The Transition to Electric Drive Vehicles in California: The Role of the ZEV Requirements

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This research was conducted by the UT Baker Center for the International Council on Clean Transportation (ICCT).

- The Light-duty Alternative Vehicle and Energy Transitions (LAVE-Trans) model was developed for the ICCT and used to estimate costs, benefits and impacts in the NRC *Transitions to Alternative Vehicles and Fuels* study.
- The California study focused on the effects of the ZEV mandate and related policies.
- It was as much concerned with creating a framework for efficient policy for a transition as it was with modeling the transition.
- The LAVE-Trans model is available to interested researchers free of charge.
- The project report is now or will soon be available to download free of charge from the Baker Center website: http://bakercenter.utk.edu/

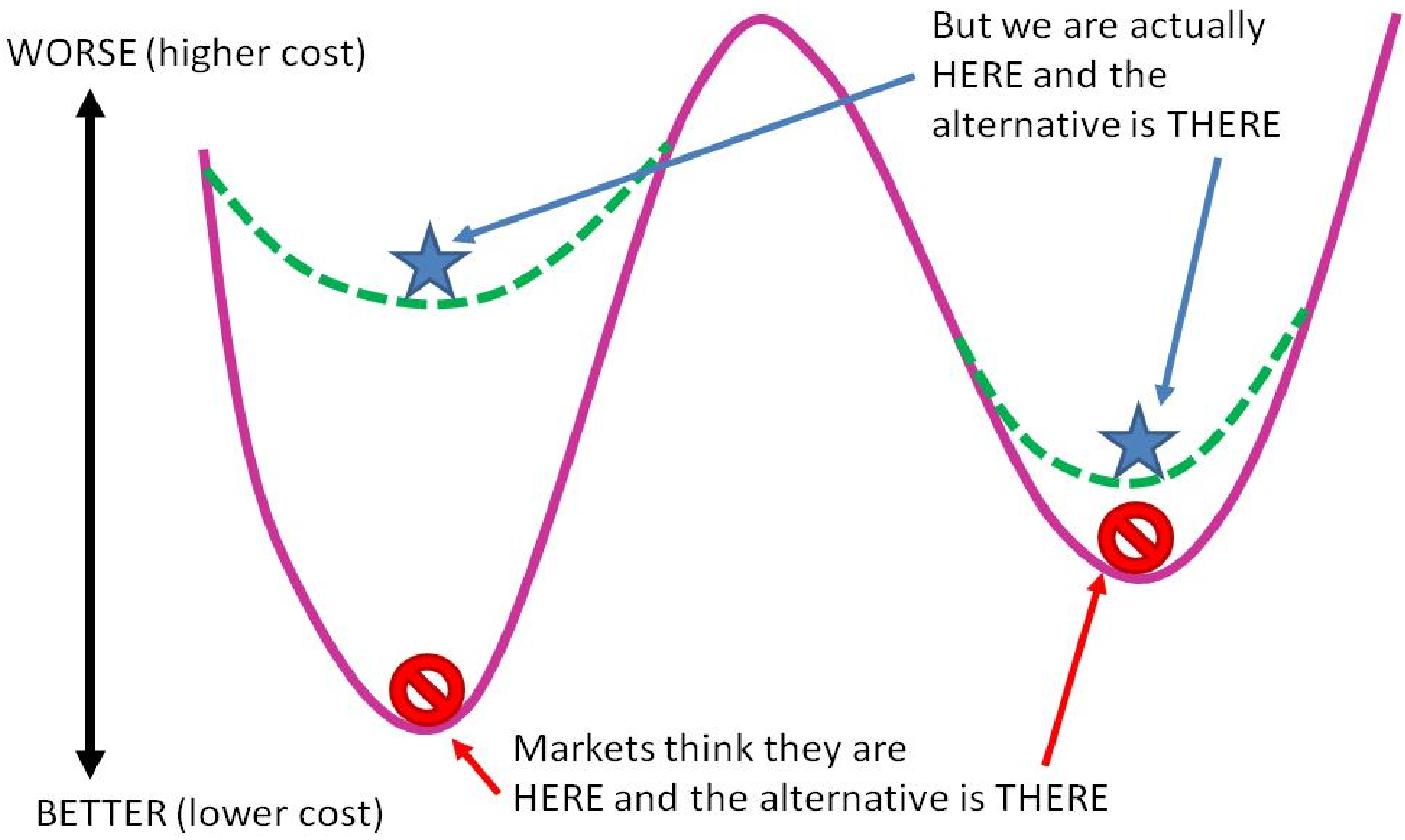
Why is an energy transition for the public good a different kind of problem?

- Such a transition takes decades. The difference between social and private discount rates becomes critical.
- The transition requires technological progress which is inherently uncertain.
- Externalities are involved but not all the social costs are externalities (e.g., monopoly power in world oil market).
- The transition creates external benefits which are difficult for private agents to capture.
  - Value of fuel availability to car buyers
  - Learning-by-doing spillover
  - Reduction of risk-aversion of majority
  - Value of choice diversity (versus scale economies)
- "Deep Uncertainty" (Requires knowledge we don't yet possess.)

There are natural market barriers to displacing an incumbent technology.

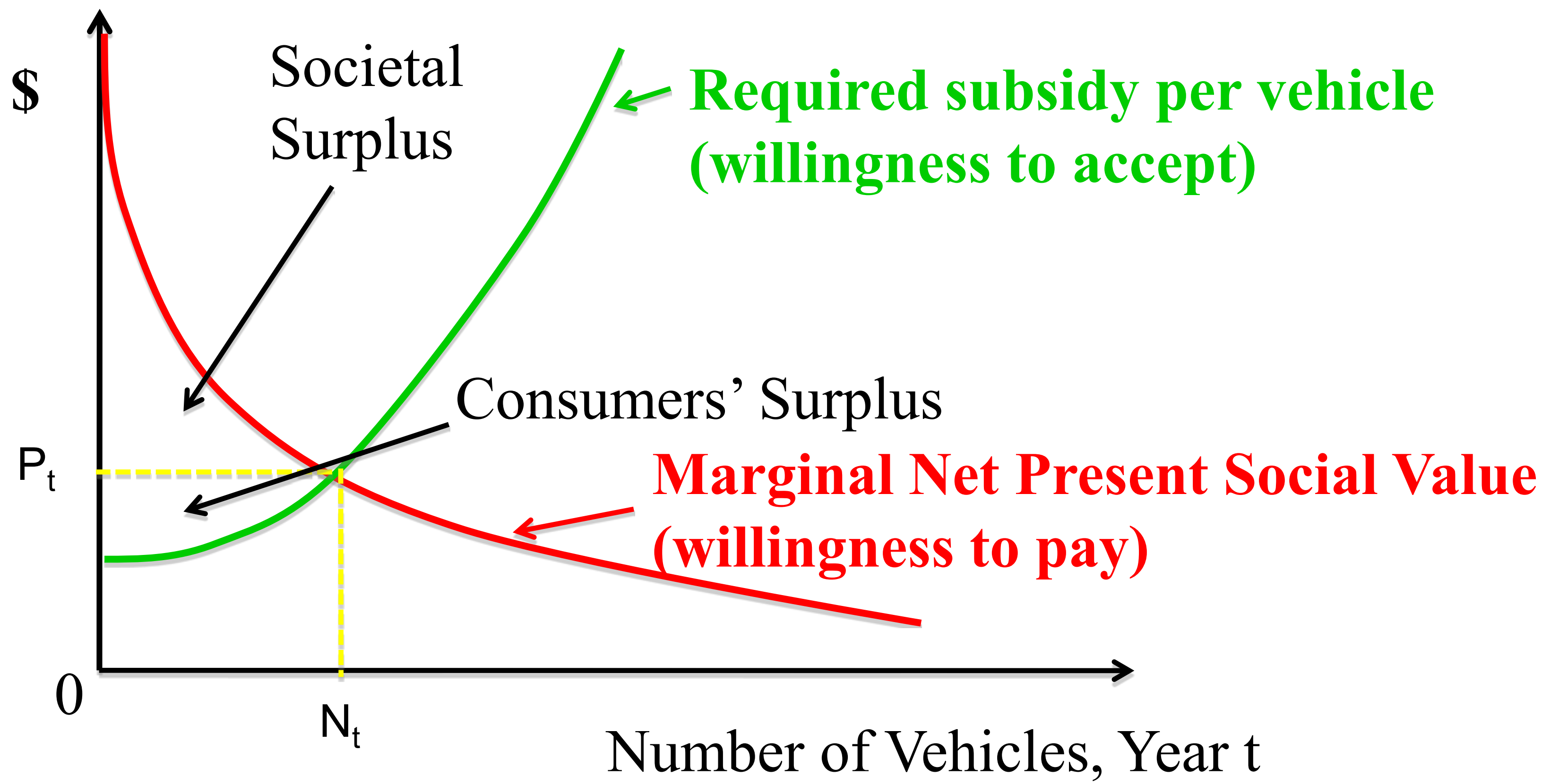
- Achieving economies of scale
- Learning by doing
- Aversion to risk (consumers & firms)
- Fuel availability
- Vehicle availability (diversity of choice)
- And energy market deficiencies
  - External costs (pollution)
  - Social costs (oil dependence)
  - Energy paradox

Markets may see no net present value to the transition, even if externalities are internalized.

