

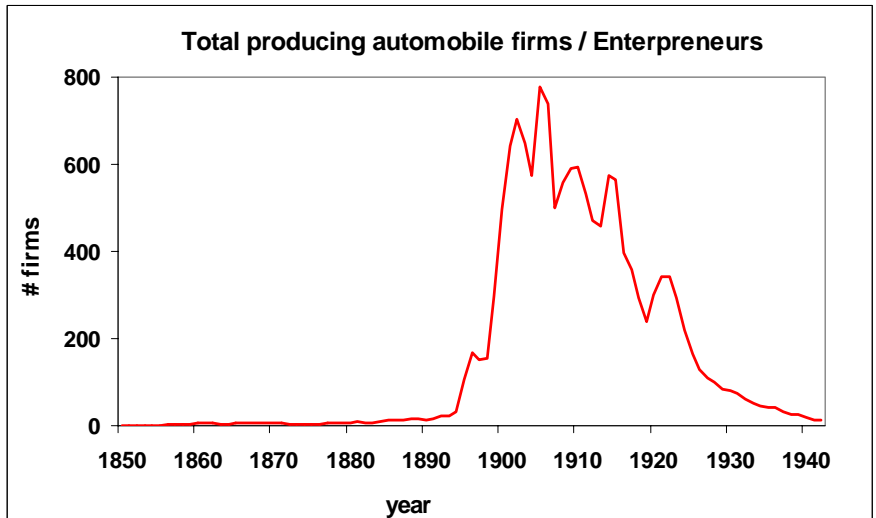
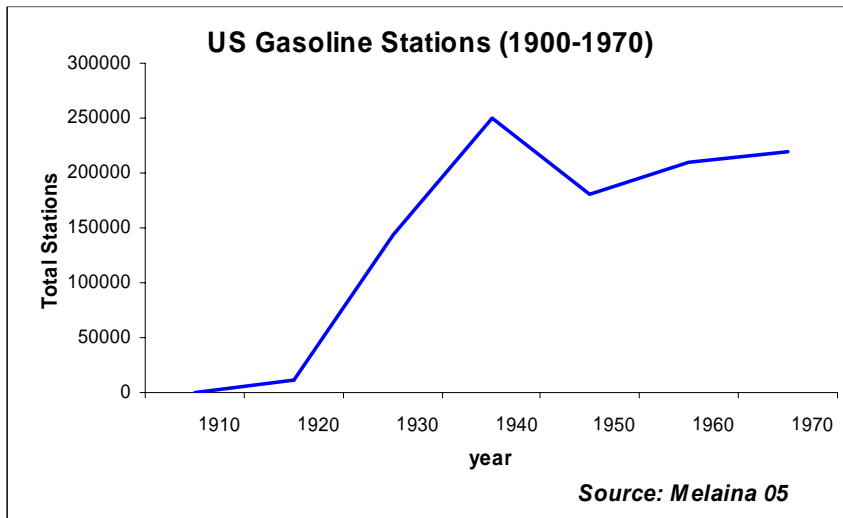
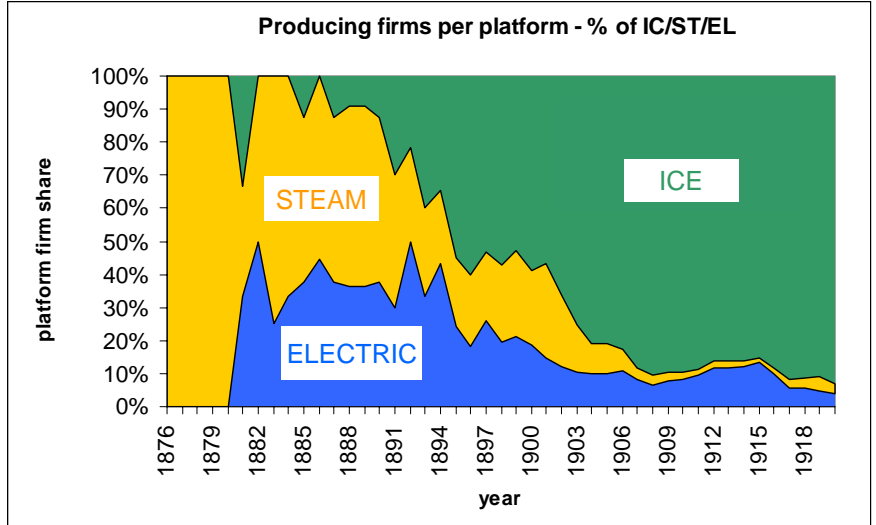
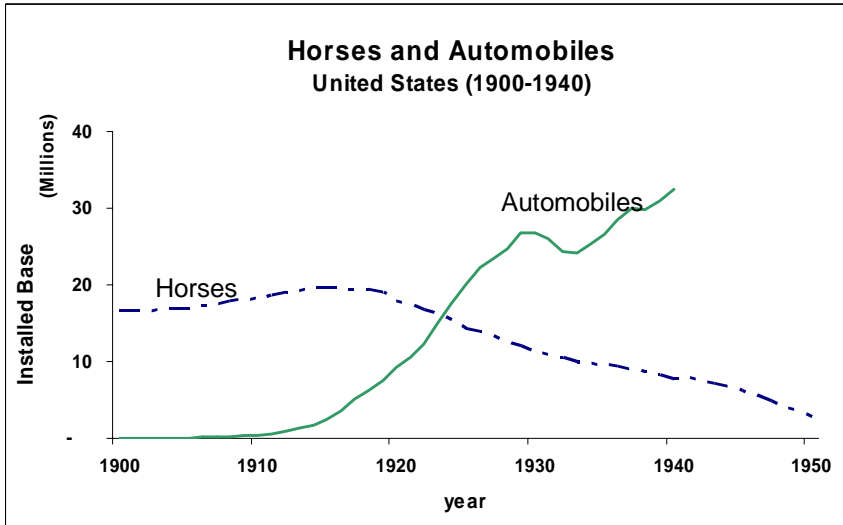
The hydrogen transition challenge: co-evolutionary dynamics between vehicle demand and fueling infrastructure

Jeroen Struben
System Dynamics Group
Sloan School of Management
Massachusetts Institute of Technology
jjrs@mit.edu

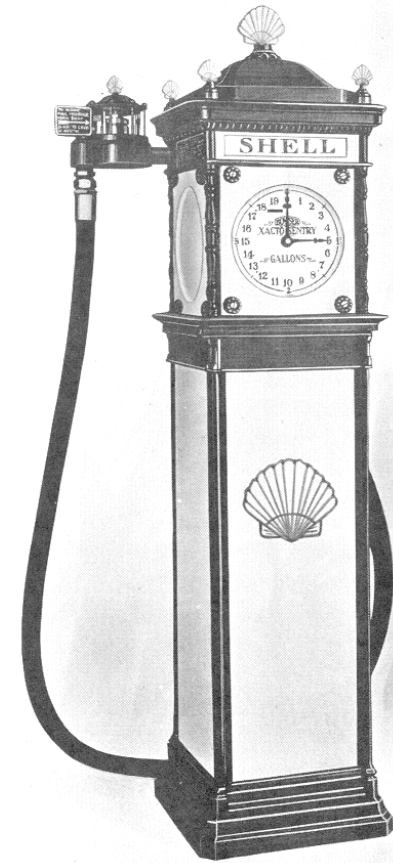
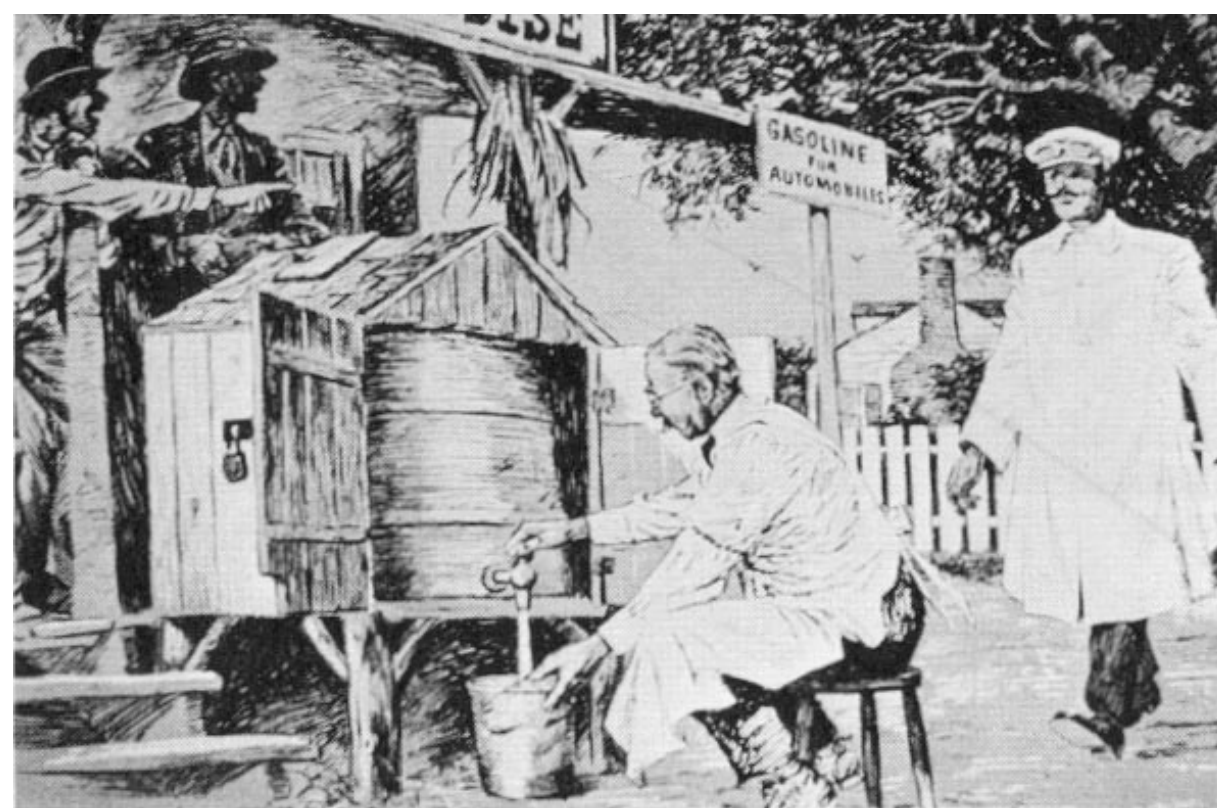
Albany-MIT Colloquium, Albany
October 14, 2005



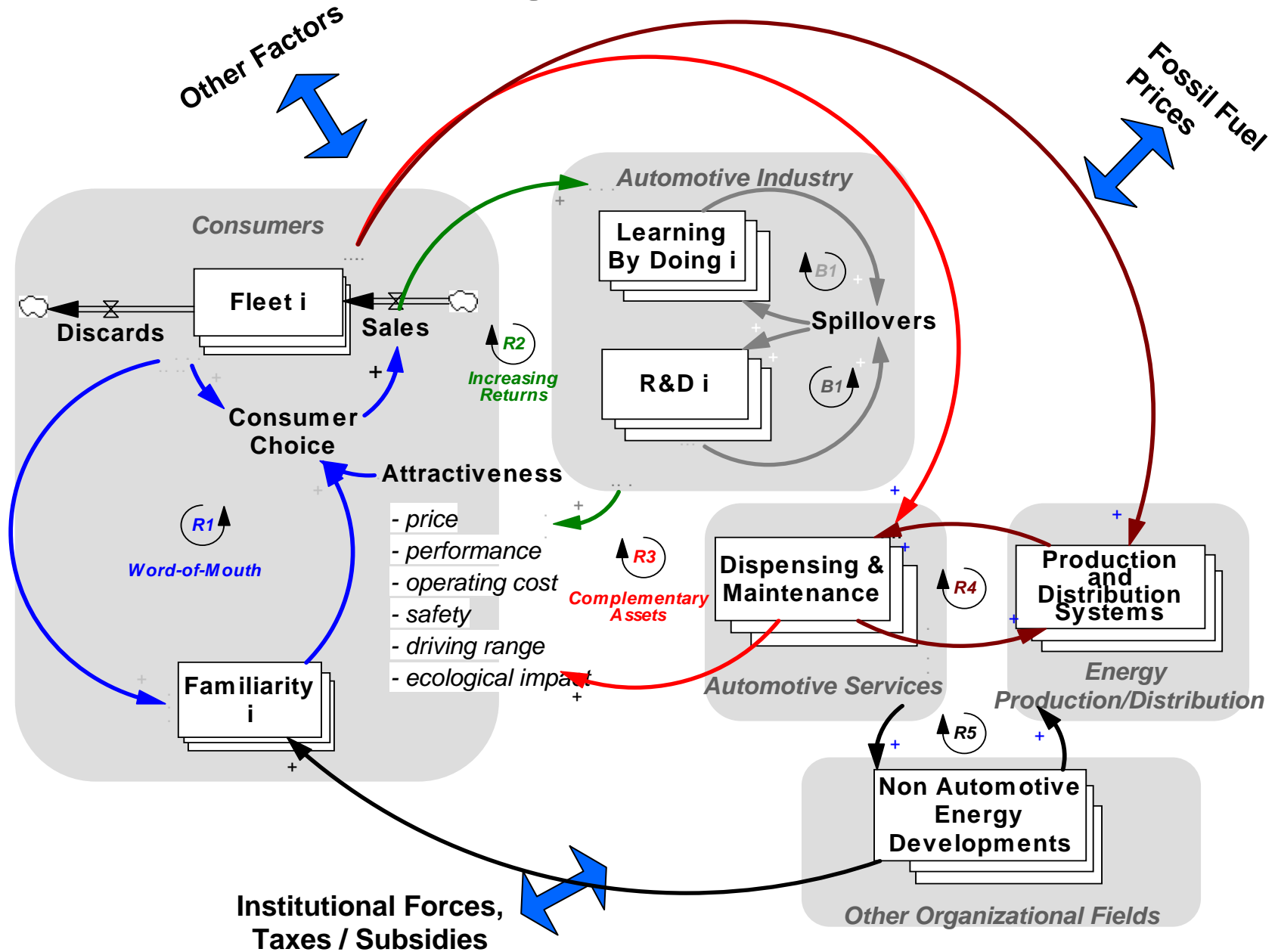
Hydrogen transition challenge in larger context



