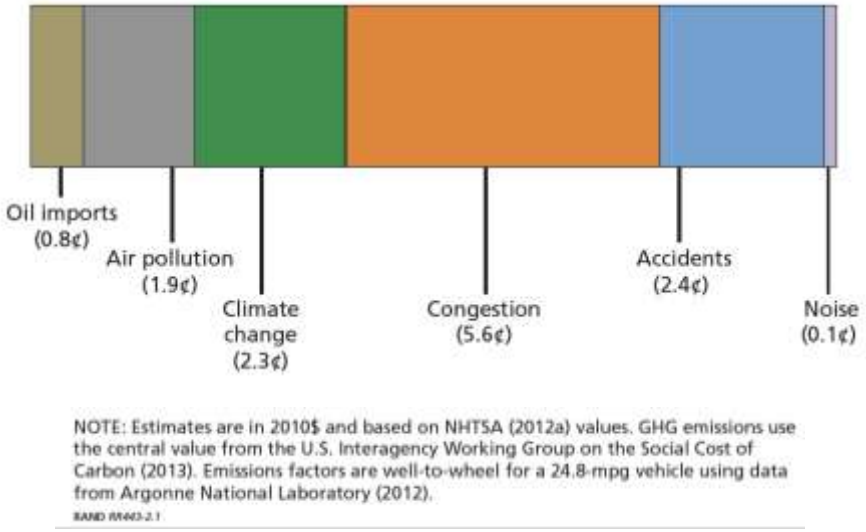
- Background on the case
  - Why decision-makers care about plug-in electric vehicles (PEVs = plug-in hybrids + electric vehicles)
  - PEV-related public problems and U.S. policy events, with deeper dive on California policy
  - Clean energy innovation decision science and frameworks re: the development and diffusion of PEVs
- Behavior and PEV diffusion
  - Insights from a diffusion framework based on the EKB model of the purchase decision process
  - A deeper dive into the gender divide on PEV interest and adoption
- Discussion of the broader applicability of this framework

Background on the Case

Why decision-makers care about light-duty 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



A brief history of PEV-related public problems and U.S. policy events

- Local air quality
  - Los Angeles smog
  - Non-attainment areas under the 1970 Clean Air Act
- Petroleum demand
  - Gasoline shortages and price shocks in the 1970s
- Economic development
  - California aerospace and the end of the Cold War
- Greenhouse gas emissions from transportation
  - Transportation exceeded electricity as the biggest U.S. GHG emissions source for the first time in 2017
- Resilience of the electricity sector

Pollution standards, California waiver

Corporate Average Fuel Economy standards

California LEV regulation with ZEV mandate, seeds a cluster

California: Clean Air Vehicle decals, vehicle GHG standards

Fed: Supreme Court decision, EPA, NHTSA harmonize w/California

LEV Regulation

- Requires mfrs of light-duty vehicles to produce any combination of LEV categories – with one exception – as long as they meet sales-weighted fleet averages for Non-Methane Organic Gases
  - In 1990 "LEV I," categories, which met different emission requirements, were transitional low-emission vehicles (TLEV), low-emission vehicles, ultra-low emission vehicles (ULEV), and zero-emission vehicles (ZEV).
  - ZEV is the exception - large mfrs required to produce and deliver for sale ZEVs as a gradually increasing percentage of their fleets (up to 10%)
- Noteworthy policy attributes
  - A departure from the single, uniform standards applied to each vehicle under previous California and federal legislation
  - Provides long lead times to manufacturers
  - Incorporates a tradable credit system
  - Establishes a biennial review process re: regulation and tech developments
- Technical advances occurred which allowed CARB to ratchet down emissions standards in LEV II in 1999 (MY 2004-2014)
- LEV III adopted in 2012 (MY 2015 onward for both smog (superseding LEV II) and GHG (superseding Pavley) emissions