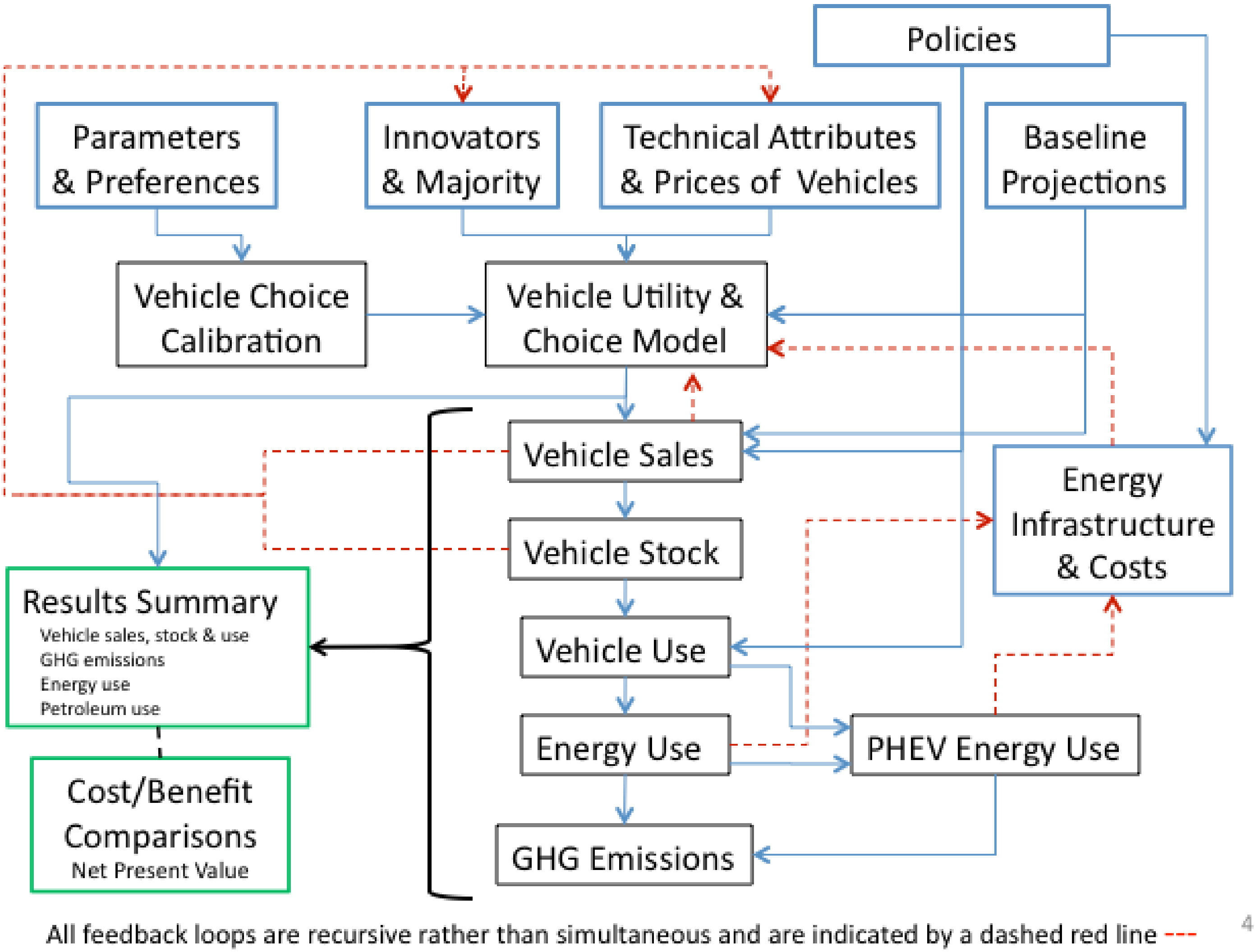


Is there such a thing as an economically efficient transition? In theory, yes.

In year t, there is a social willingness to pay for having more vehicles and infrastructure in operation (dNPV/dN) and a market willingness to accept vehicles and provide infrastructure (dN/dP). There is an equilibrium that provides "surplus" to both and results in sales of N_t vehicles at a subsidy of P_t.

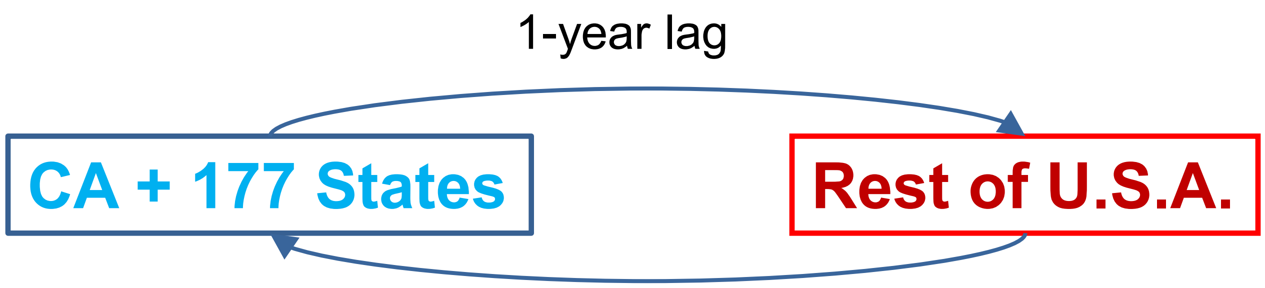


The Light-duty Alternative Vehicle Energy Transition Model was build for the ICCT and used in the NRC “Transitions” study.

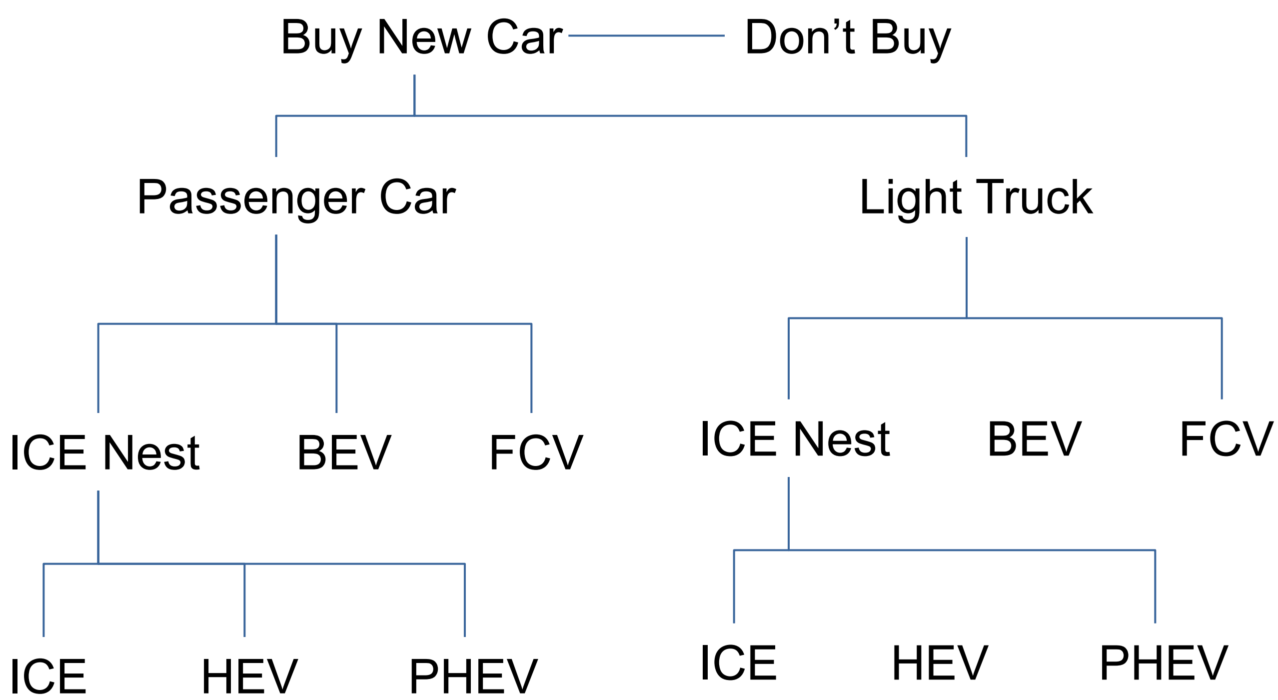


The analysis for CA and the section 177 states links 2 LAVE-Trans models together with a 1-yr lag from CA to the Rest of U.S.

LAVE-Trans is not geographically detailed. It is highly generalized.



The model's vehicle choice structure is focused on choice of drive train.



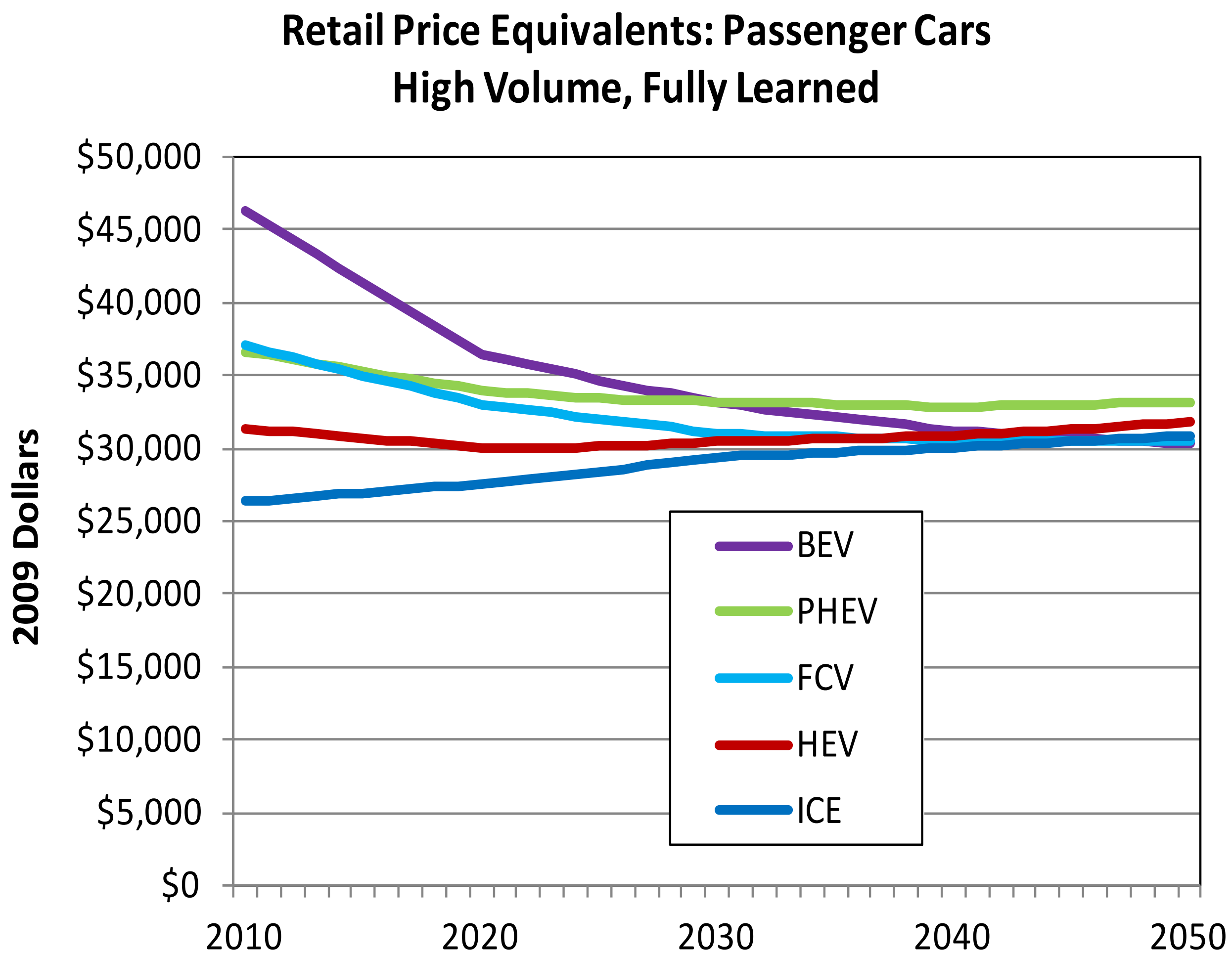
CNG vehicles can be substituted for FCVs but at present the two cannot be included at the same time.