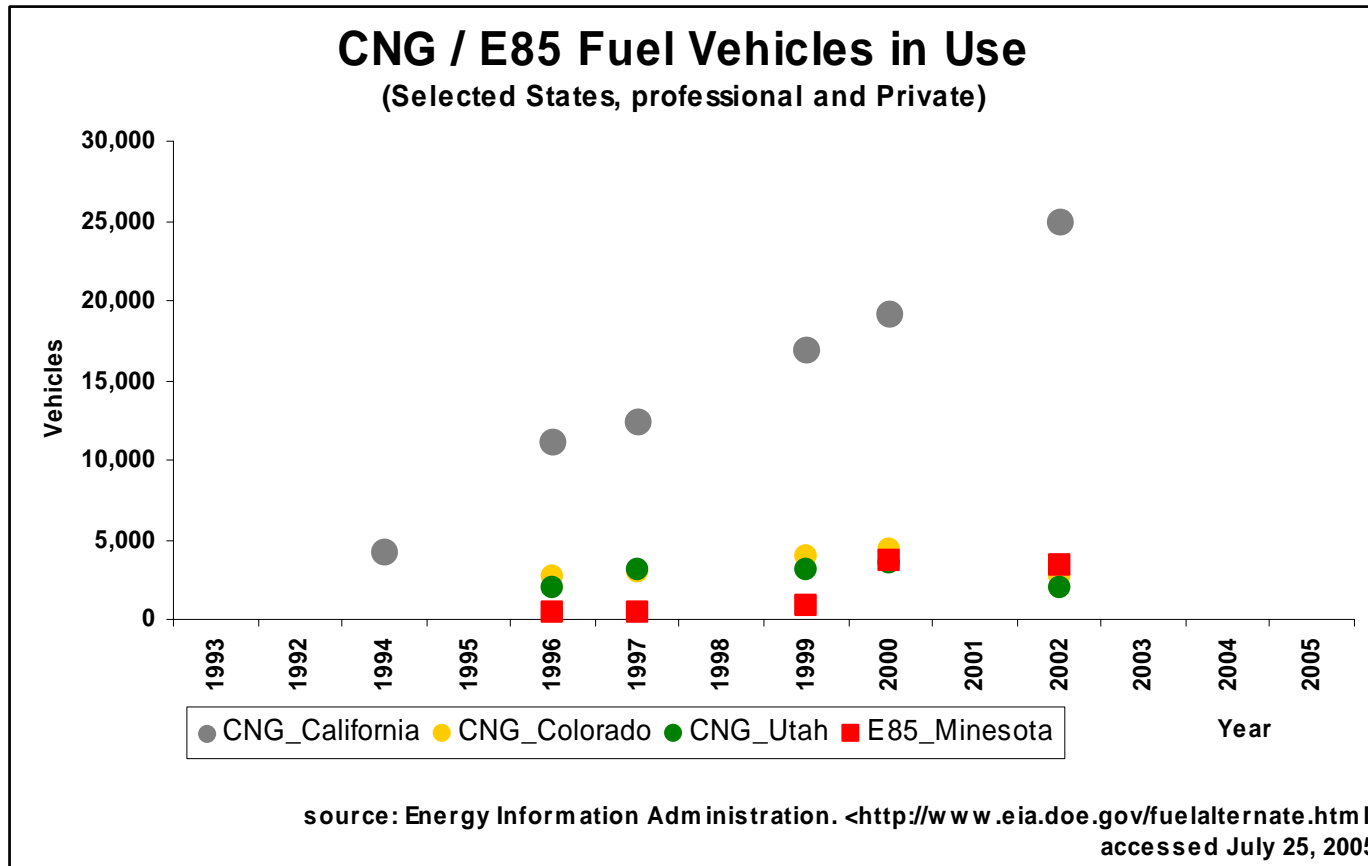
Gasoline dispensing in the early 1900's



Conceptual diagram HFCV research



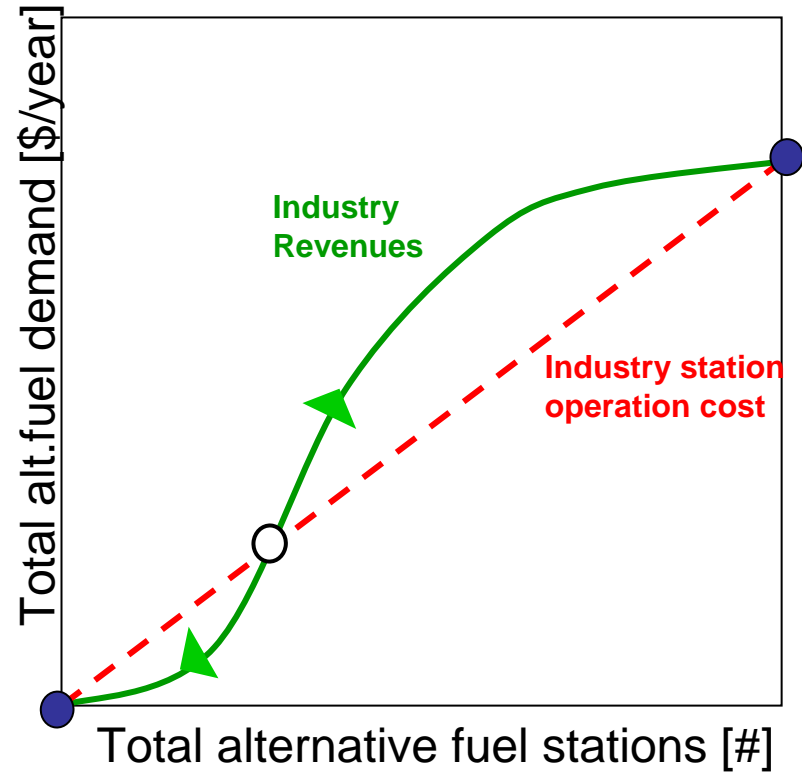
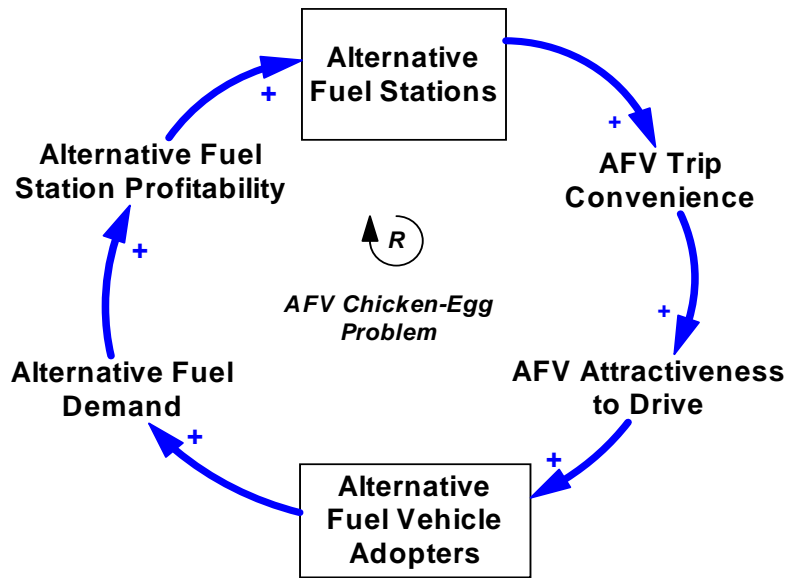
Vehicle-Fleet/Fueling Infrastructure Chicken-Egg Problem