ZEV Regulation

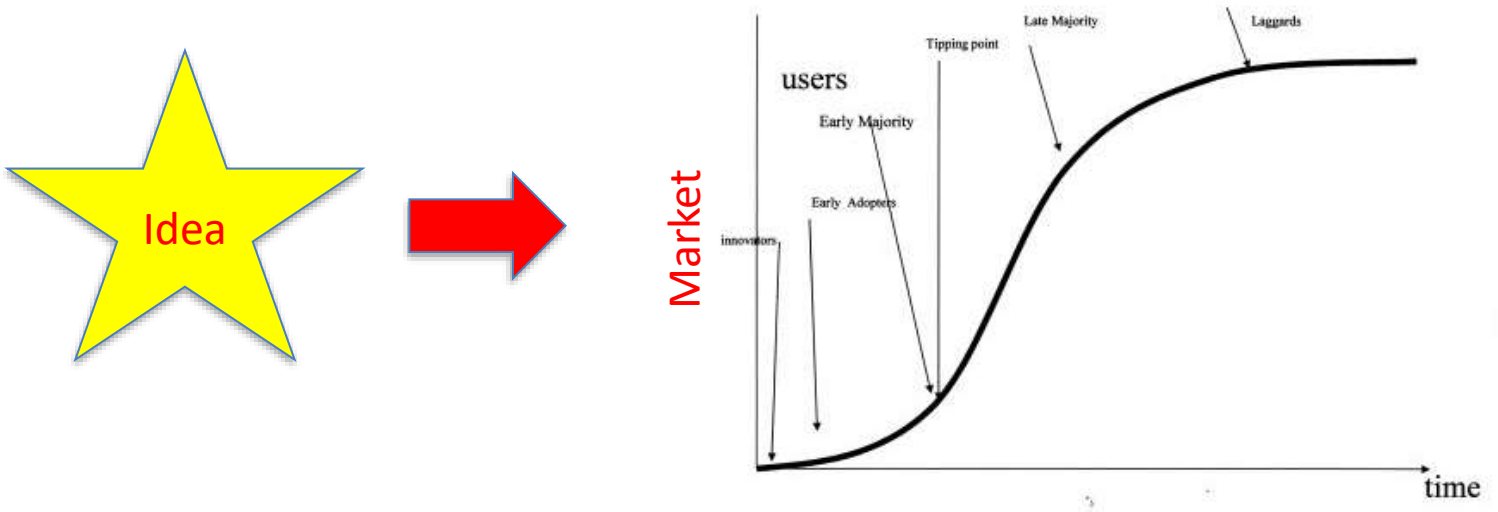
- ZEV exists because of expectation that non-ICEs were required as a long-term solution to severe air pollution in CA
- Originally required mfrs of LDVs to produce and deliver for sale 2% in MY1998, 5% in MY2001, and 10% in MY2003
  - Manufacturers could purchase ZEV credits from other manufacturers or produce extra ZEVs and bank the credits for future use
- Noteworthy policy attributes
  - Officially technologically neutral
  - Performance-based standard, but with sales mandates
- Technical advances in BEVs, the technology expected to quality soonest for the ZEV program, were slower to develop than anticipated
  - Requirements reduced/changed several times, starting in 1996, when ARB dropped the 1998 and 2001MY targets (it retained the 2003 10% target, however)