For each technology type, utility is measured as a function of vehicle attributes, fuel costs and availability. This allows external benefits to be measured.

$$U_i = \sum_{j=1}^{n} \alpha_j X_{ij} + \beta P_i = \beta \left(\sum_{j=1}^{n} \frac{\alpha_j}{\beta} X_{ij} + P_i \right)$$

U_i = *average utility of vehicle technology type i*
X_{ij} = *jth attribute of vehicle technology type i*
P_i = *RPE of vehicle technology type i*
α_j = *average utils per unit of* X_{ij}
β = *average utils per dollar (of purchase price)*
α_j/β = *average \$/unit of attribute j (dollar value)*

The technology assumptions used in the ICCT analysis for both vehicles and fuels are the same as those of the NRC Transitions study.



In all scenarios, 13.5 billion gge of drop-in biofuel is assumed to become available nationwide by 2030.

TABLE 3.5 Estimates of Future Biofuel Availability

	Annual Plant Investment Rate (billion dollars per year)			
	1	4	7.2	10.4
Biofuel production (billion gge per year) by				
2022	0.9	3.7	6.7	9.7
2030	1.8	7.4	13.3	19.2
2050	4.3	17.3	31.2	45.0
Biomass required in 2050 (million dry tons per year)	68	270	488	703
Estimated land-use change (million acres)	5.5	22.2	40.1	57.8
Total investment to 2050 (billion dollars)	38	152	275	396
Average number of biorefineries built per year	2.7	10.8	19.5	28.2

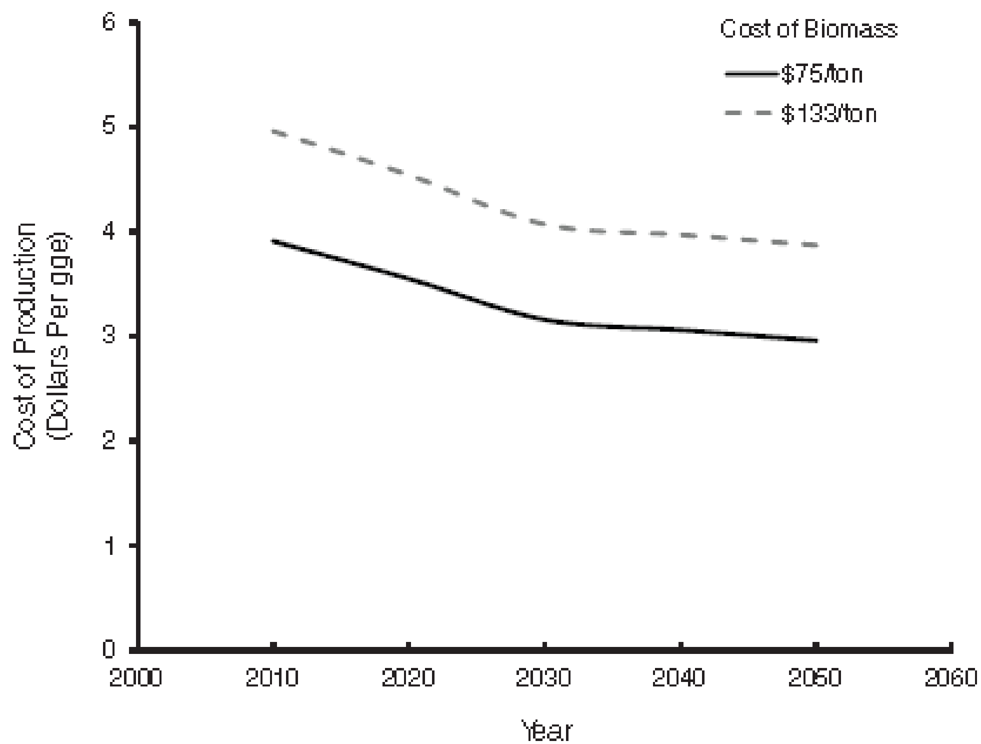
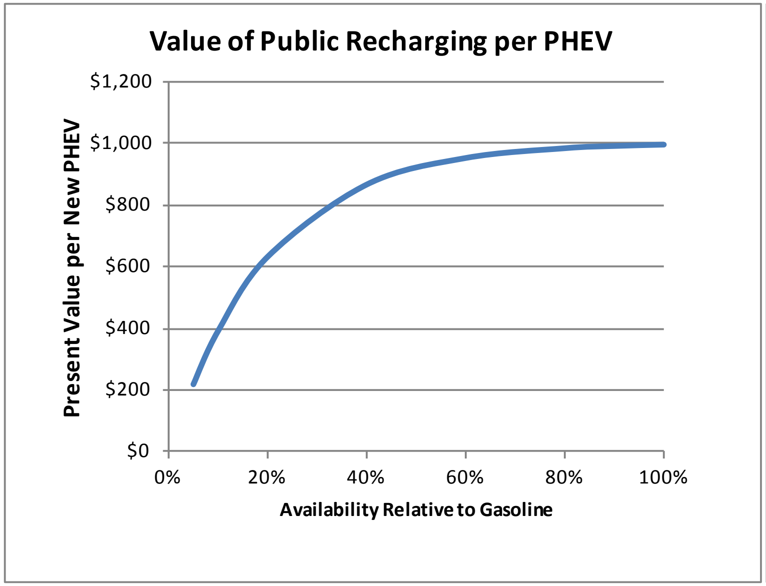
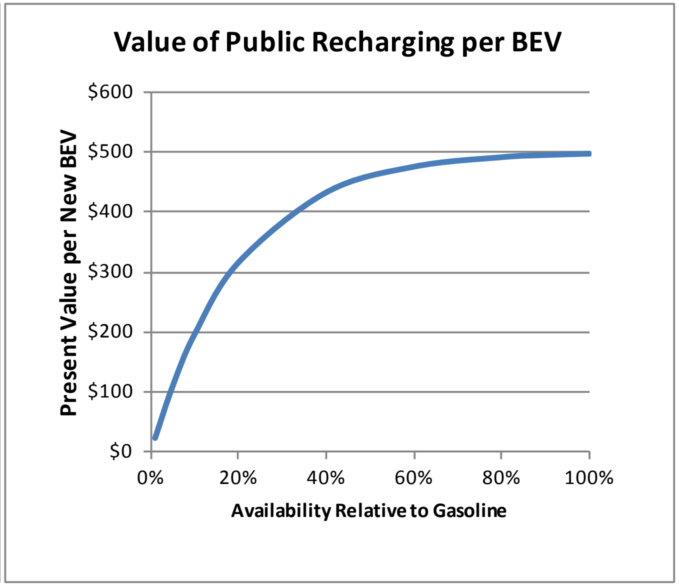
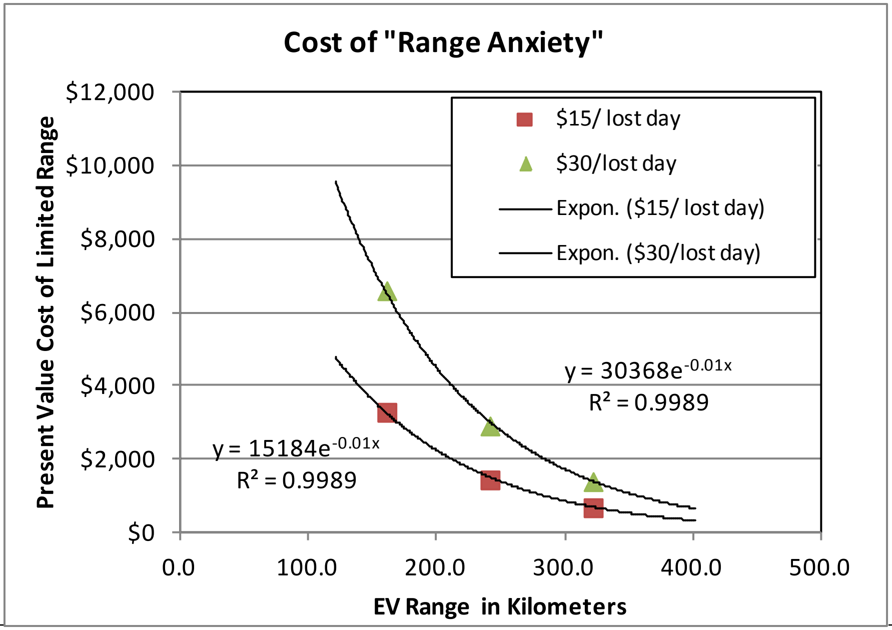


FIGURE 3.2 Sensitivity of biofuel cost to biomass cost.