Source: <http://www.eia.doe.gov/cneaf/alternate/page/datatables/table10.html>

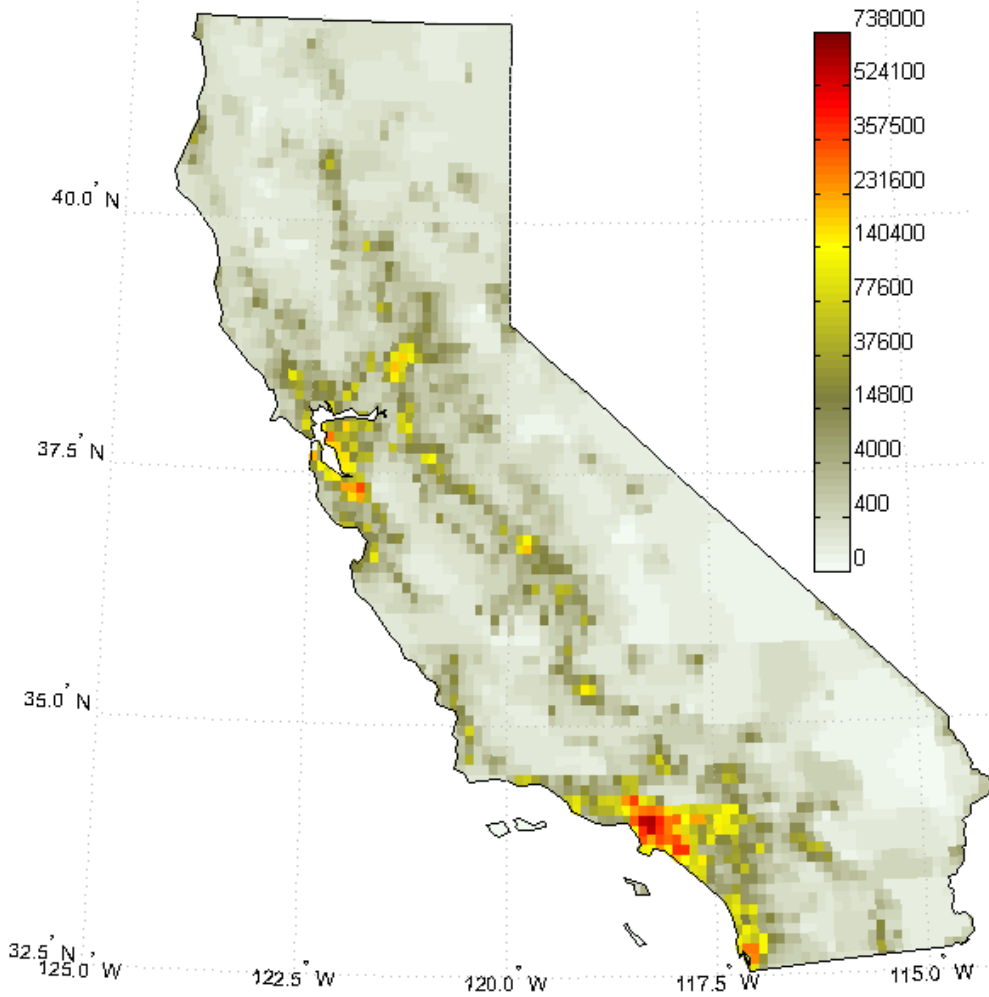
Chicken-egg dynamics

AFV chicken-egg dynamics

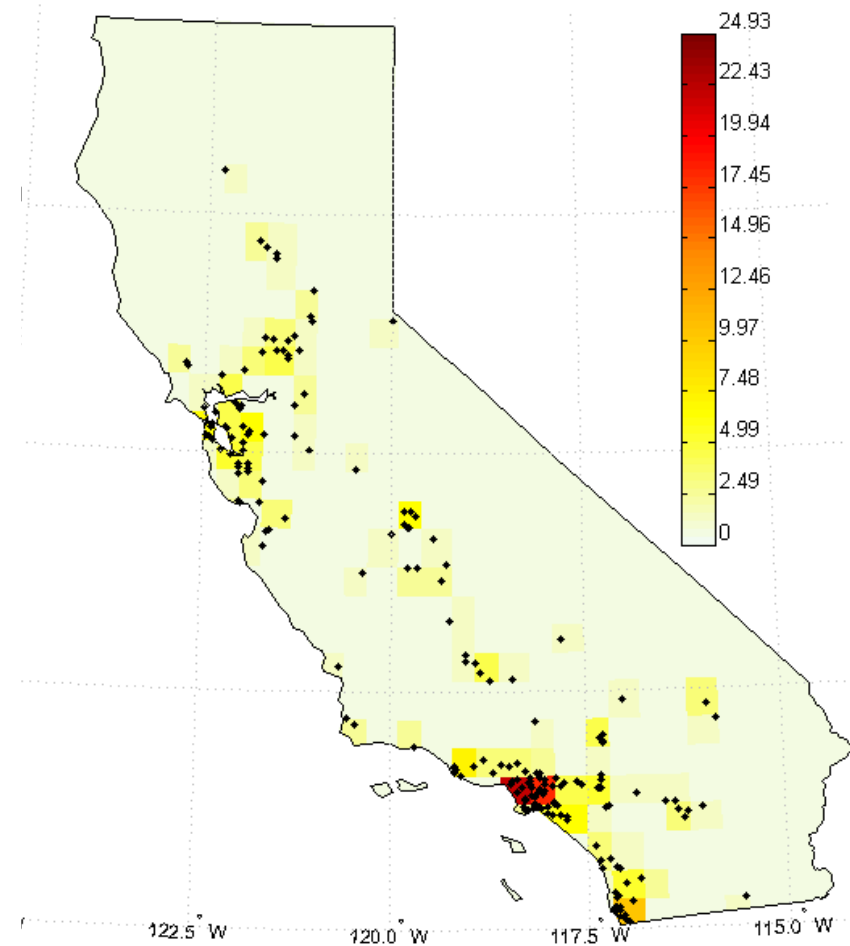


Observation: Co-location of Demand and Supply

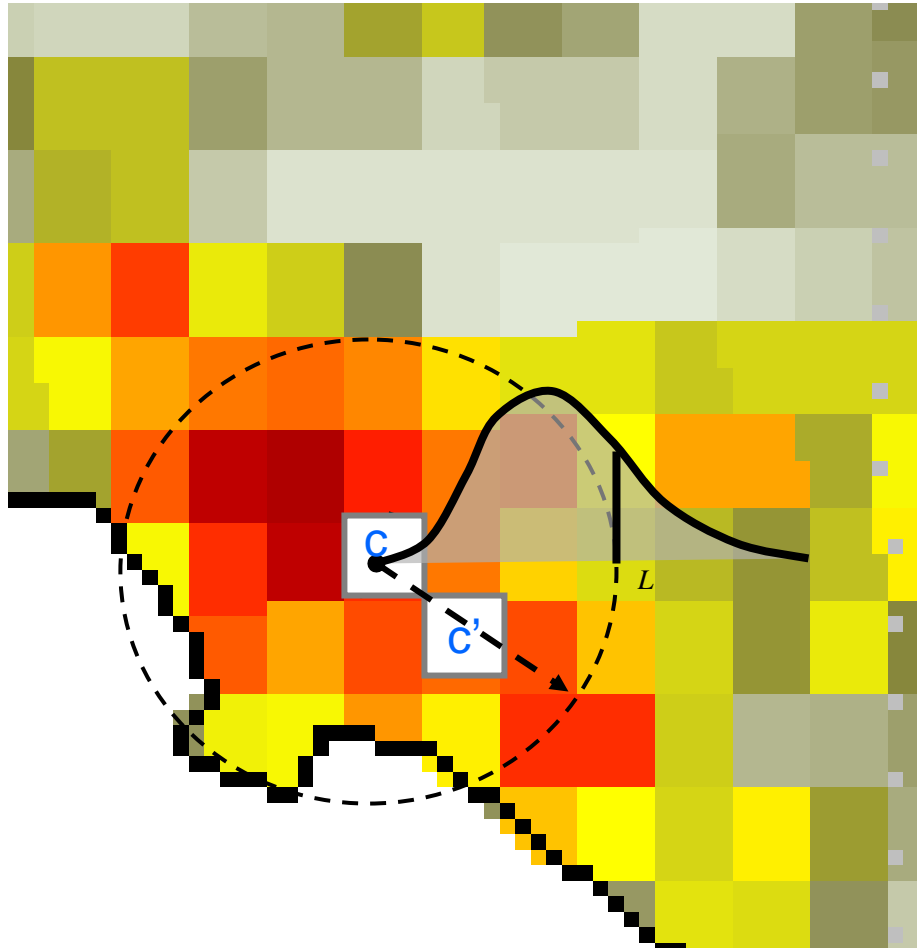
Population (2000): CA



All CNG Stations - 2002: CA



A behavioral spatial dynamic model



household density in c ($\rho_c^{households}$)

trip distribution for (L, θ) in c ($f_{c,l}^{drive}$)

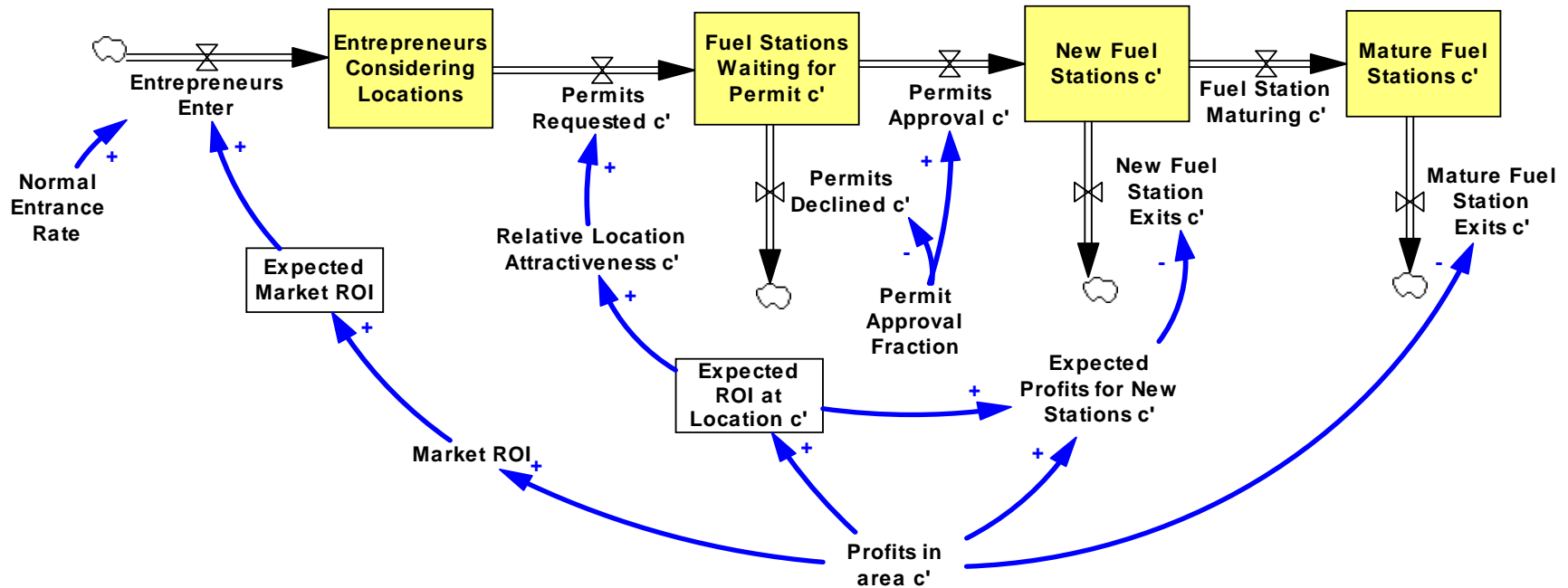
vehicle miles for households in c (m_c)

fraction of trip L through c' ($f_{cc'l}^{share}$)

station density in c' ($\rho_{c'}^{stations}$)

adoption fraction in c ($f_c^{adoption}$)

Station entrance process



Hypothetical “Market Seed” Scenario:

for illustration of spatial dynamics only

- **24,990 initial alt. fuel vehicles**
 - 2002 EIA estimate for total CNG vehicles in CA
 - Spatially distribute vehicles per maximum driver utility (true distribution unknown)
- **216 initial alternative fuel stations**
 - 2002 TOTAL CNG stations (public/non-public) per NREL alt. fuel database
 - Spatially distributed per actual station lat/long in database
- **To ISOLATE the infrastructure effect, assume:**
 - Vehicle & Station/Fuel Costs/Performance EQUAL for Alt. Fuel & Gasoline ICE
 - EVERY existing alt. fuel station is accessible (about 1/2 really aren't!)
 - Consumers have perfect AWARENESS of vehicle availability & station locations
- **To understand MARKET driven dynamics, assume:**
 - All stations seek profitability (not true with EPA mandates)
 - Vehicle drivers/purchasers are typical citizens (i.e., not Federal/State/Utility fleets)
- **Finally, for ILLUSTRATION of potential dynamics, assume:**
 - Low driver sensitivity to add'l effort & “out of gas” risk

End of Animation

Subsidy Strategy # 1

Total Stations: CA - year 20

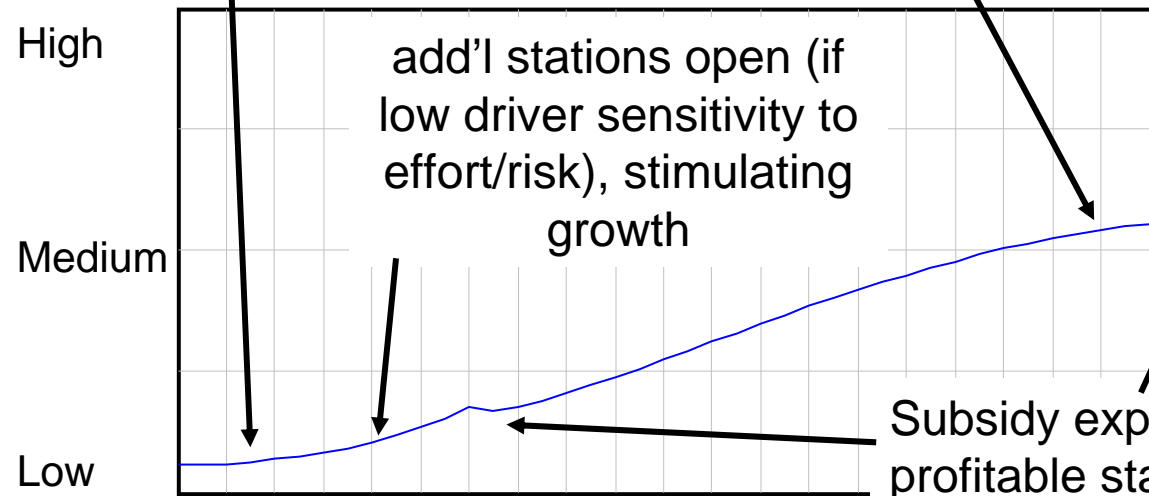
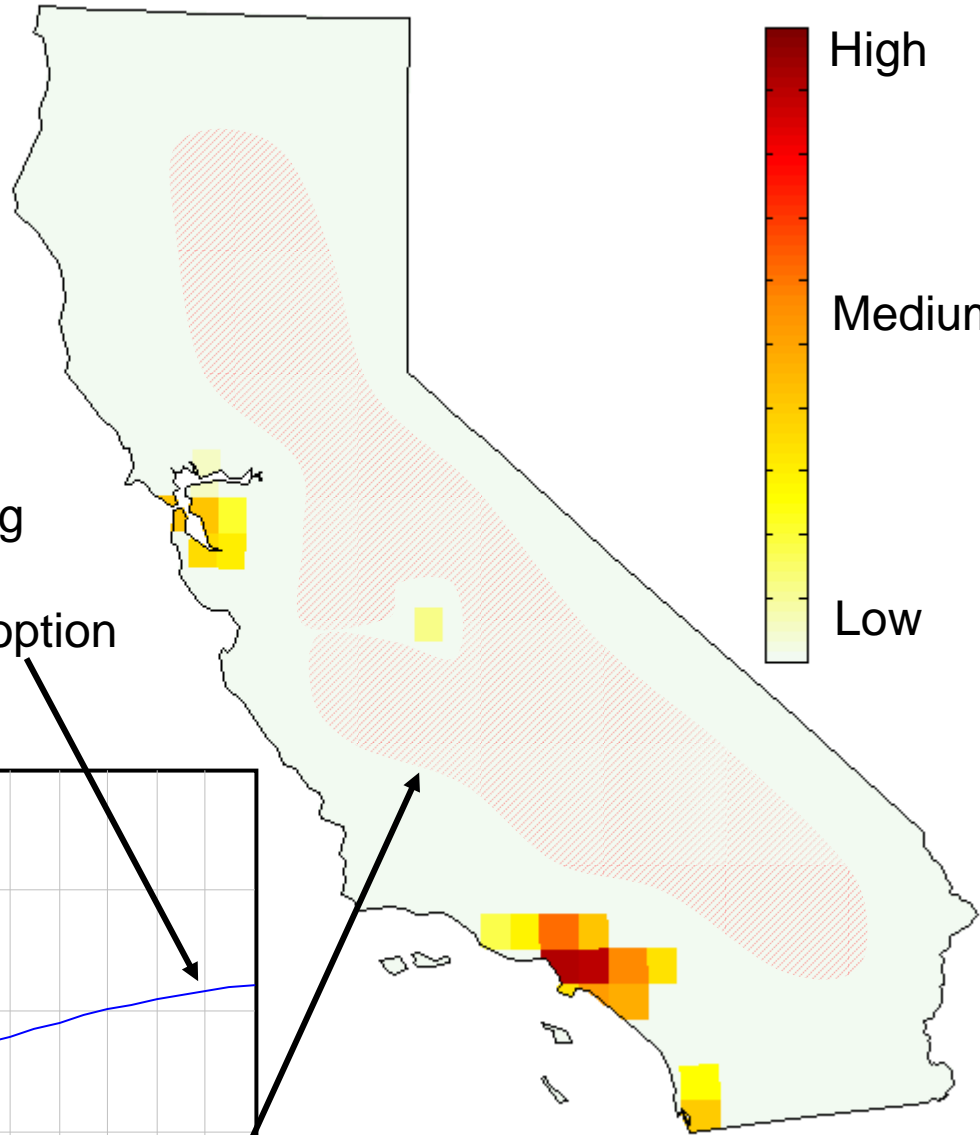
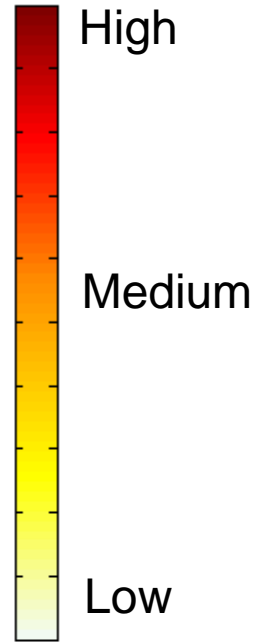
No Stations
Close: Losses
Subsidized