Clean Energy Innovation Decision Science

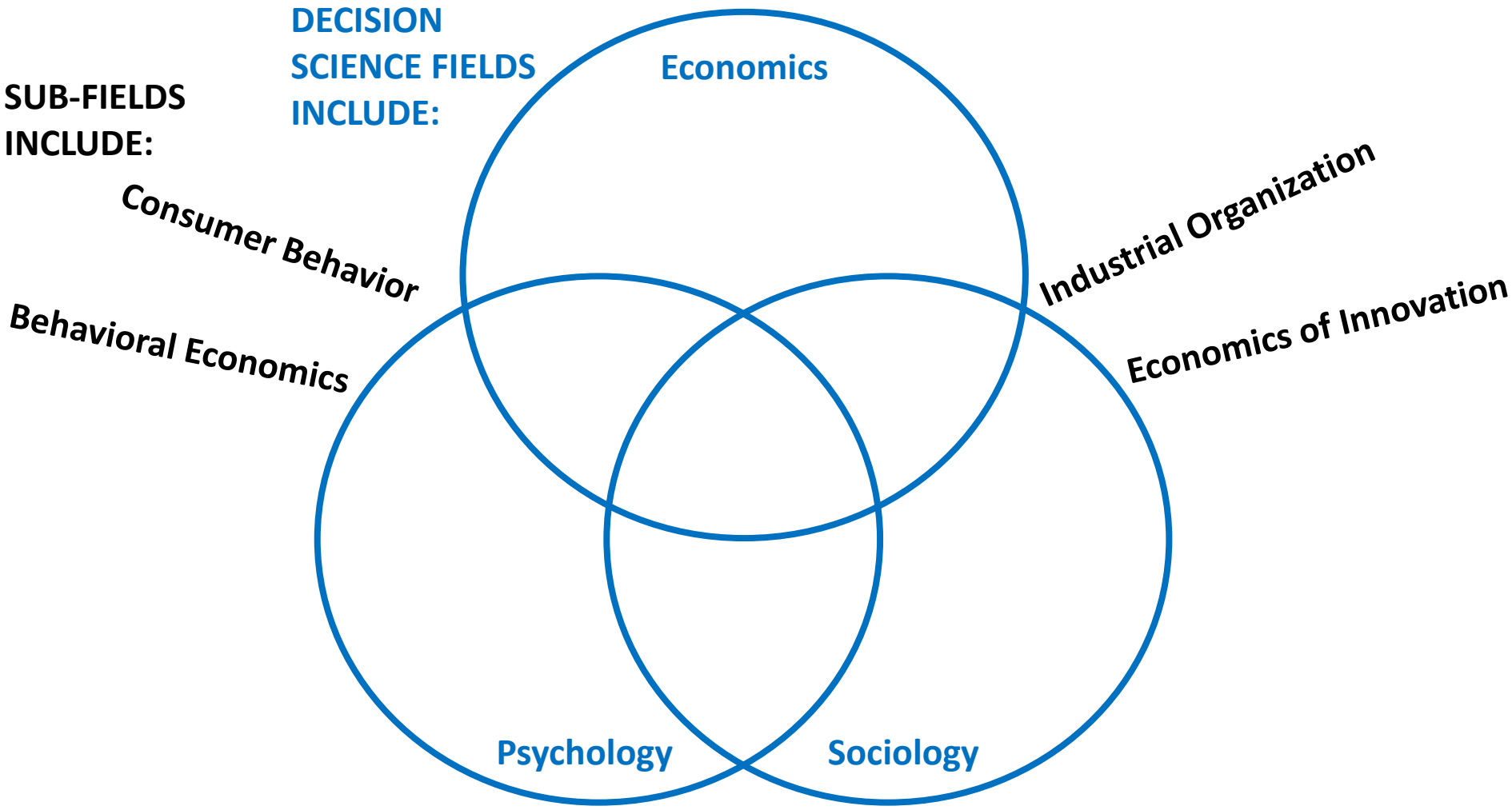
"To accelerate … clean energy technologies, RDD&D should address … design, adoption, and use... [at] the intersection of technology, behavior, and decision science"

2015 DOE Quadrennial Technology Review

- Study of the dynamics by which energy technologies are invented, incorporated into commercial designs, and adopted and used by consumers and businesses
- Involves understanding the forces that shape the market for these technologies



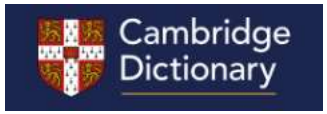
Relevant Fields of Knowledge



Studied a lot of cases of Regulations and Technologies

Type of Regulation	SO2	NOx	Wind	PV	STE	SWH	Dom Apps	Com Prods	Cars
Performance-based standard	✓	✓							✓
Cap-and-trade program	✓	✓							
Rate guarantees			✓	✓	✓	✓			
Renewable portfolio standard			✓	✓	✓				
Minimum efficiency performance standards							✓		
Procurement regulation								✓	
Building regulation				✓					
CA ZEV									✓