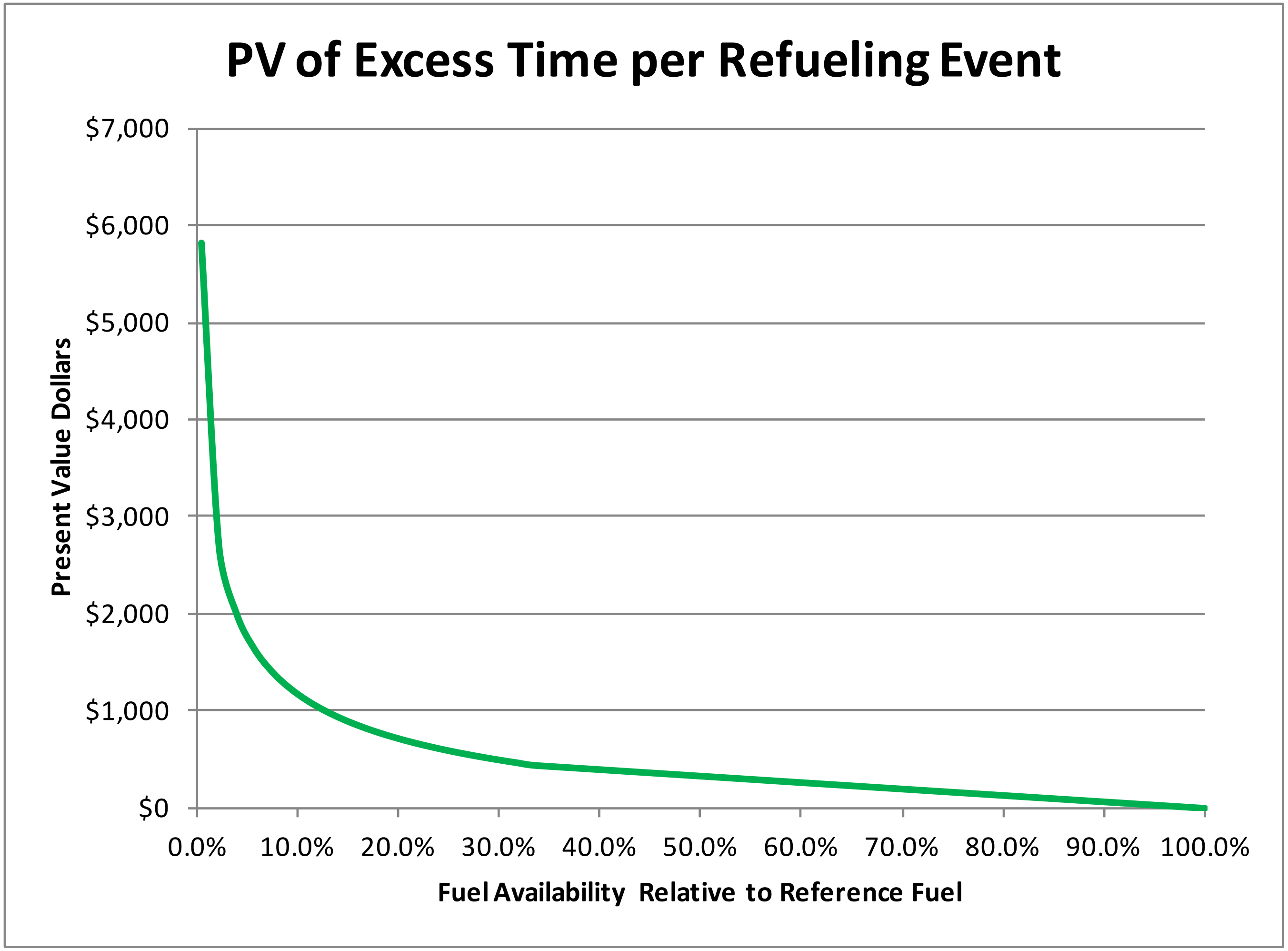
Costs of limited range/long refueling time, values of public recharging are capitalized in the price of vehicles.



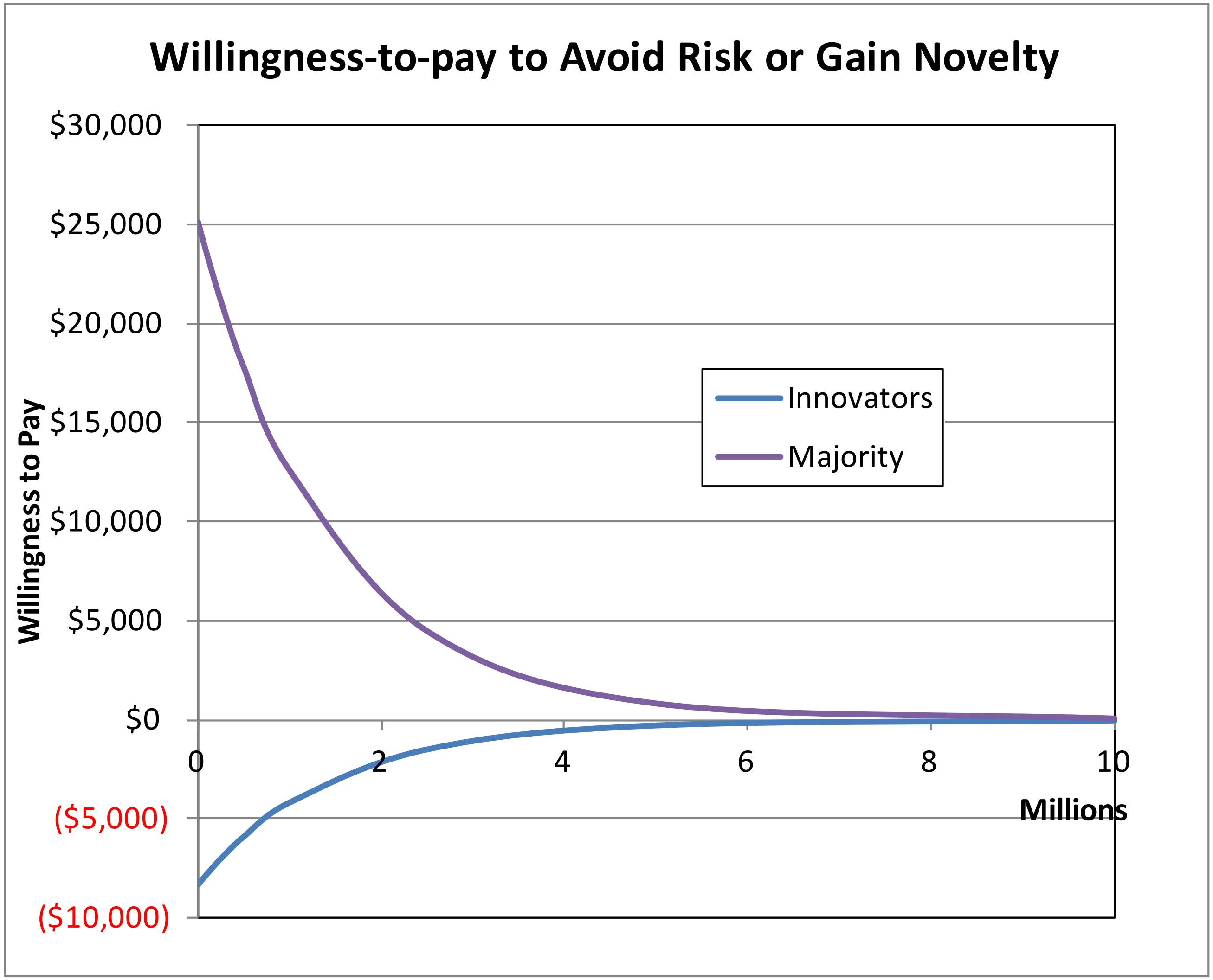




The cost of limited fuel availability is represented by the capitalized cost of increased time to travel to scarce stations.



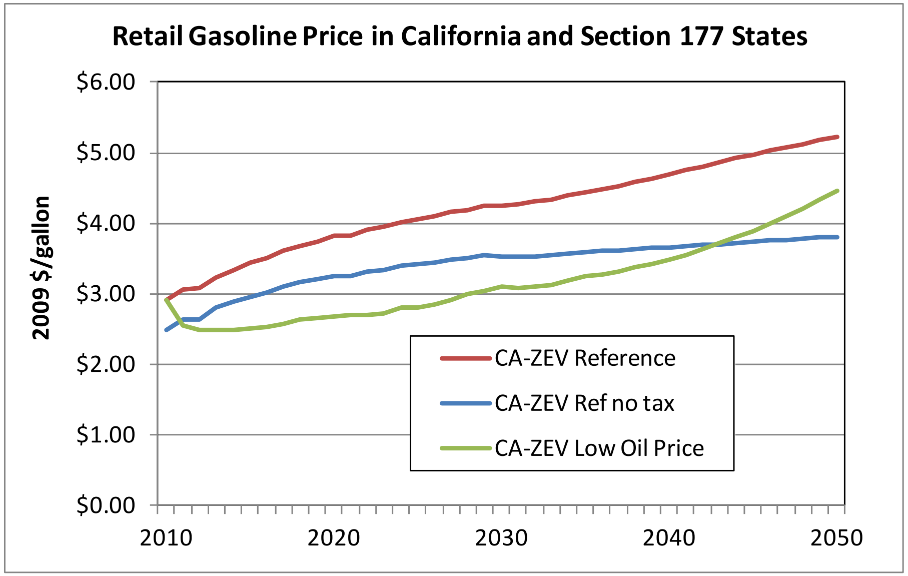
The majority resists, innovators/early adopters will pay more for advanced technologies.