Approaching
equilibrium
stations/adoption

Total Stations

add'l stations open (if
low driver sensitivity to
effort/risk), stimulating
growth

Subsidy expires, un-
profitable stations close

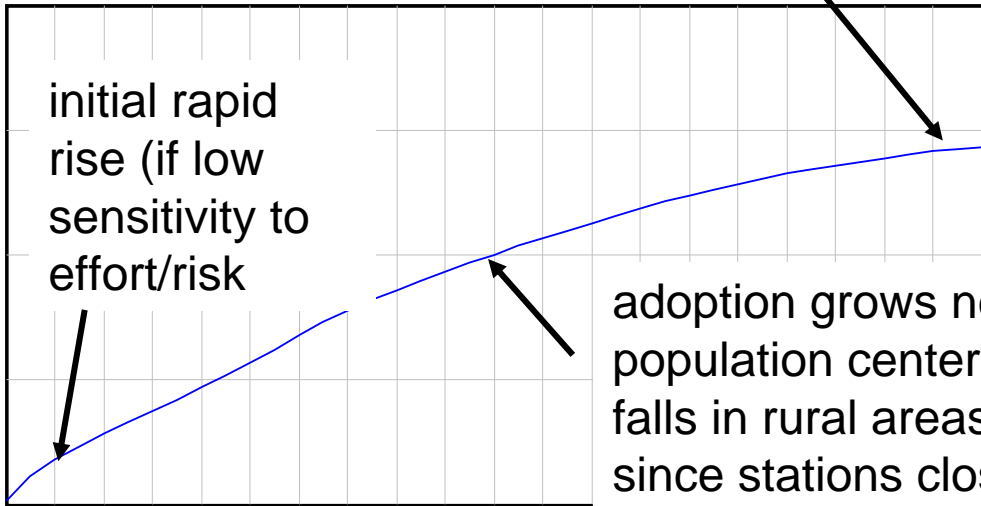
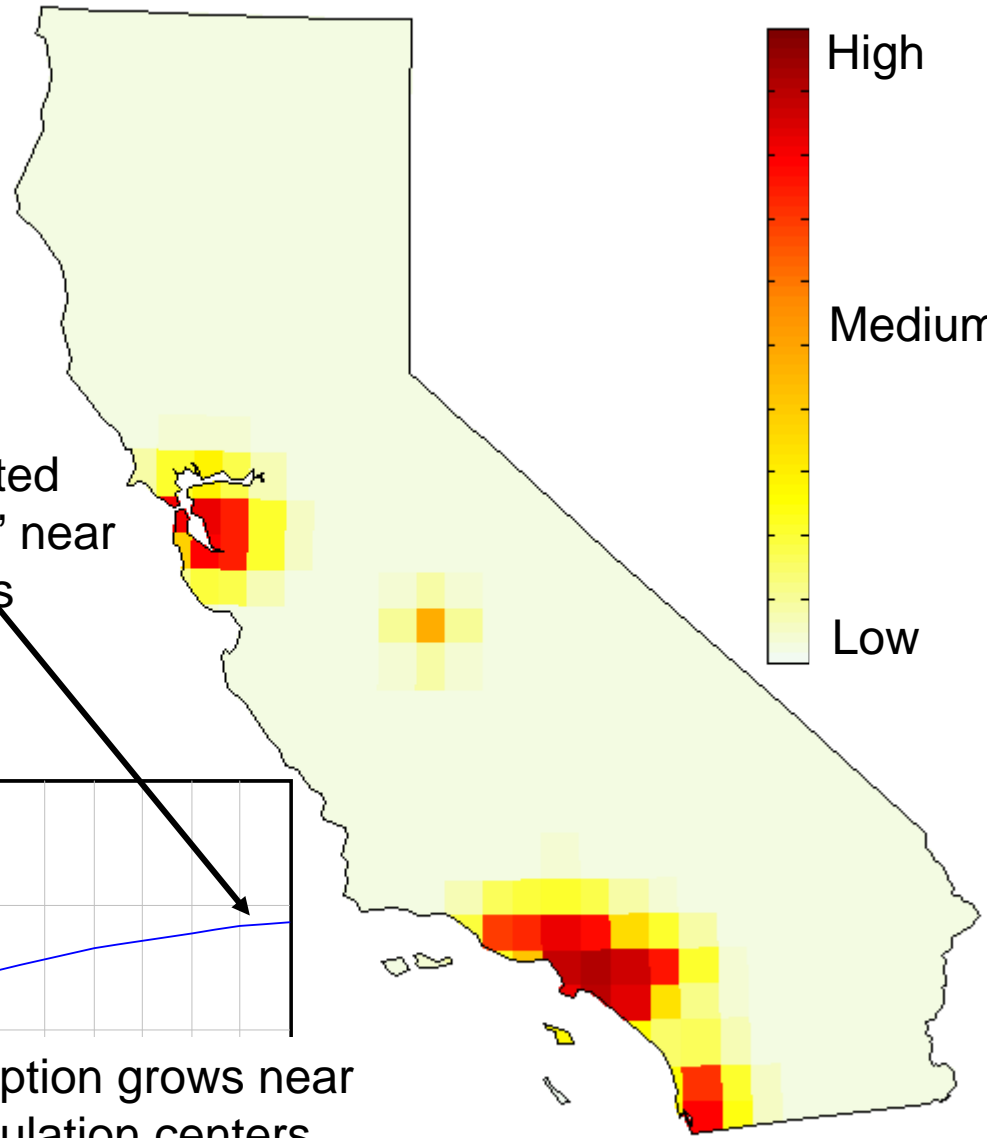
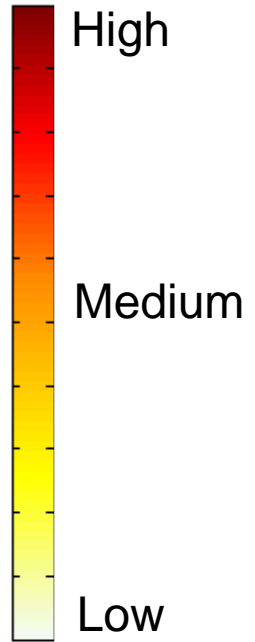


End of Animation

Subsidy Strategy # 1

final adoption limited due to “clustering” near population centers

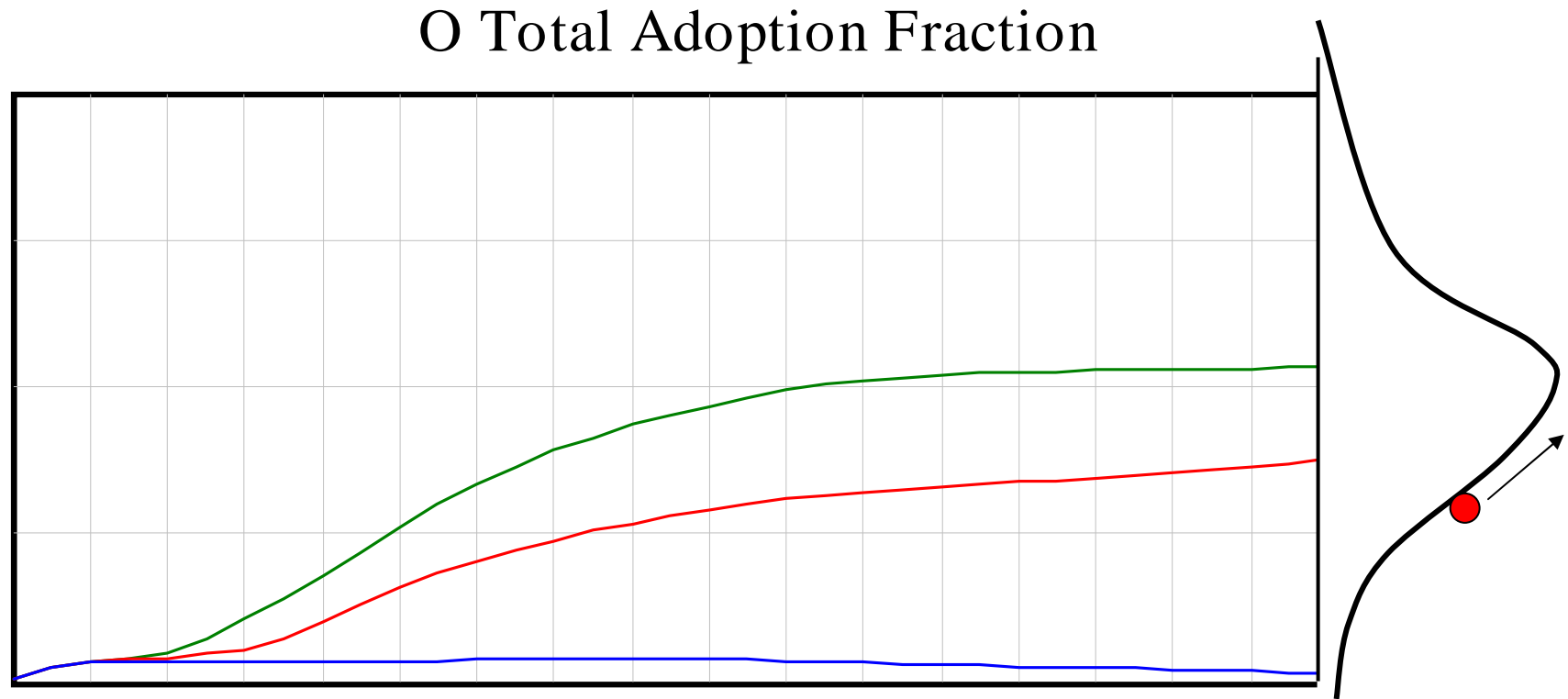
○ Total Adoption Fraction



initial rapid rise (if low sensitivity to effort/risk)

adoption grows near population centers, falls in rural areas since stations closed

Vehicle Adoption Sensitivity to Station Subsidy



- O Total Adoption Fraction : XY10_2002_All_CNG_40PercentSub6yrs — dmnl
- O Total Adoption Fraction : XY10_2002_All_CNG_60PercentSub6yrs — dmnl
- O Total Adoption Fraction : XY10_2002_All_CNG_90PercentSub6yrs — dmnl

Parameters of Relevance

Supply Side

Economics/Technology

- Station operating cost
- Station capacity
- Refill capacity
- Fuel cost
- ...

Behavioral

- Planning horizon
- Normal time to exit market
- “Expected demand formation”
- ...

Demand Side

Economics/Technology

- Population distribution
- Tank size
- Fuel efficiency
- ...