About Frameworks



framework

noun

UK /ˈfreɪm.wɜːk/ US /ˈfreɪm.wɝːk/

[C]

a supporting structure around which something can be built

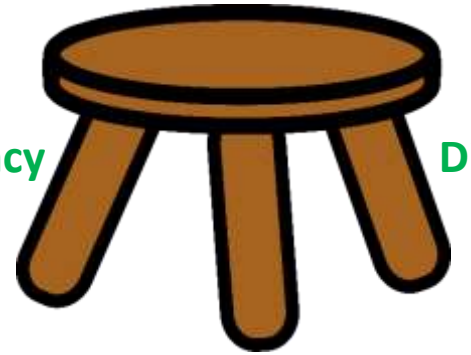
C2

a system of rules, ideas, or beliefs that is used to plan or decide something:

- *a legal framework for resolving disputes*

Frameworks re: the development and diffusion of PEVs

California's framework for sustainable transportation policy

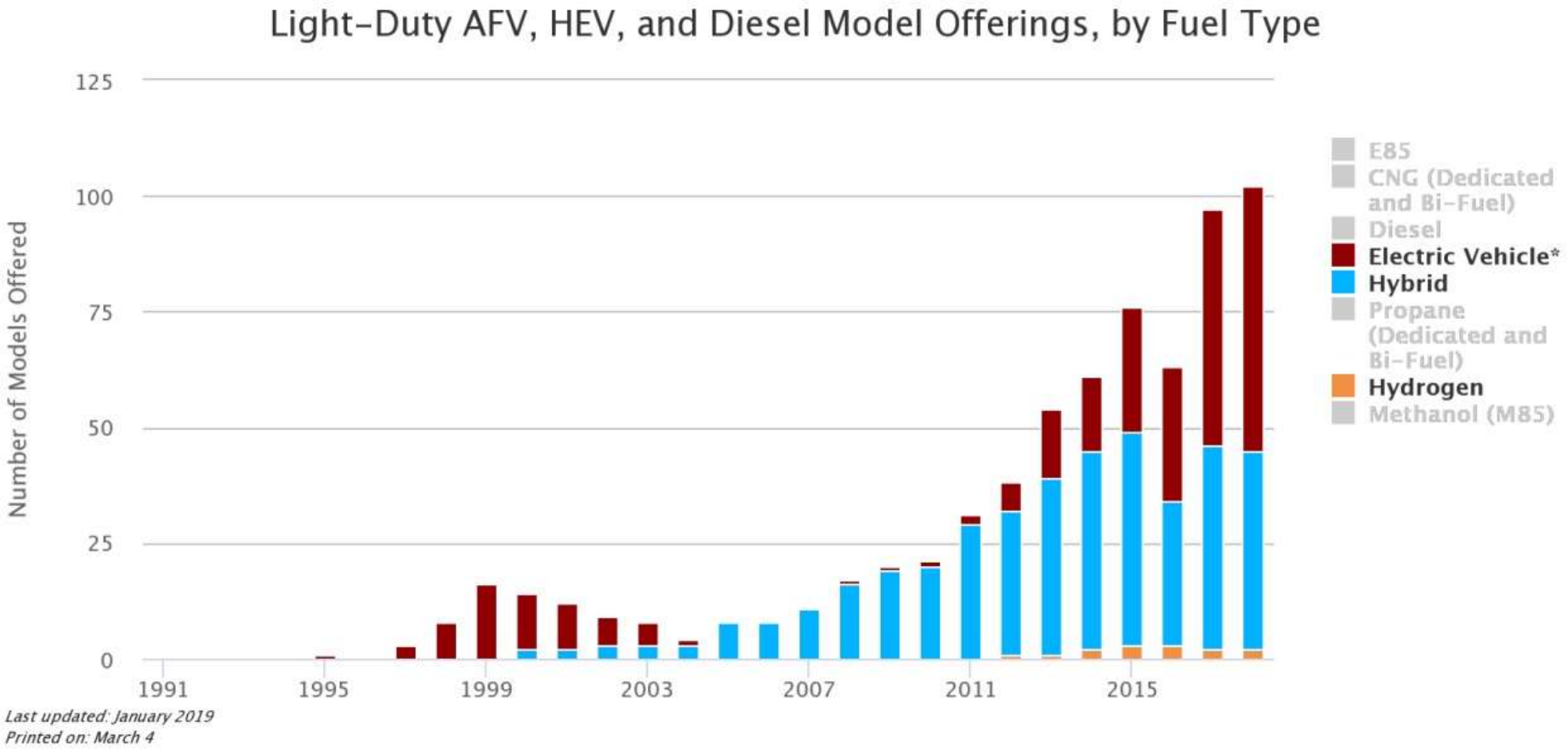


On vehicles, California's LEV/ZEV policy framework was more invention-oriented, or focused on the supply-side of technology. This is in keeping with pollution standards and demonstrated technologies (e.g., the development of the catalytic converter for cars).