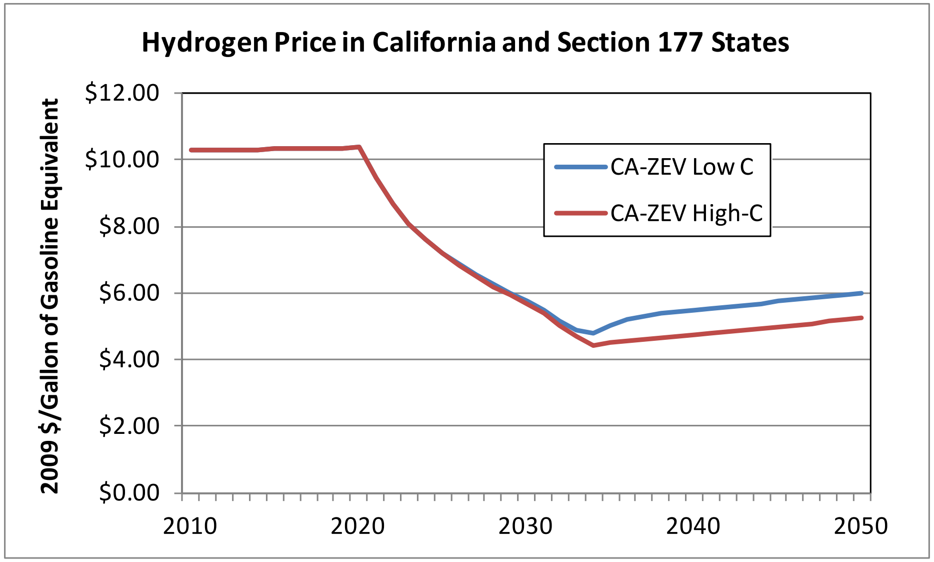


Other key parameters.

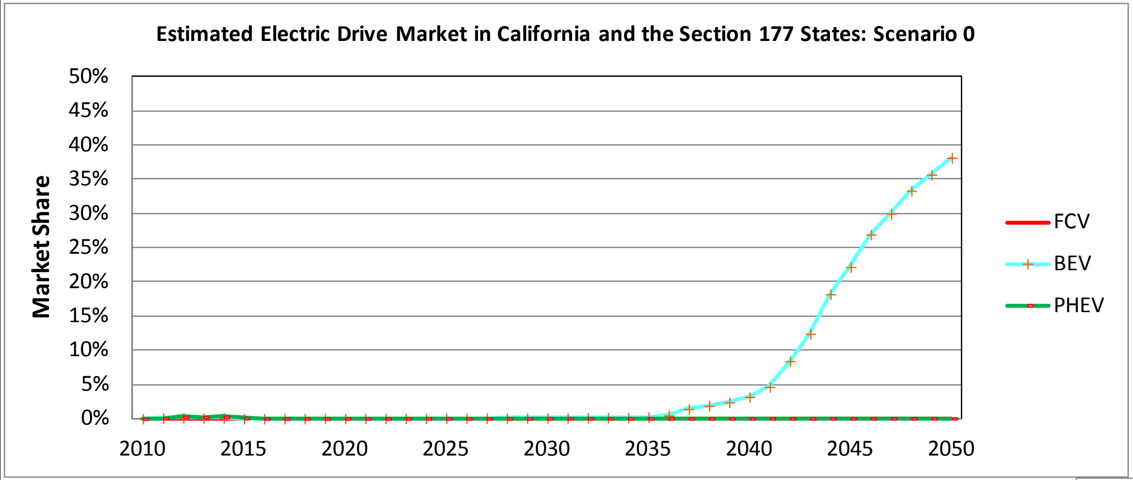
- Payback period for fuel savings: 3 years
- Price elasticities of vehicle choice:
  - Buy/No-buy: -1.0
  - ICE/HEV/PHEV: -4.8
- Economies of scale
  - Scale elasticity: -0.2
  - Full scale: 200,000 units
- Progress ratios: 0.95

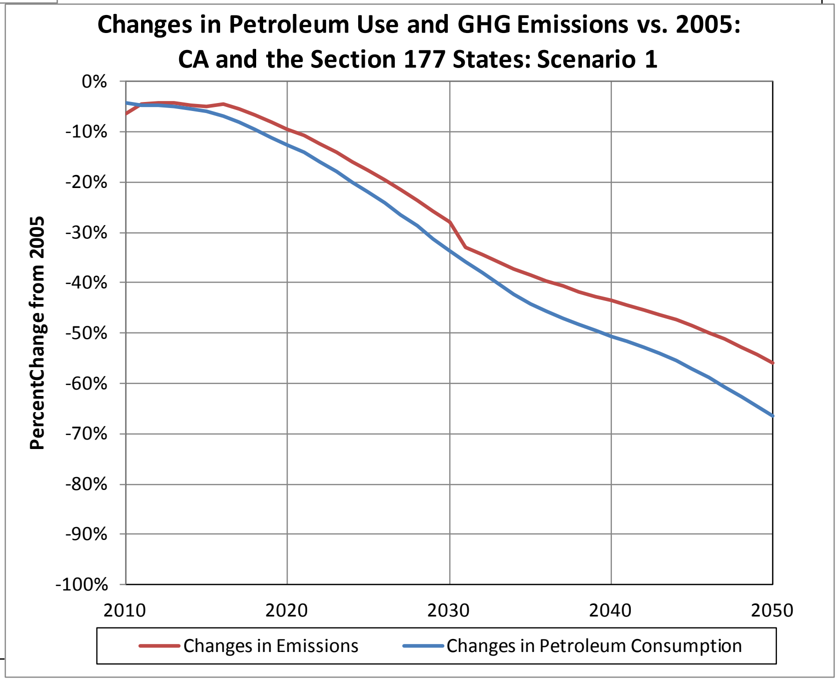
The retail price of hydrogen depends on volume, declining from over $10/kg to $4-$5/kg (taxed).



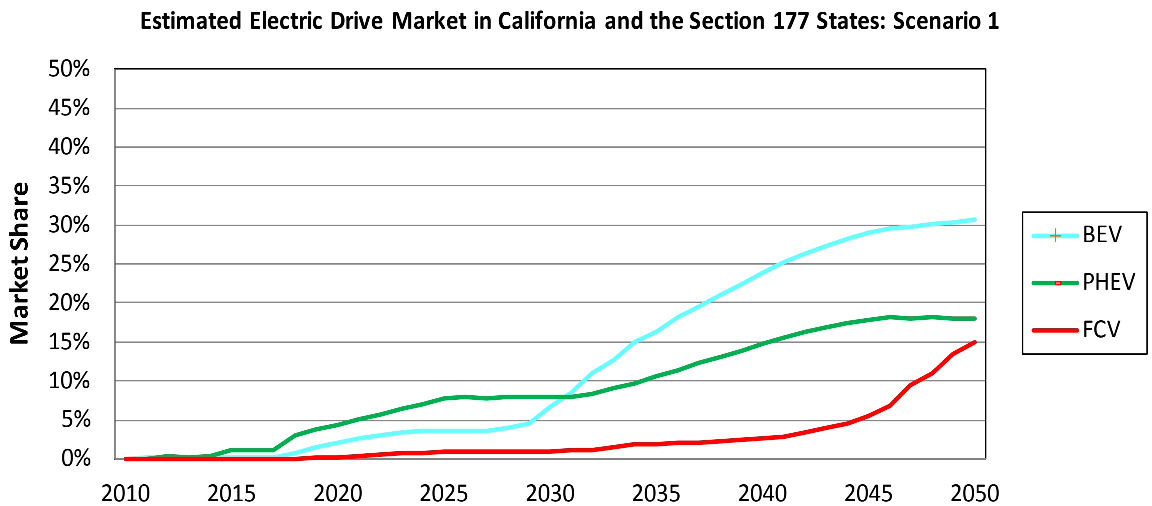


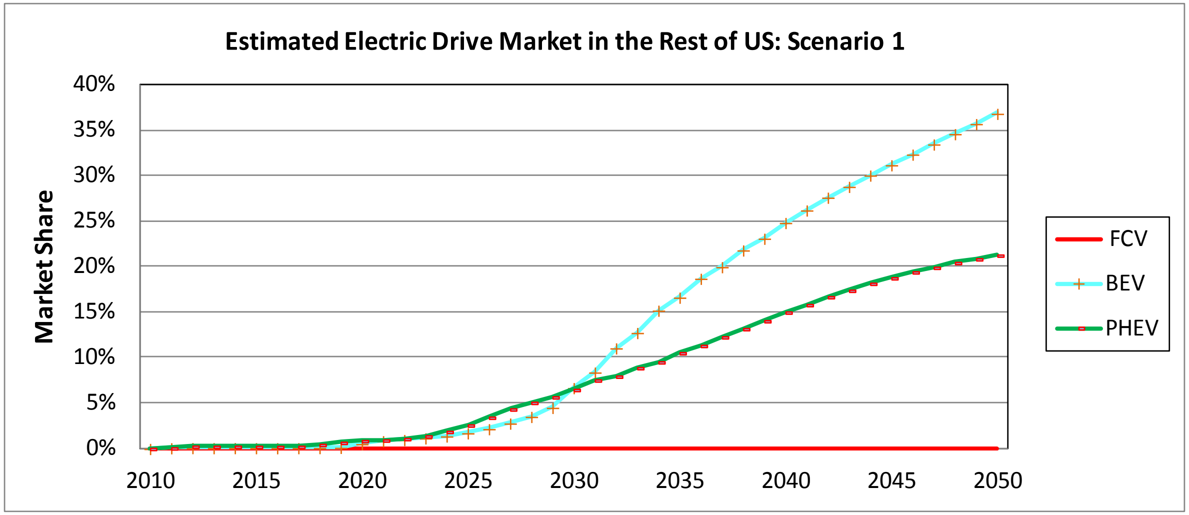
With current policies ending in 2015 (except MPG/emissions standards + biofuels), only BEVs eventually succeed. Still, oil and GHG emissions are more than 50% lower. Costs and benefits of transition are relative to this case.