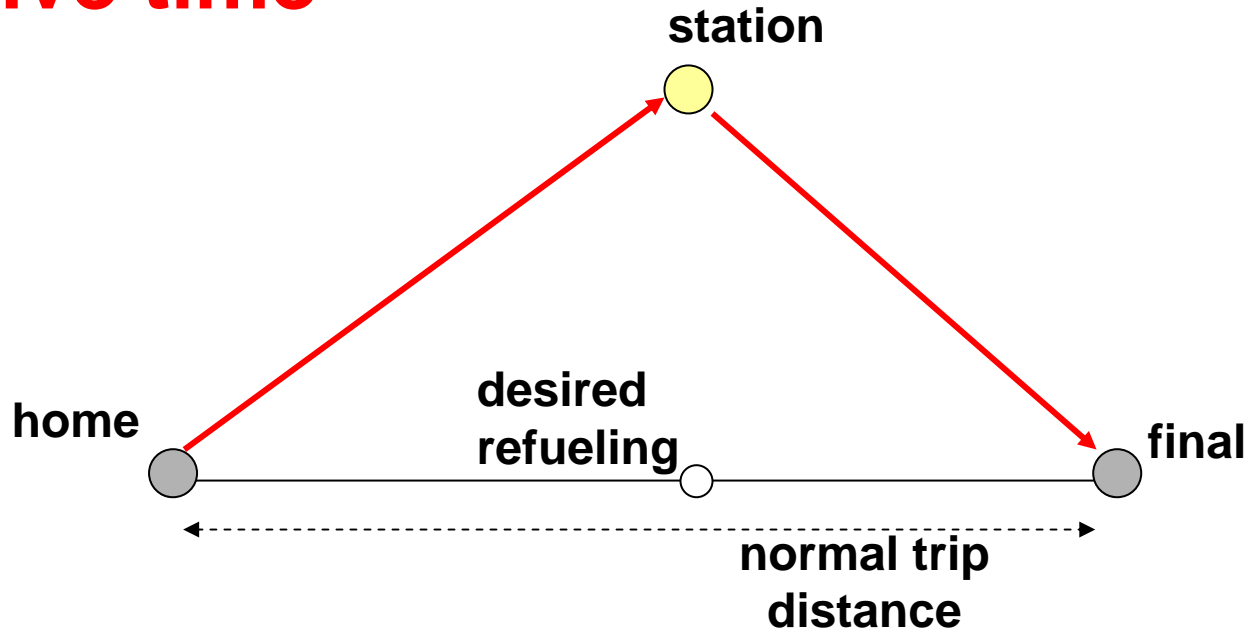
Behavioral

- Value of time
- Sensitivity to trip cost
- Normal trip distributions
- ...

Policy levers: Taxes (supply/demand), subsidy, Strategic Entrance

Refueling cost from finding station

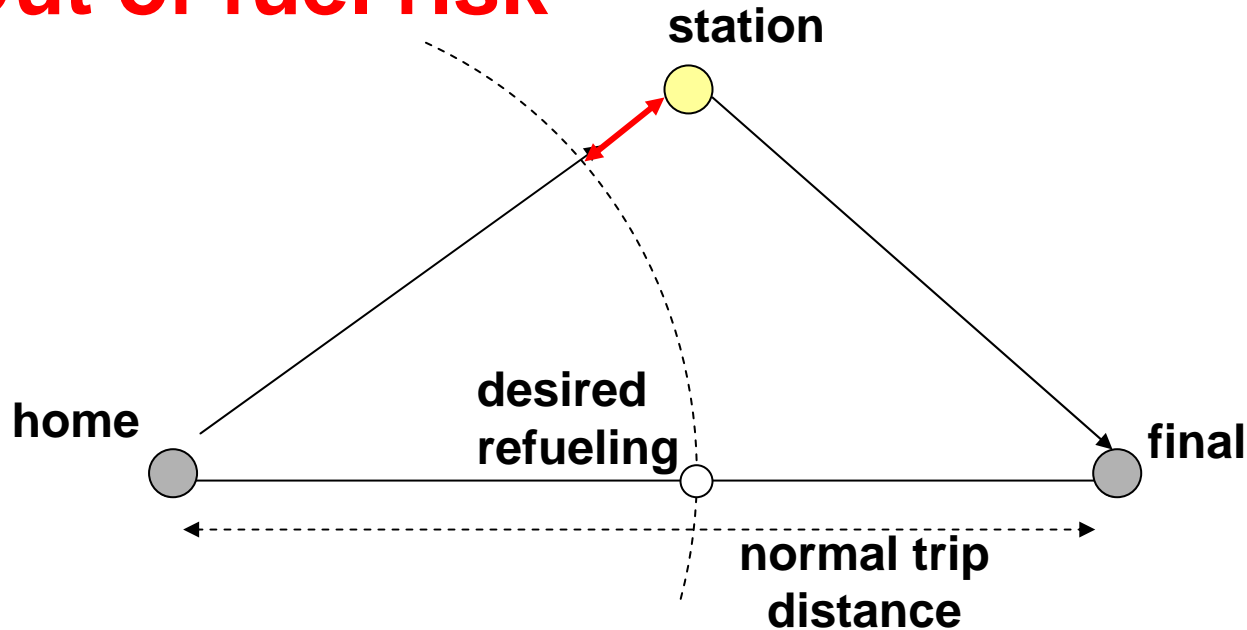
1. drive time



*Critical in **short** trips*

Refueling cost from finding station

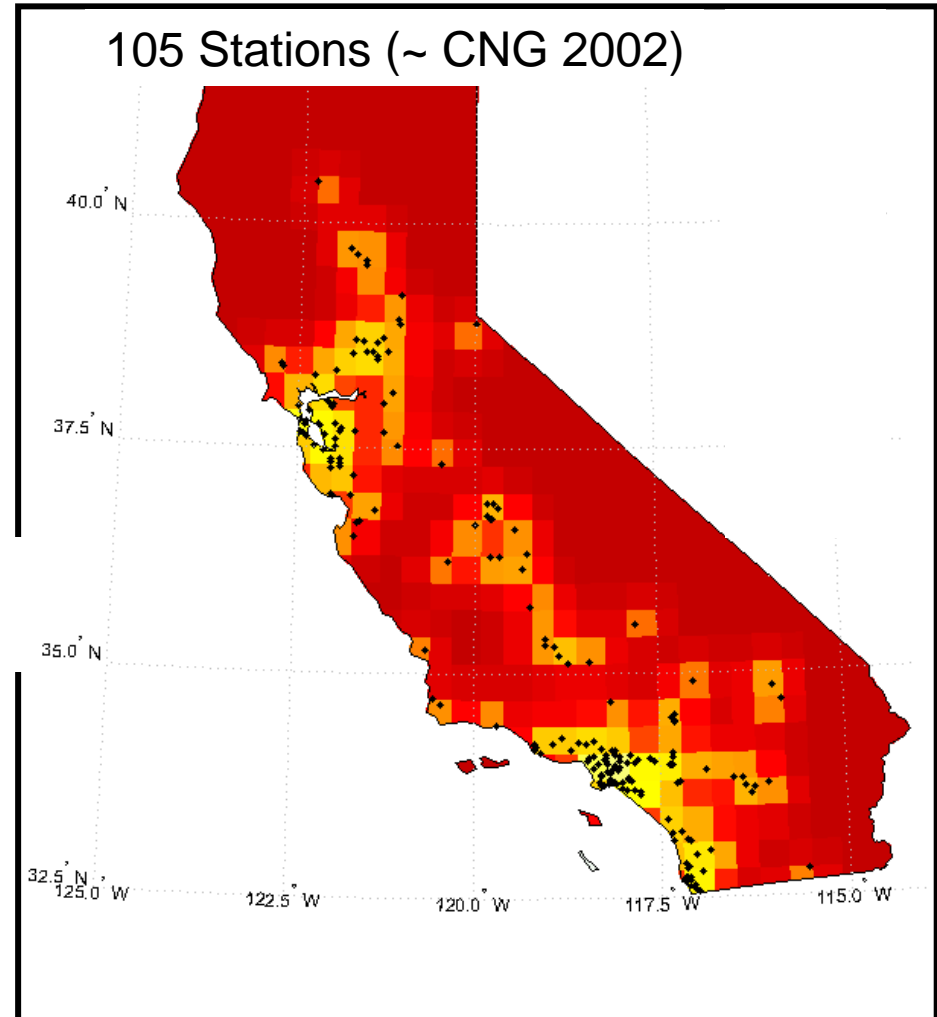
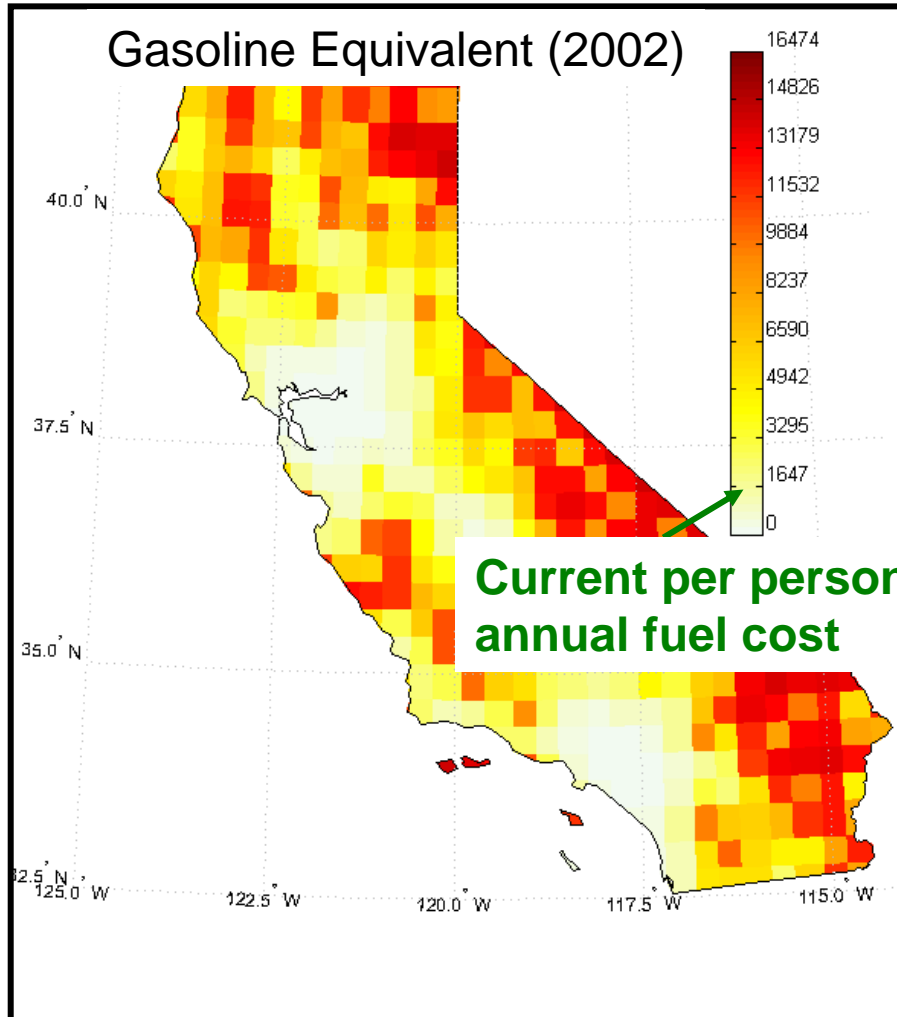
2. Out of fuel risk



*Critical in **long** trips*

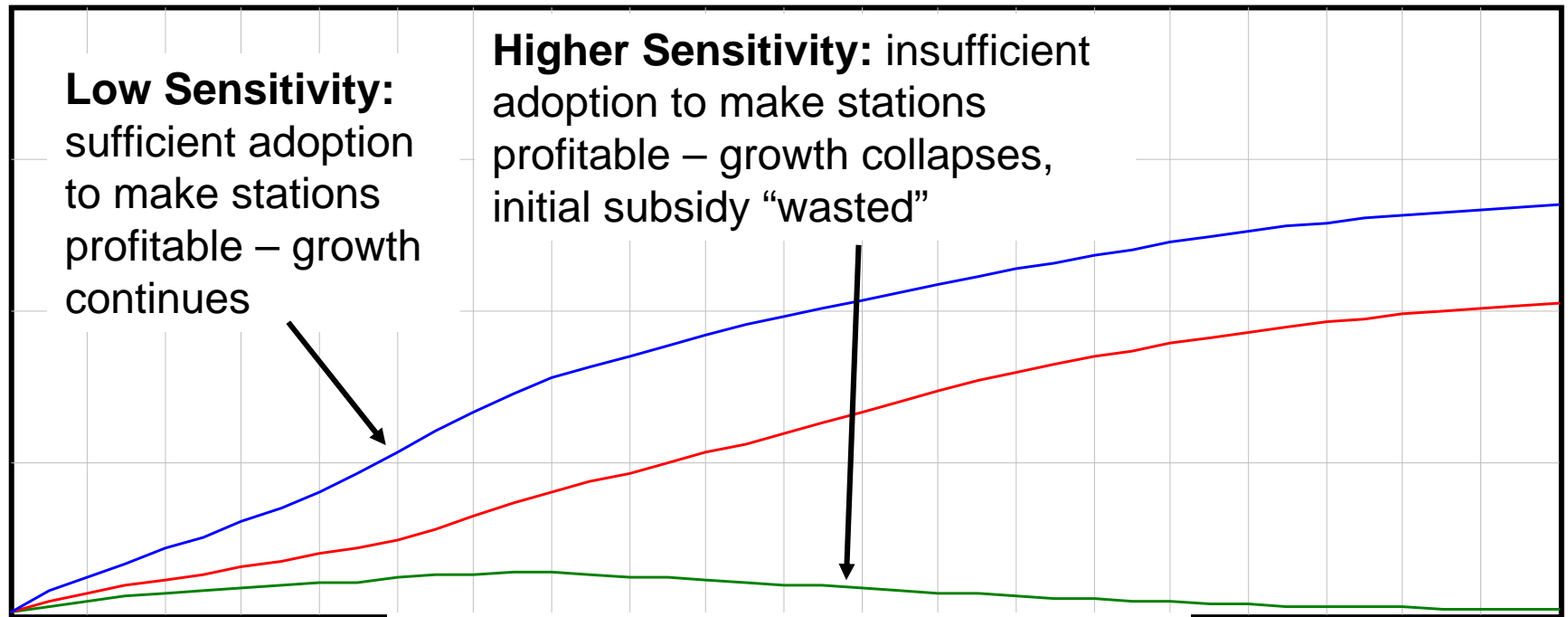
Refueling cost from finding station

Station induced cost of travel (minus Reference Cost) [\$/year/Person]