Today's PEVs have Consumer Value beyond "Green"

- Fun and safe to drive
  - Electric drivetrains provide full torque fast and the lower center of gravity brought on by battery weight improves handling
- Convenient to charge
  - Mostly fueled at home overnight
- Inexpensive to maintain
  - Many less parts to electric motors, and remaining "consumables" like brakes tend to last longer
- Costs are becoming more comparable, especially with leasing and rebates

Lots of EV models offered for sale



56 MY2018 EVs available in the U.S.

Source: Alternative Fuels Data Center and the *Transportation Energy Data Book 38*

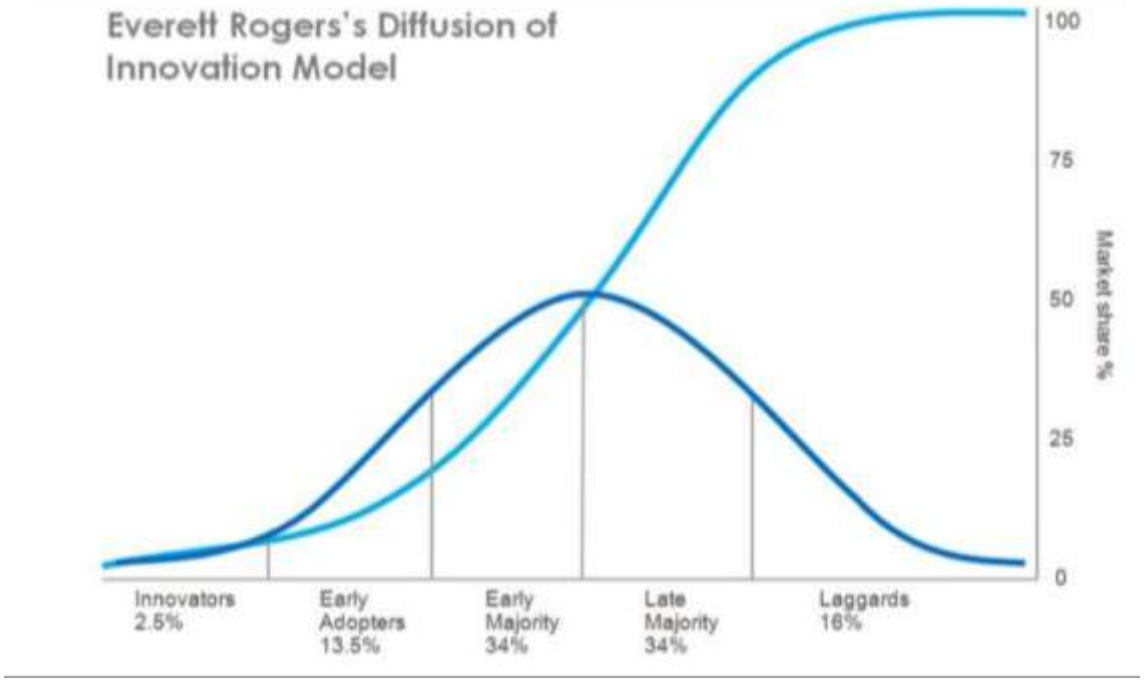
Utility of a diffusion framework on the demand for innovation: Consider vehicle sales