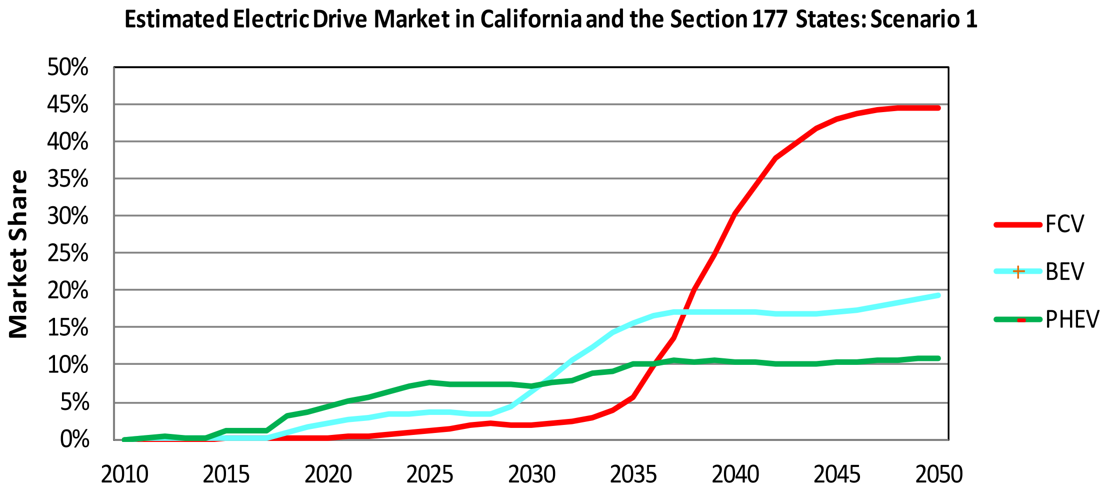


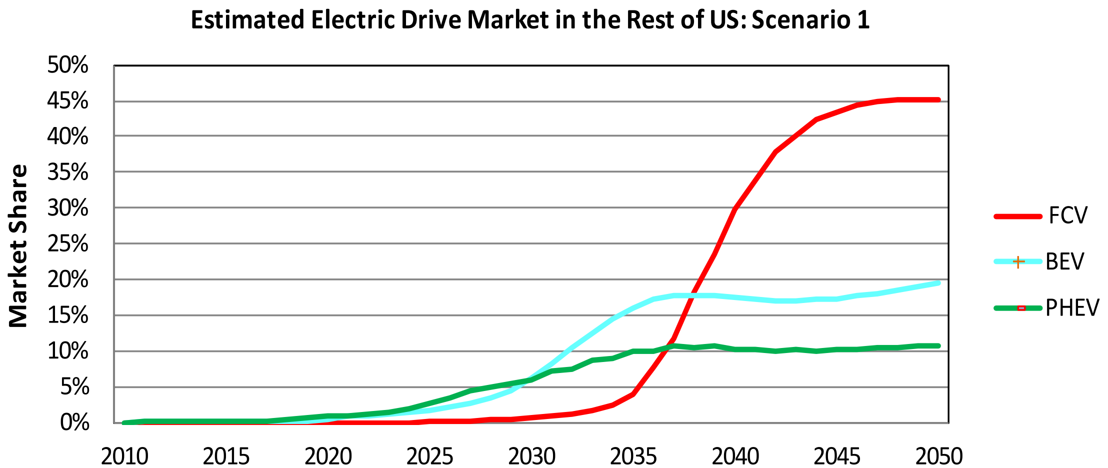
If only California and the Section 177 states implement ZEV mandates and early hydrogen infrastructure, FCVs don't succeed in the rest of the U.S. and struggle in California.



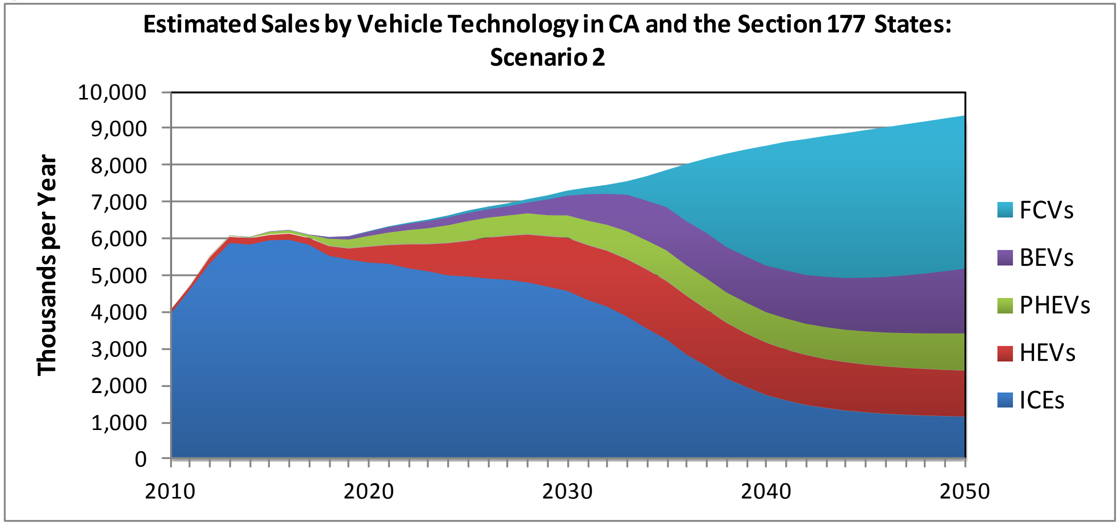


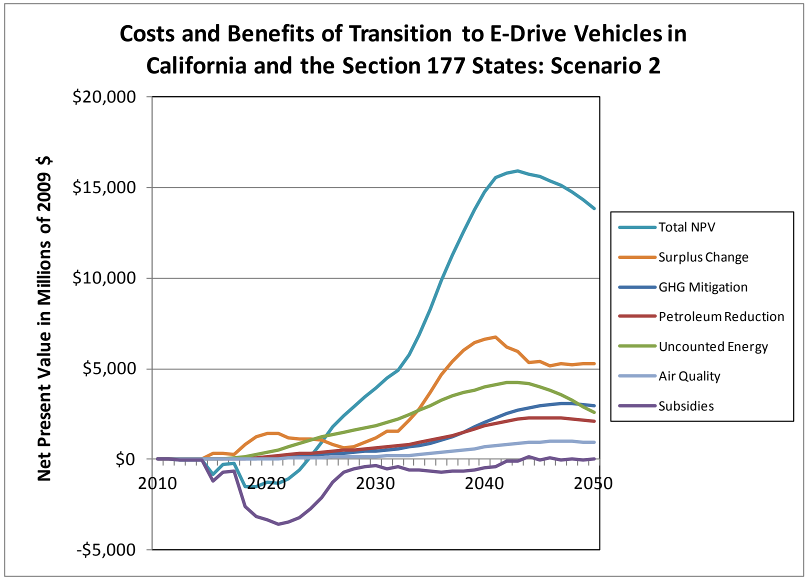
But if even a few hydrogen stations are built in the rest of the U.S. (e.g., 50-100) a tipping point is reached. (Really?)

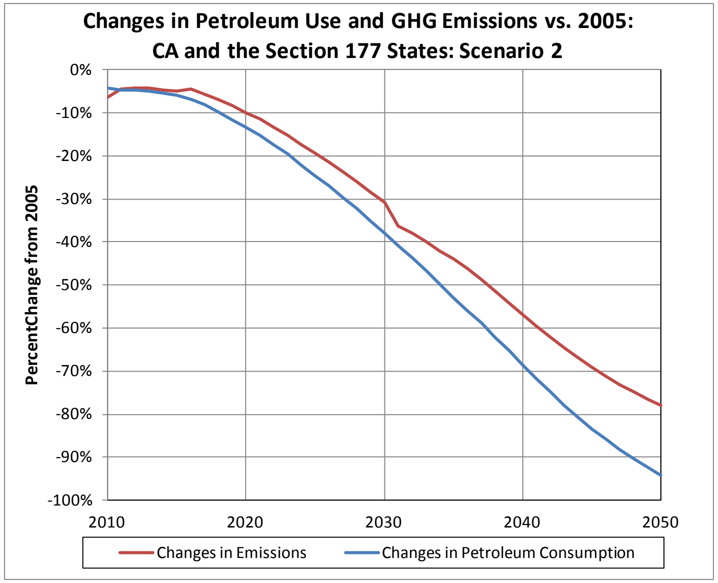




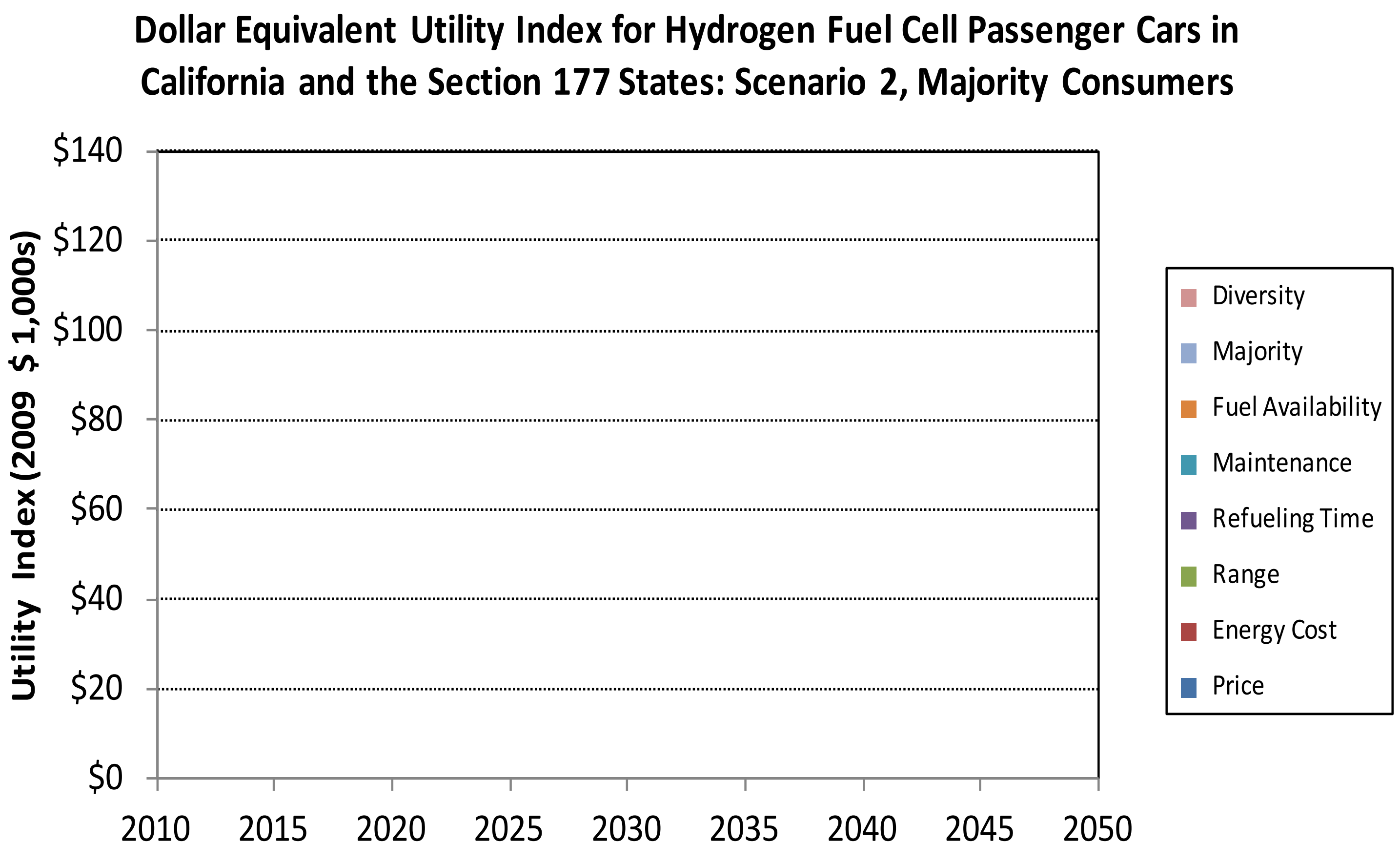
If the U.S. follows California with a 5-year lag, there is a sustainable nationwide transition, GHG and oil goals are met, benefits outweigh costs by about an order of magnitude.