Adoption Fraction Sensitivity: Vehicle Purchaser Elasticity to Add'l Effort/Risk

O Total Adoption Fraction

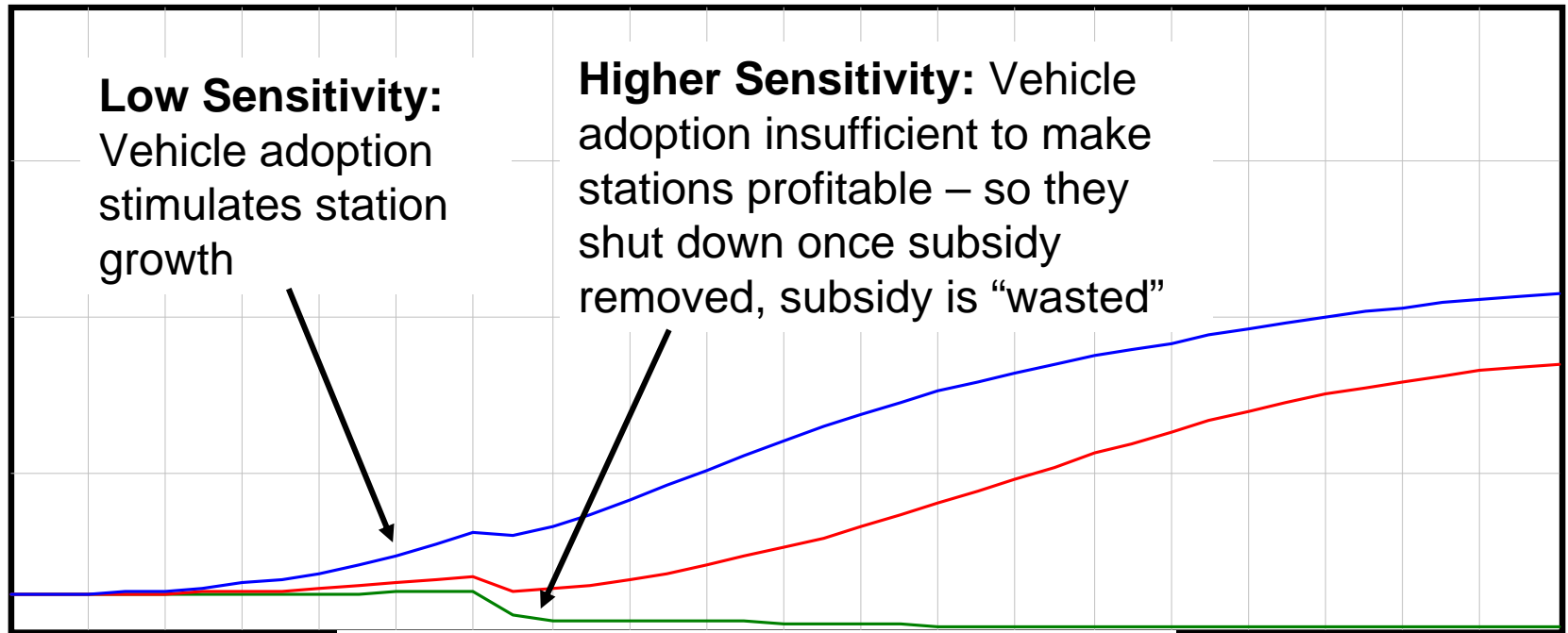


**Critical Thresholds Exist:
Highly Nonlinear**

- O Total Adoption Fraction : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p2 — dmnl
- O Total Adoption Fraction : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p3 — dmnl
- O Total Adoption Fraction : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p4 — dmnl

Total Stations Sensitivity: Vehicle Purchaser Elasticity to Add'l Effort/Risk

Total Stations



**Critical Thresholds Exist:
Highly Nonlinear**

Total Stations : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p2 — stations
Total Stations : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p3 — stations
Total Stations : XY10_2002_All_CNG_Hnymn5p5yr_Elasticity_M0p4 — stations

Analysis of a generic Grid

for dynamic insights only

- **Environment:**

- 200x200 Miles Region
- “Unbounded” / “Torus shaped”
- Relevant AVERAGE demographic parameters are conform California
- Compare role of different forms of Heterogeneity

- **Supply (Vehicle/Infrastructure):**

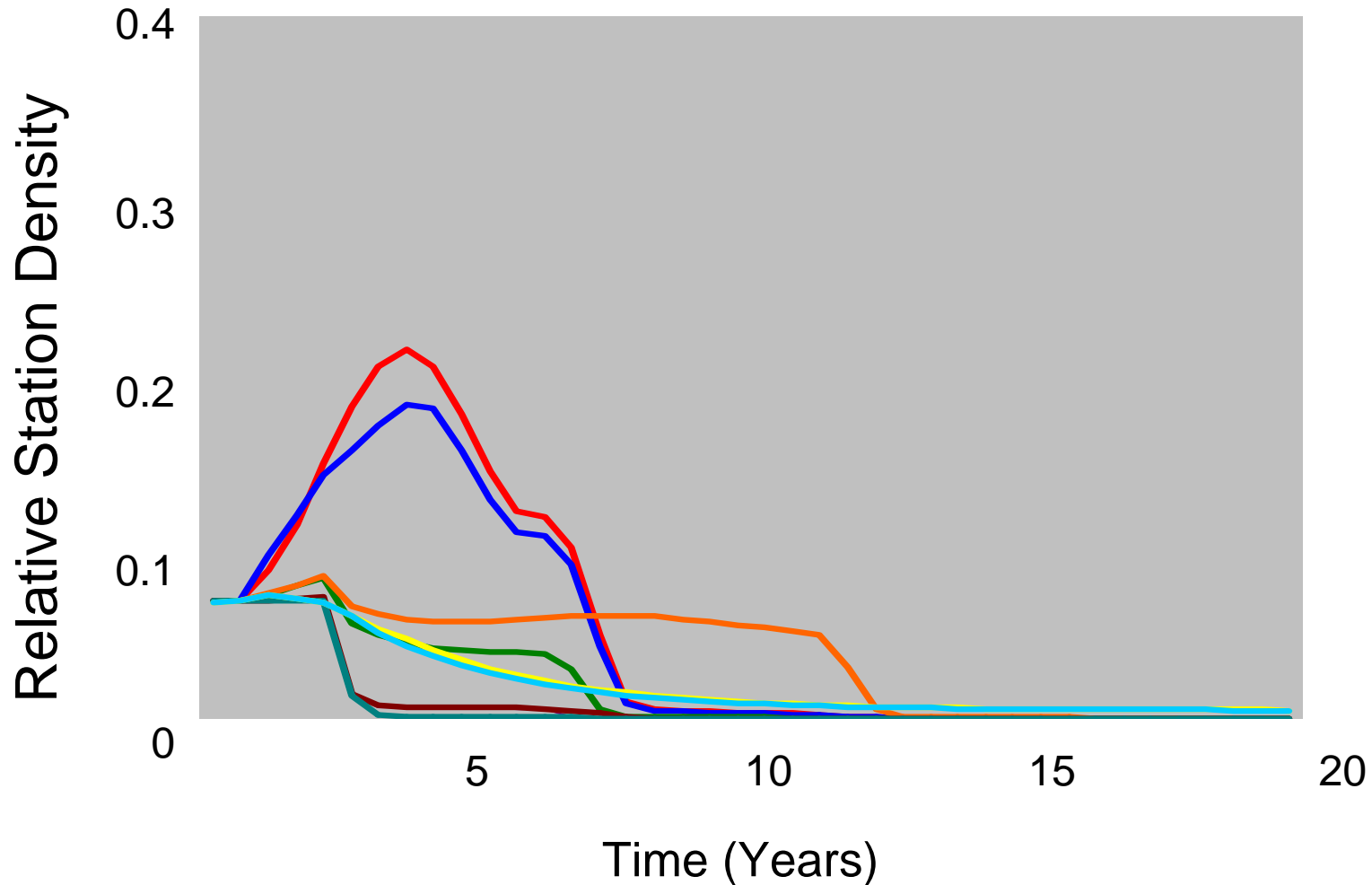
- One Incumbent platform, conform ICE/Gasoline
- Entrant Vehicle Technology by default equal to Incumbent
- All stations seek profitability

- **Demand:**

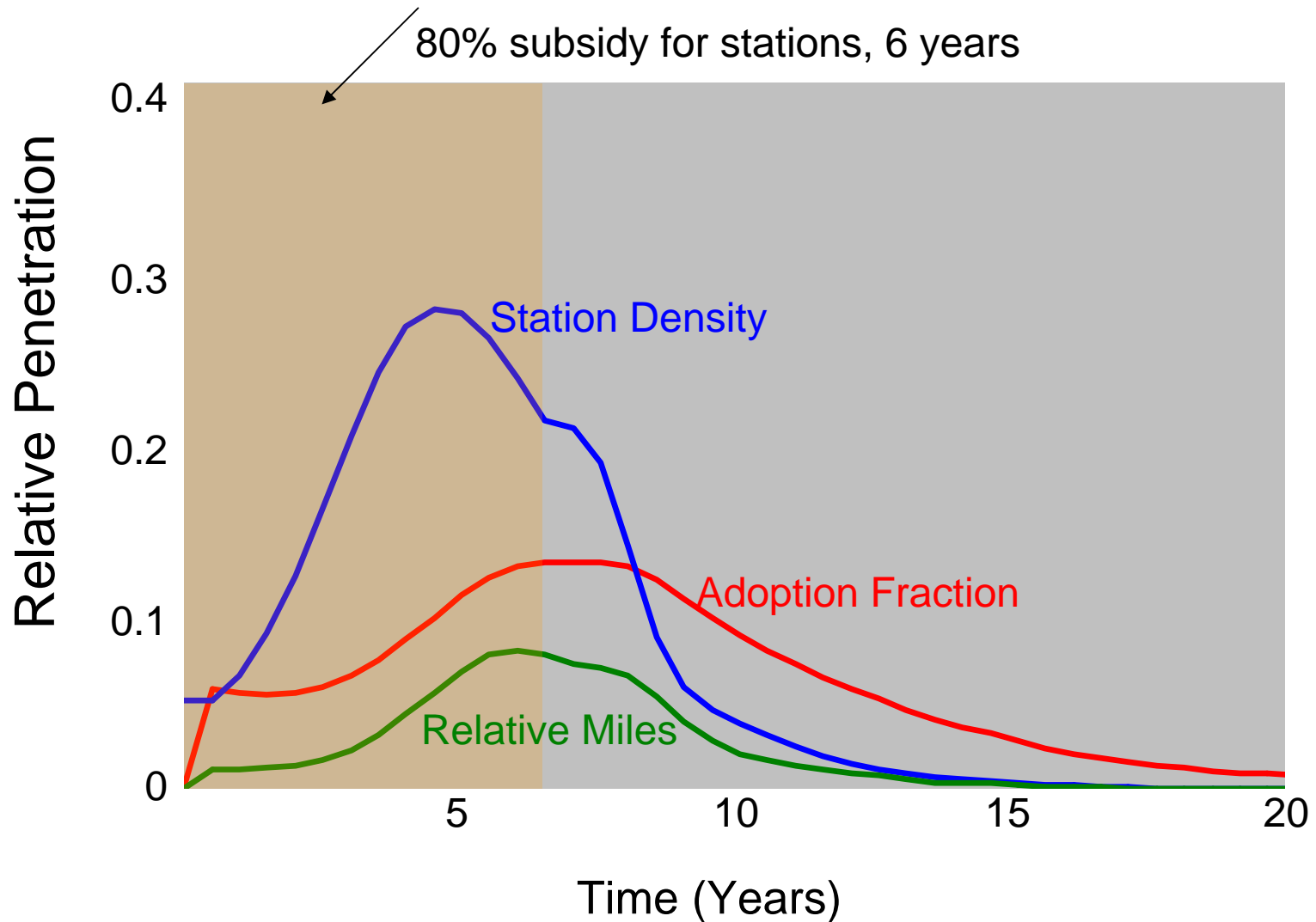
- Vehicle drivers/purchasers are typical citizens (i.e., not Federal/State/Utility fleets)
- EVERY existing alt. fuel station is accessible
- Consumers have perfect AWARENESS of vehicle availability & station locations
- Desired trip distribution – average 20 miles