Table 6.2
Hybrid and Plug-In Vehicle Sales, 1999-2018

Calendar year	Hybrid vehicle sales (thousands)	Plug-in hybrid vehicle sales (thousands)	All-electric vehicle sales[a] (thousands)	All light vehicle sales[a] (thousands)	Hybrid share of all light vehicles	Plug-in hybrid share of all light vehicles	All-electric share of all light vehicles
1999	0.0	0.0	0.0	16,711	0.0%	0.0%	0.0%
2000	9.4	0.0	0.0	17,164	0.1%	0.0%	0.0%
2001	20.3	0.0	0.0	16,950	0.1%	0.0%	0.0%
2002	36.0	0.0	0.0	16,675	0.2%	0.0%	0.0%
2003	47.6	0.0	0.0	16,494	0.3%	0.0%	0.0%
2004	84.2	0.0	0.0	16,737	0.5%	0.0%	0.0%
2005	205.9	0.0	0.0	16,774	1.2%	0.0%	0.0%
2006	251.9	0.0	0.0	16,336	1.5%	0.0%	0.0%
2007	351.1	0.0	0.0	15,867	2.2%	0.0%	0.0%
2008	315.8	0.0	0.0	13,015	2.4%	0.0%	0.0%
2009	290.3	0.0	0.0	10,236	2.8%	0.0%	0.0%
2010	274.6	0.3	0.0	11,394	2.4%	0.0%	0.0%
2011	266.5	7.7	10.1	12,542	2.1%	0.1%	0.1%
2012	434.6	38.6	14.6	14,220	3.1%	0.3%	0.1%
2013	495.5	49.0	48.1	15,279	3.2%	0.3%	0.3%
2014	452.2	55.4	63.5	16,192	2.8%	0.3%	0.4%
2015	384.4	43.0	71.1	17,095	2.2%	0.3%	0.4%
2016	346.9	72.9	86.7	17,169	2.0%	0.4%	0.5%
2017	362.9	91.1	104.4	16,818	2.2%	0.5%	0.6%
2018	343.2	122.8	238.8	16,913	2.0%	0.7%	1.4%
Average annual percentage change							
2000-2018	22.2%	[c]	[c]	-0.1%			
2011-2018	3.7%	48.6%	57.1%	4.4%			

Source: *Transportation Energy Data Book 38*

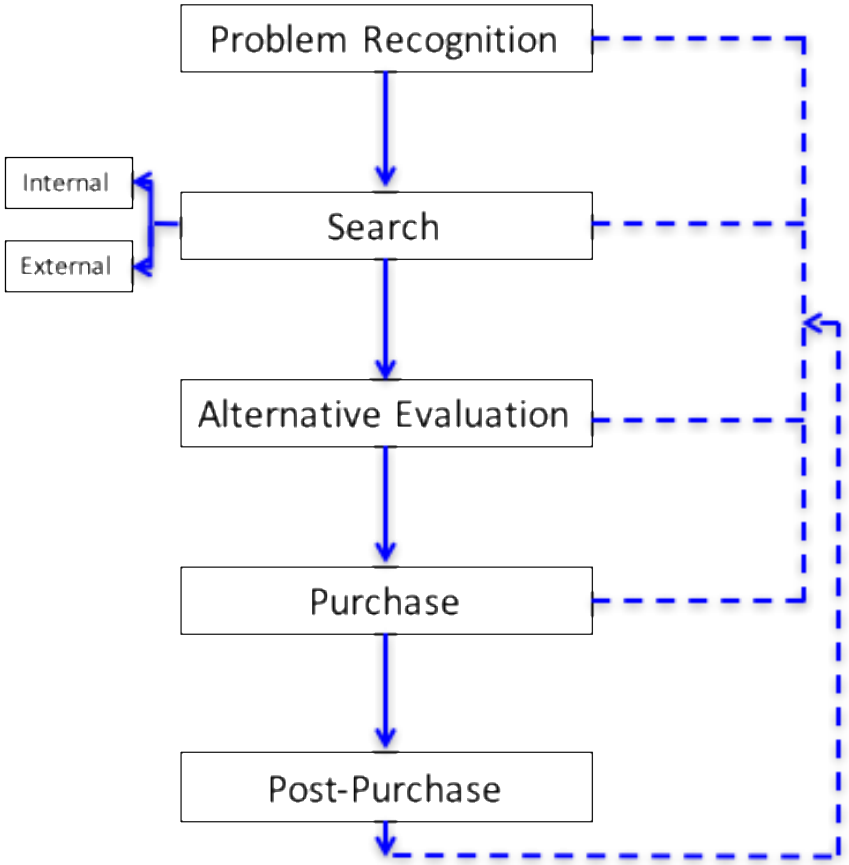
Most common framework for diffusion



Versions of this chart are shown a lot in Silicon Valley. This is a particularly useful framework for thinking about a new technology that doesn't one-to-one substitute for an existing technology with large market saturation.