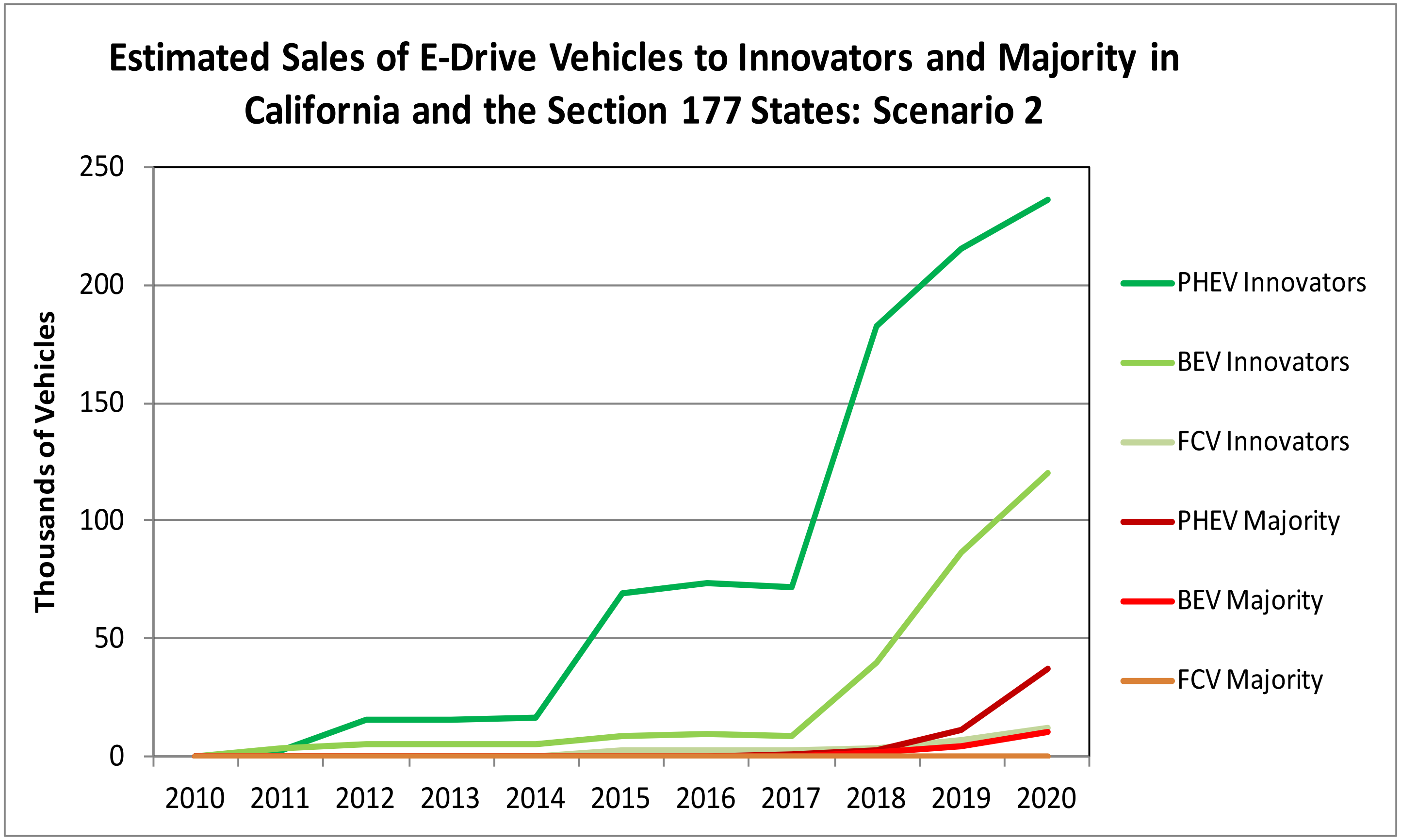




The LAVE-Trans model allows us to estimate changes in monetized consumer utility as the market evolves (to measure network external benefits)…



…and to see who is creating the network external benefits. Unfortunately, quantitative knowledge of this subject is meager.



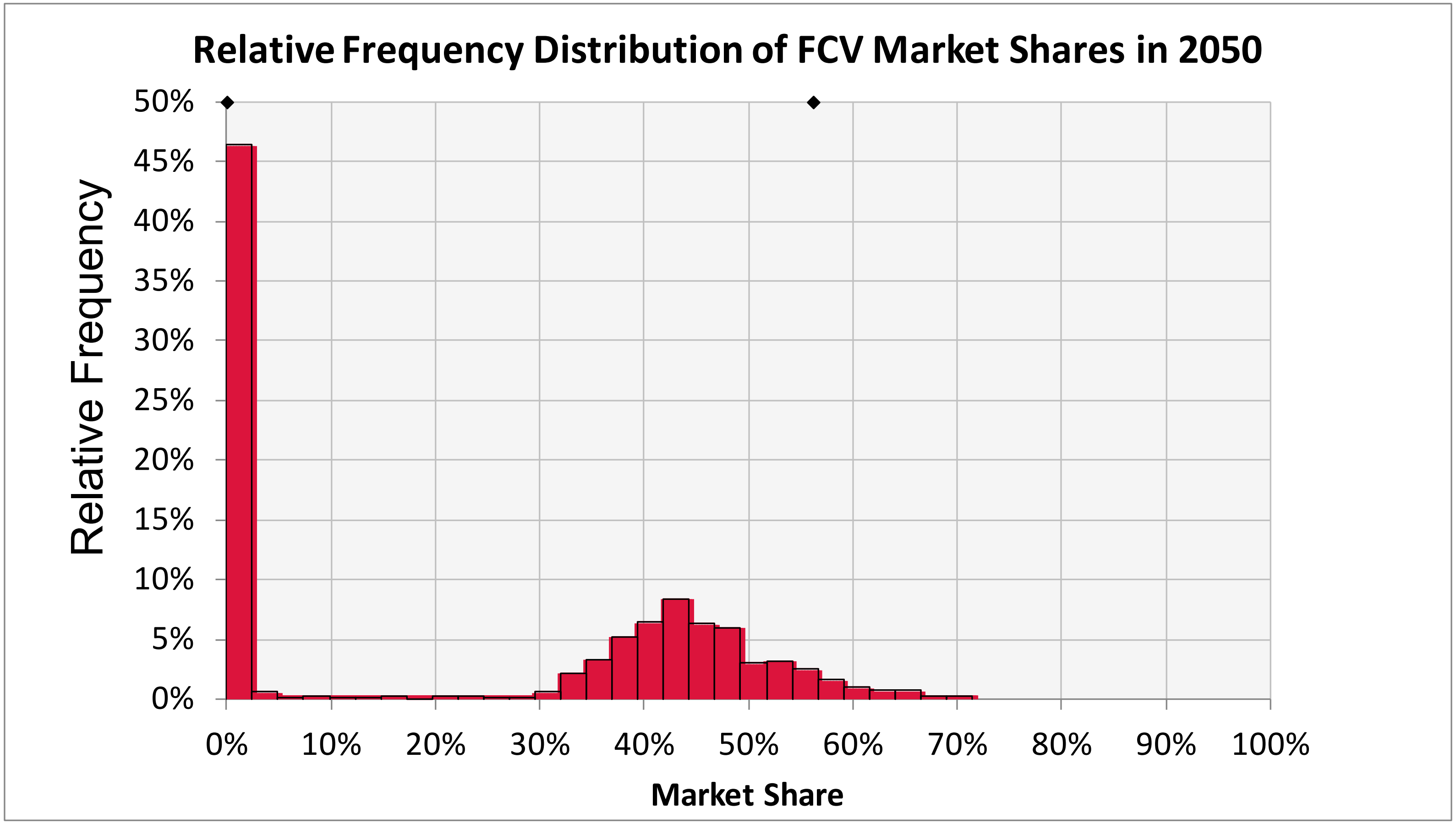
Other cases explore sensitivities and limitations of the model.

- Scenario 3: What happens in the rest of the world matters.
- Scenario 4: No early infrastructure, no hydrogen transition.
- Scenarios 5 & 6: Better technology, better transitions.
- Scenario 2 without ZEV "Travel Provision" → somewhat faster transition for FCVs.
- Scenario 2 with Low Oil Prices: E-drive vehicle share of new vehicle sales in 2050 drops from 75% to 70%.
  - Vehicles are cheaper
  - Vehicles are extremely energy efficient
- But, uncertainty is great, knowledge is meager.