Seeding the Chicken-egg problem

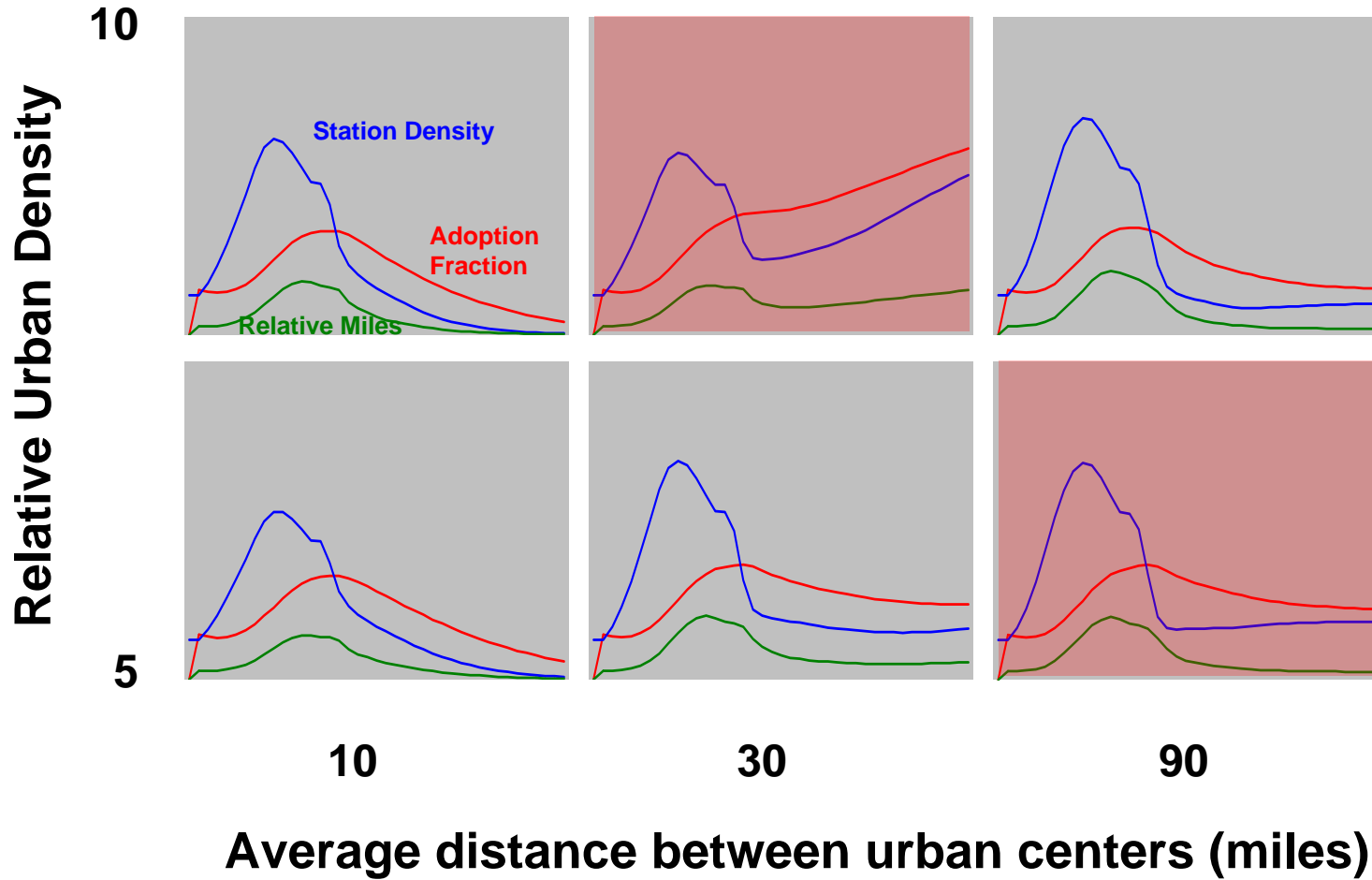
Subsidies 20-80% / 5-10 year



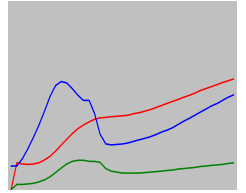
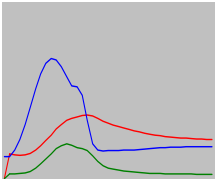
Stimulating Adoption



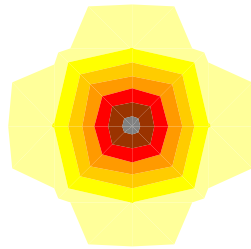
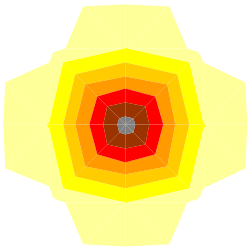
Demographic Heterogeneity: Including urban and rural



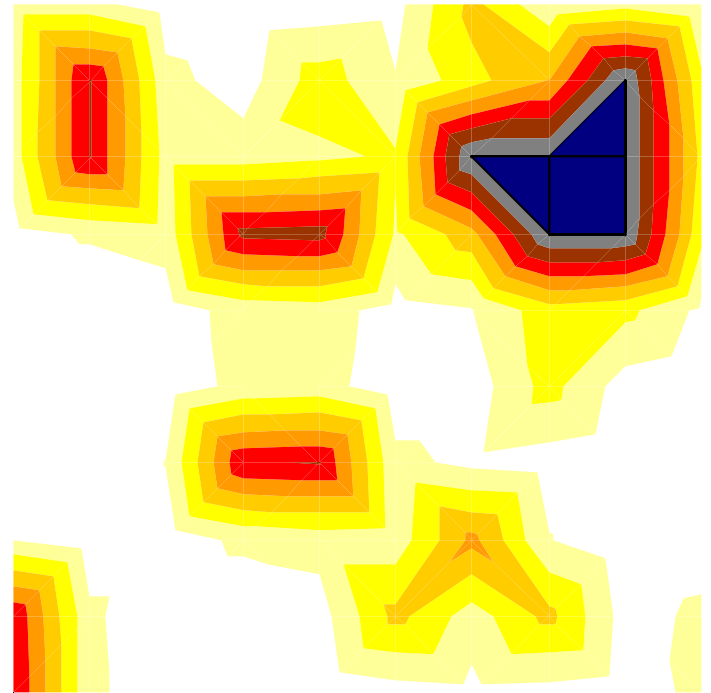
Adoption in Space

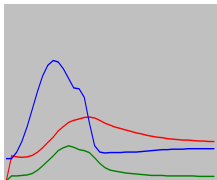


“Texas”



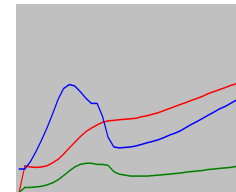
“Bay Area”



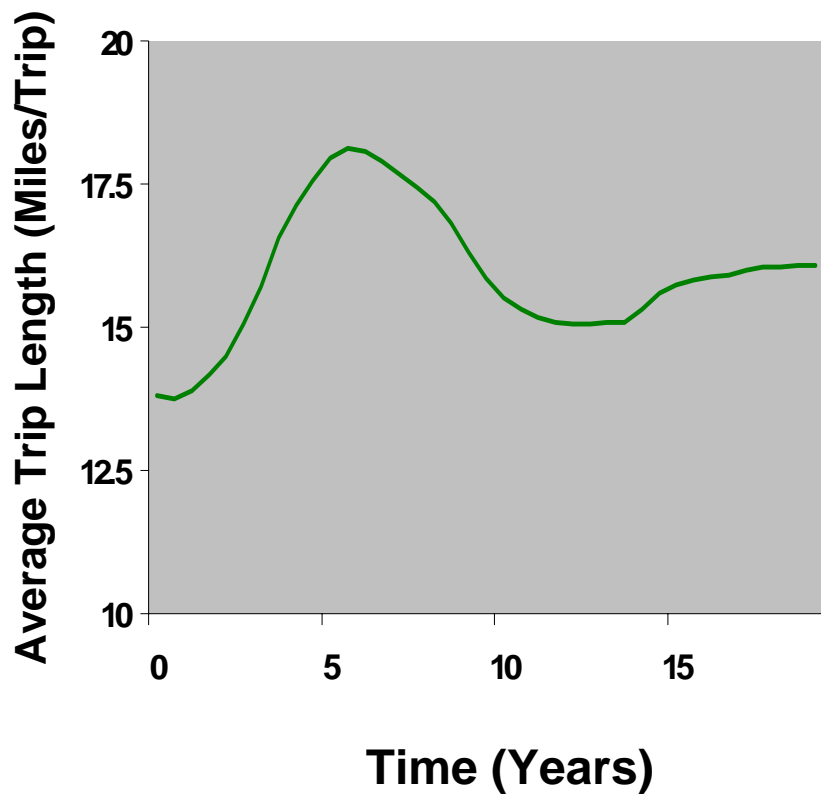


Endogeneity of trip choice

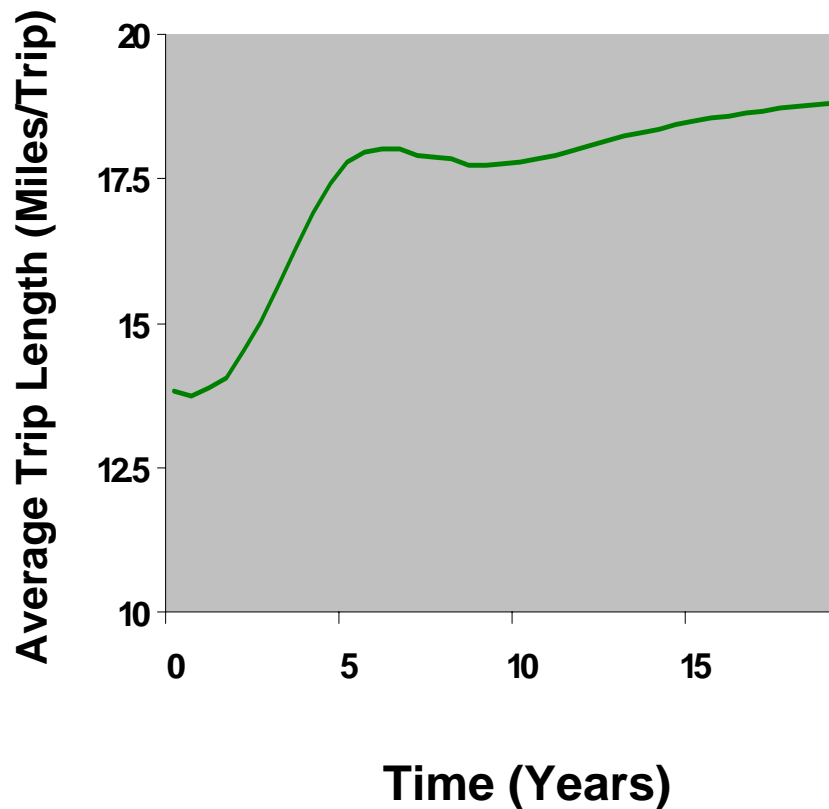
average trip length



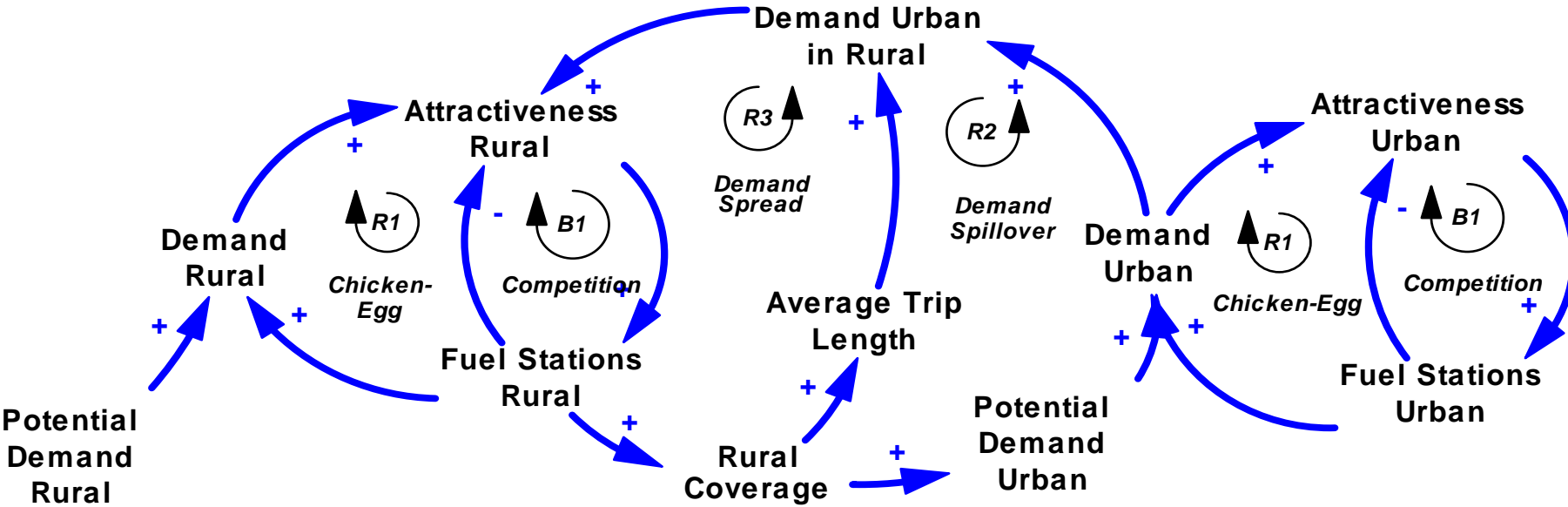
“Texas”