A More Policy-Leverageable Framework? The EKB Model of the Purchase Decision Process

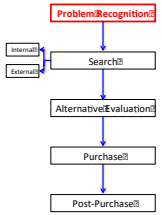
Decision Process Steps



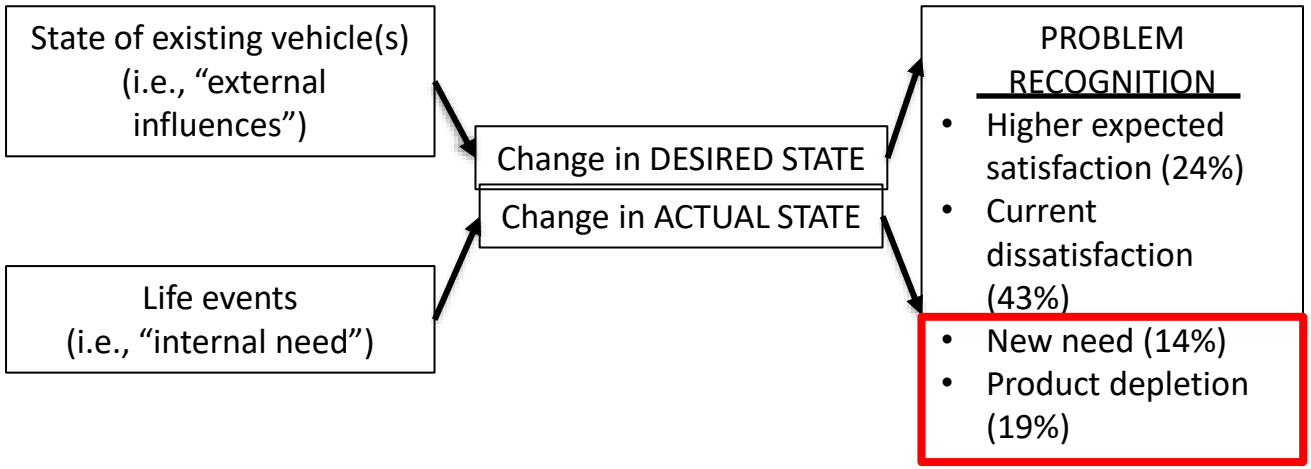
Influences

- **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

Behavior and PEV Diffusion



Problem Recognition Insight: The Purchase Context Matters



Source: Punj & Srinivasan (1992)

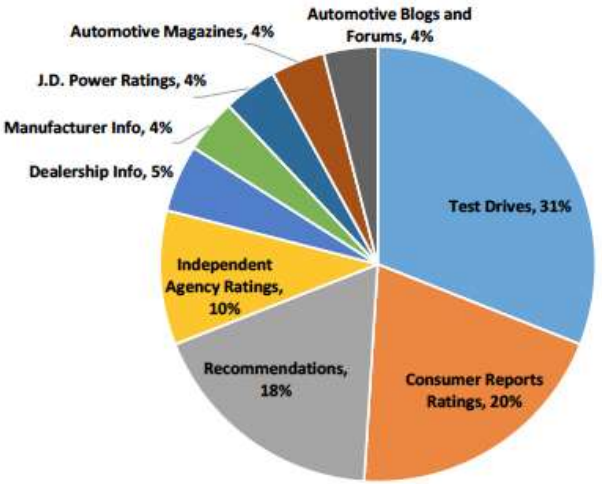
- **New need** segment (18% today?):
  - Shopped for the highest number of aggregate models across dealer visits
- **Product depletion** segment (30% today?):
  - Considered the smallest number of makes before visiting a dealership;
  - Made the smallest number of pre-decisions;
  - Shopped for the smallest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