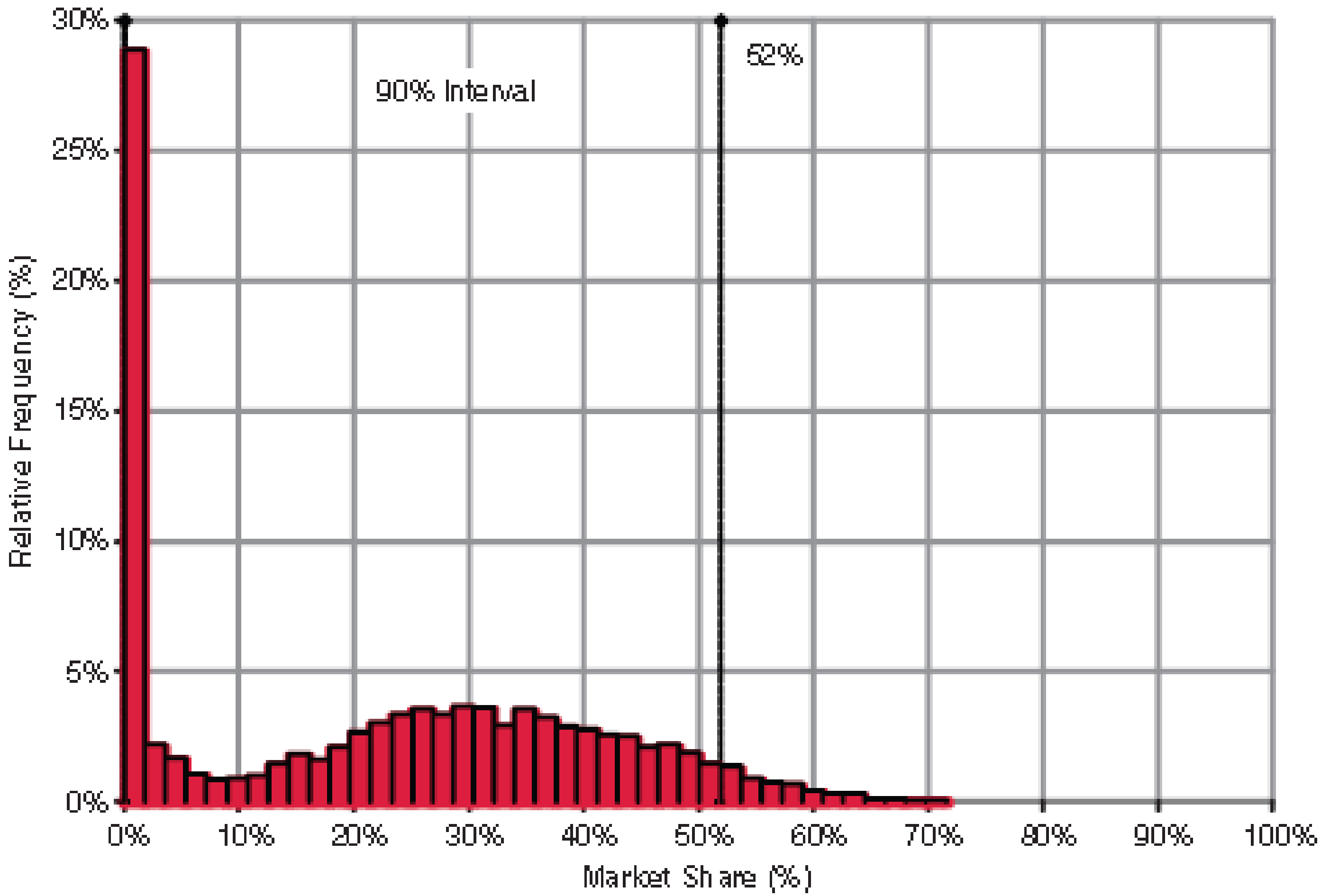
There is great uncertainty about markets and about technological progress.→ Sensitivity analysis.

Parameters	Distribution	Min	Mean	Max
Importance of diversity of makes and models to chose from	Triangle	0.50	0.67	0.9975932
Value of time ($/hr.)	Triangle	$10.00	$20.00	$39.86
Maximum value of public recharging to typical PHEV buyer	Uniform	$500	$1,000	$1,500
Cost of one day on which driving exceeds BEV range	Uniform	$10,002	$20,000	$29,999
Maximum value of public recharging to typical BEV buyer	Uniform	$0	$500	$1,000
Importance of fuel availability relative to standard assumption	Triangle	0.67	1.00	1.67
Payback period for fuel costs (yrs.)	Triangle	2.0	3.0	5.0
Volume threshold for introduction of new models rel. to std. assumptions	Uniform	0.80	1.00	1.20
Optimal production scale relative to standard assumptions	Uniform	0.75	1.00	1.25
Scale elasticity relative to standard assumptions	Uniform	0.50	1.00	1.50
Progress Ratio relative to standard assumptions	Uniform	0.96	1.00	1.04
Price elasticities of vehicle choice relative to standard assumptions	Uniform	0.60	1.20	1.80
Percentage of new car buyers who are innovators	Triangle	5.0%	15.0%	20.0%
Willingness of innovators to pay for novel technology ($/mo.)	Uniform	$100	$200	$300
Cumulative production at which innovators WTP is reduced by 1/2	Uniform	1,000,000	2,000,000	3,000,000
Majority's aversion to risk of new technology ($/mo.)	Uniform	-$900	-$600	-$300
Cumulative production at which majority's risk is reduced by 1/2	Uniform	$500,000	$1,000,000	$1,500,000

Adaptive strategies are missing from our sensitivity analyses. (Tipping points)



Tipping points were less extreme for plug-in vehicles but uncertainty is still great.

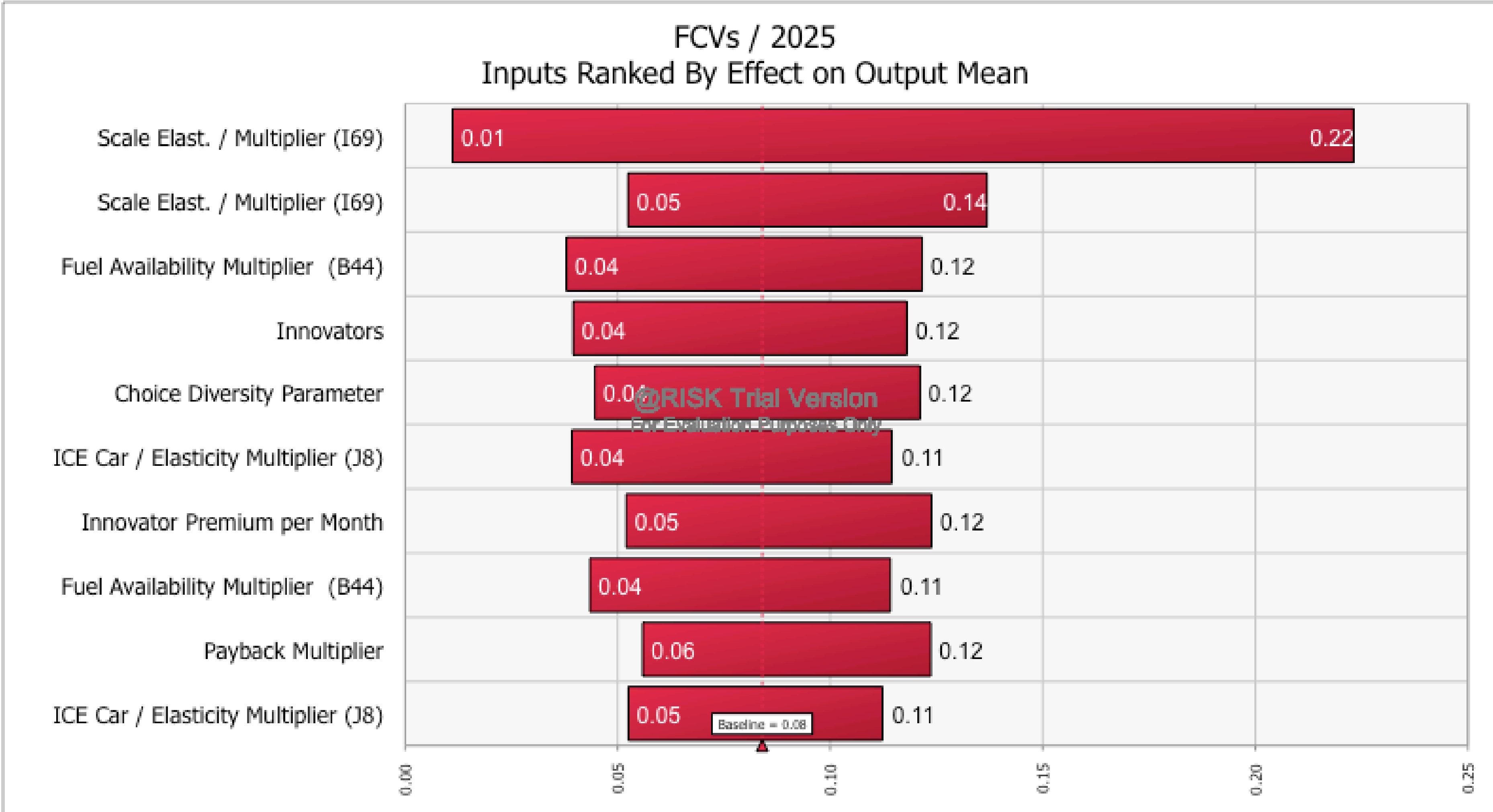


The modeling results suggest some interesting inferences.

- Benefits of transition greatly exceed costs, but
  - Subsidies needed for extended period (~2025, 2030)
  - Must do more than "internalize the externalities"
  - Order of magnitude greater benefits sufficient to outweigh the risks due to deep uncertainty? (Planning fallacy?)
- There are "tipping points" in vehicle deployment
- "Network external benefits" are large
- Mandates (ZEV) or subsidies important driver
- Early hydrogen infrastructure is critical
- FCEV market potential > BEV > PHEV
- What happens elsewhere strongly affects US (global market)

THANK YOU.

In 2025 FCVs are most strongly affected by manufacturing costs, fuel availability, and innovators.



Even in 2050, the FCV market share is chiefly determined by the factors that affect the early transition.