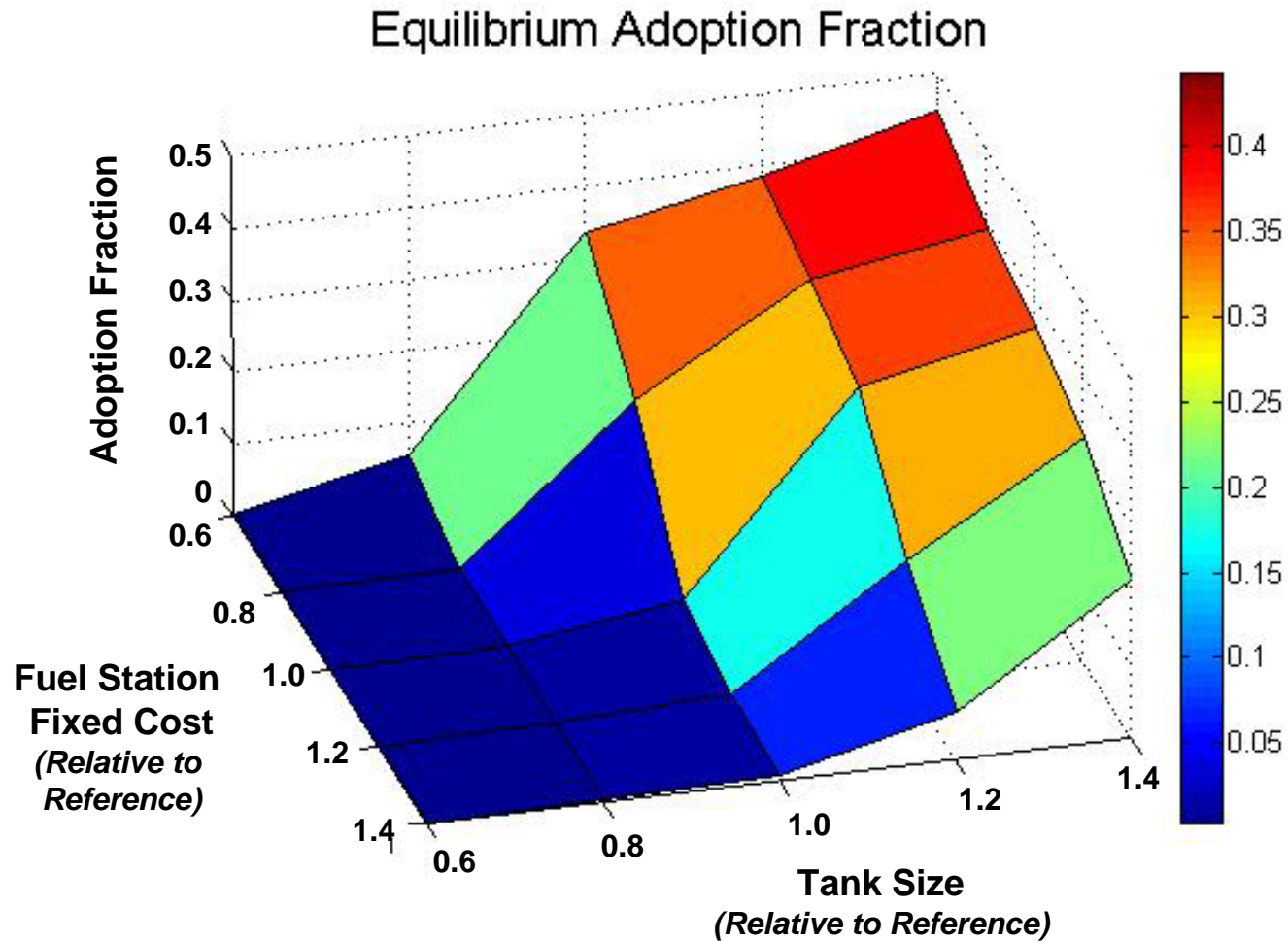
“The Bay Area”



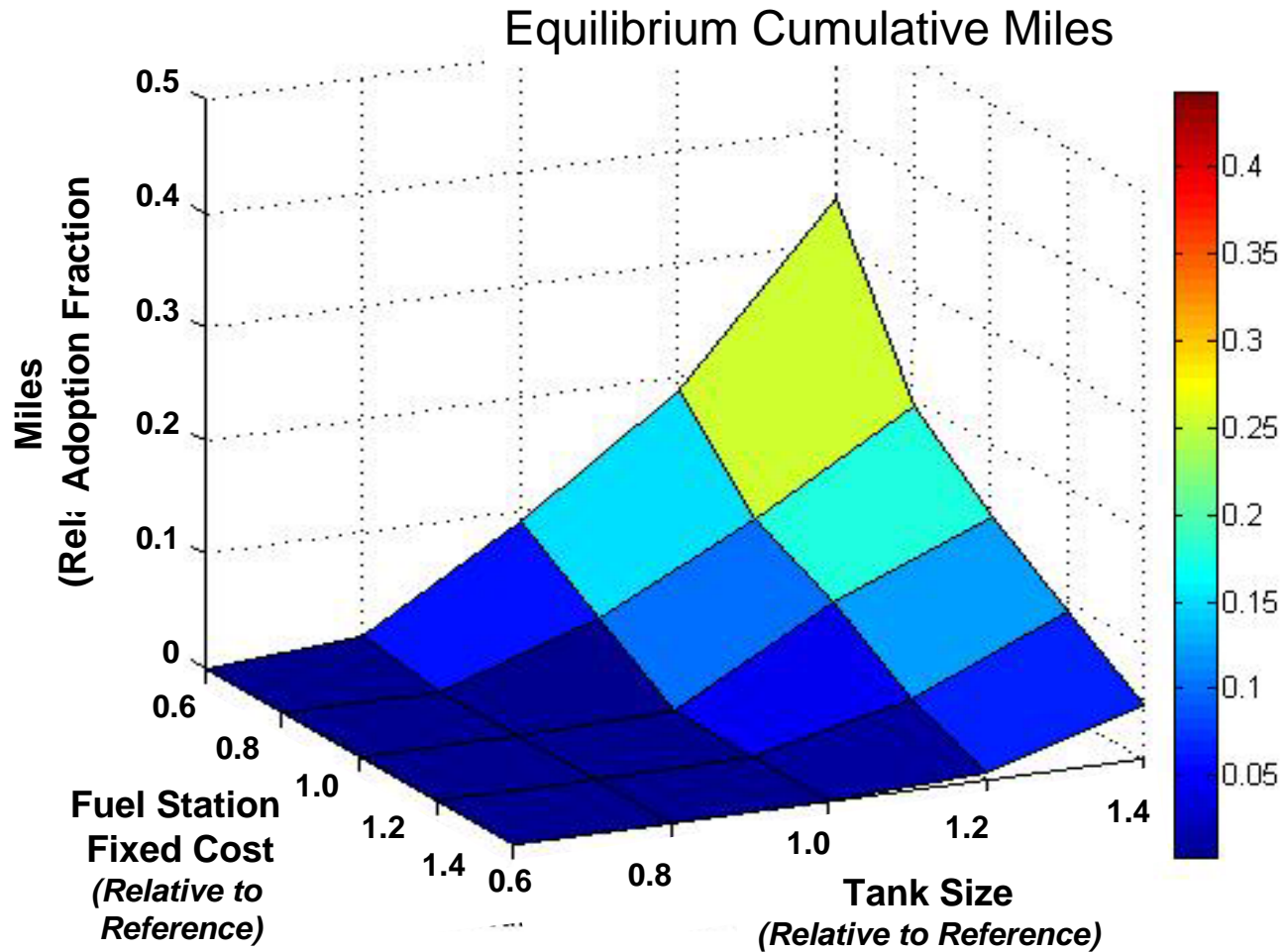
The Rural-Urban Challenge



Sensitivity to technical performance factors



Sensitivity to technical performance factors



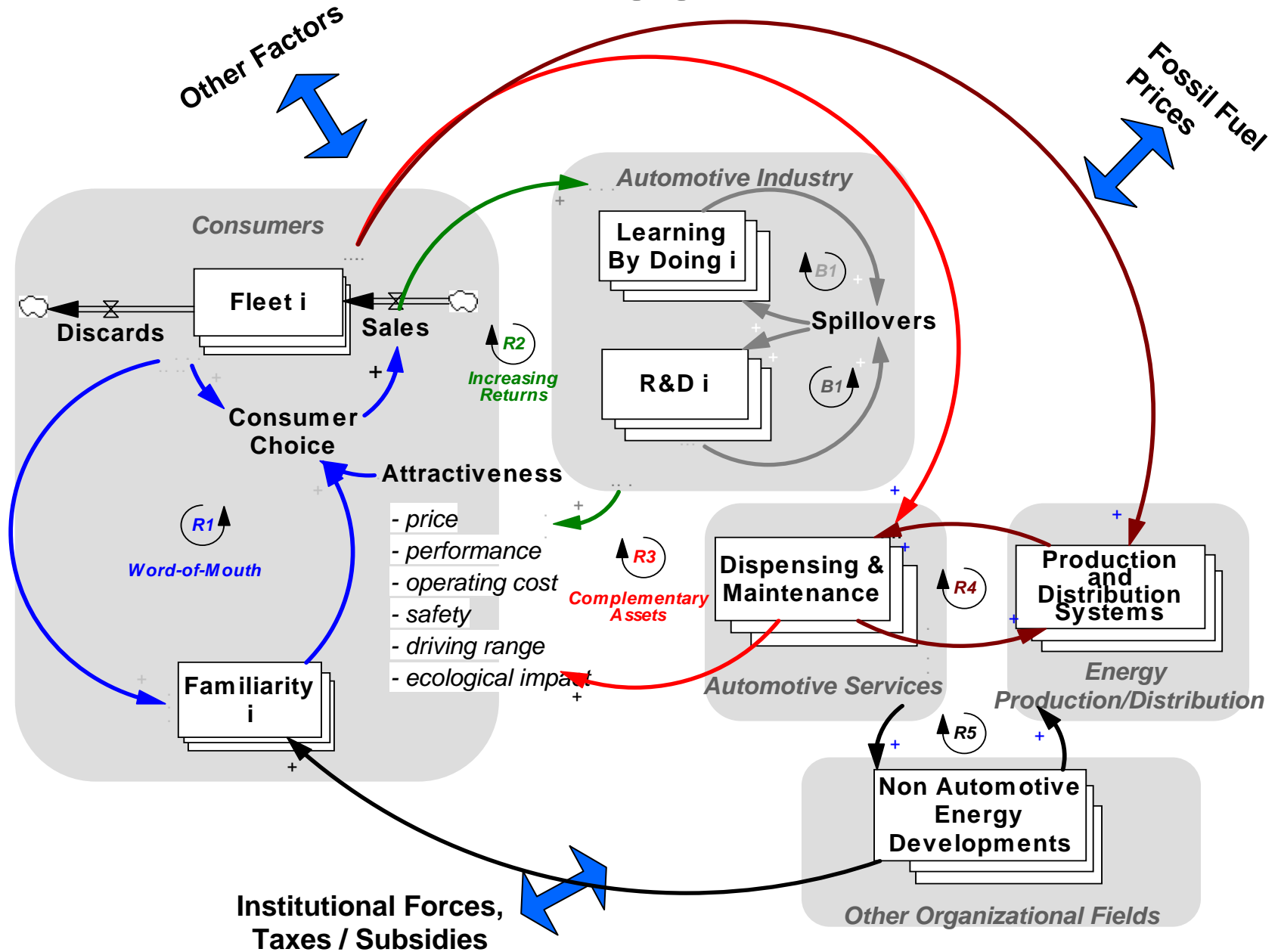
Dynamic insights

- Endogeneity of “locus” of demand AND supply due to strategic entrance
- Clustering as mechanism for adoption
- Significant barriers to adoption
 - Multiple thresholds
 - Alternatives/Standardization tradeoffs
 - Endogeneity of vehicle miles increase “tipping point”
- ...

Sample insights policy analysis

- Typical policies that come out / or can be tested
 - Location of fuel stations / subsidy strategies
 - Replacement rate acceleration (Leasing)
 - On the road refueling
 - Effect of exits on negative word-of-mouth dynamics, emphasizing stability
- Areas of scenario analysis
 - What if DOE targets are met?
 - Selection of pilot regions
 - California Blueprint
- ...

Model part of a bigger picture study



The hydrogen transition challenge: co-evolutionary dynamics between vehicle demand and fueling infrastructure

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