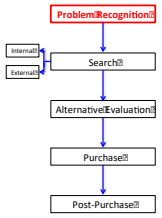
Search Insight: Uneven PEV + Infrastructure Distribution Matters

HEV Density

BEV Density

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





Alternative Evaluation Insight: 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

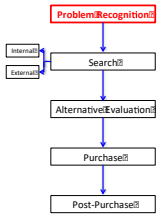
1. Too expensive
2. Not available in desired vehicle class
3. Technology not dependable
4. Poor performance
5. Other

Sources: Surveys by Strategic Vision (2013); Santulli (2015); Singer (2016)

Purchase Insight: Dealerships Matter

- Shrinking number of dealerships
- Uneven distribution of product across dealerships
- Purchase complexity
  - Heterogeneous 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 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...
- Evidence that customers are generally very satisfied, more so than many expected. This makes them potentially helpful as product evangelists.

A deeper dive into the gender divide on PEV interest & adoption

- 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)
  - Consistent finding across regions, countries, and time

The PEV Gender Gap & the Whole Traveler Survey

- 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

Hypothesis Testing on the Gender Gap

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 Short travel time index	- 1.36** - 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 Child transport index Vehicle seats (#) † Multiple stops index Low hassle index Vehicle cargo capacity †	0.28** 1.57** 3.17**† 7.28** 0.6** 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%)	

Suggestive of policies beyond rebates

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Implications for charger locations

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Implications for carpool lane access

Broader Applicability of this Framework

Uncertain Energy Impacts: Automated Vehicles

+200%

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

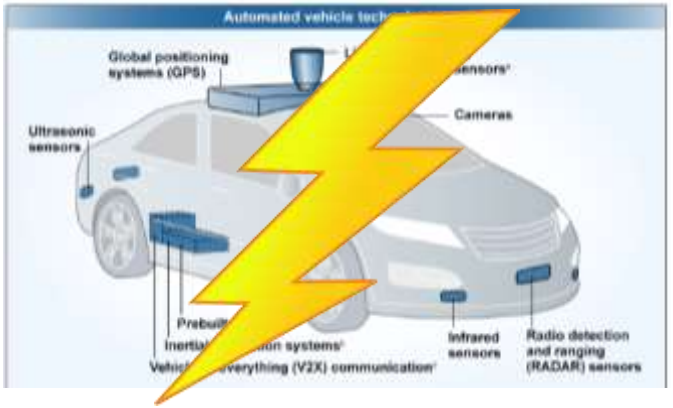
+ Reduced Travel Costs
+ Increased Vehicle Miles Traveled (VMT)
+ Zero-Occupancy Vehicles
+ Access for New User Groups
+ Faster Driving Speeds
+ Shipment of Goods
+ Increased Features

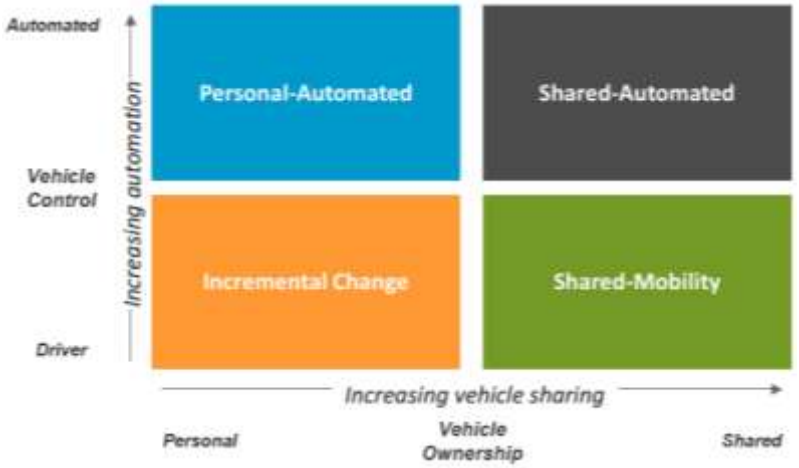
Current energy consumption levels

*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

-60%





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

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

Thank you!
Questions?

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