VIRTUOUS CIRCLES ENHANCING THE TRANSITION TO RENEWABLES: CAUSAL RELATIONS AMONG ELECTRIC VEHICLES, ROOFTOP SOLAR, INSTALLATION COSTS, AND CHARGING STATIONS

ROBERT K. KAUFMANN
DEREK NEWBERRY
CHEN XIN
SUCHARITA GOPAL

PROJECT LINK
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WHAT YOU SHOULD REMEMBER

- Causal relations among rooftop solar, its cost of installation, electric vehicles, and changing stations create feedback loops that accelerate the transition to carbon free sustainable technologies.
- Causal relations are created by ‘learning by doing’ and the psychology of decision making in the real world.
- Policy must use the spatial and psychological nature of decision making to initiate feedback loops that accelerate the transition to carbon free sustainable technologies.

SINGLE FACTOR APPROACH

- Electric vehicles
  - Up front cost
  - Range anxiety
  - Demographics of adopters

- Charging stations
  - Location
  - Type

- Rooftop solar
  - Levelized cost of electricity

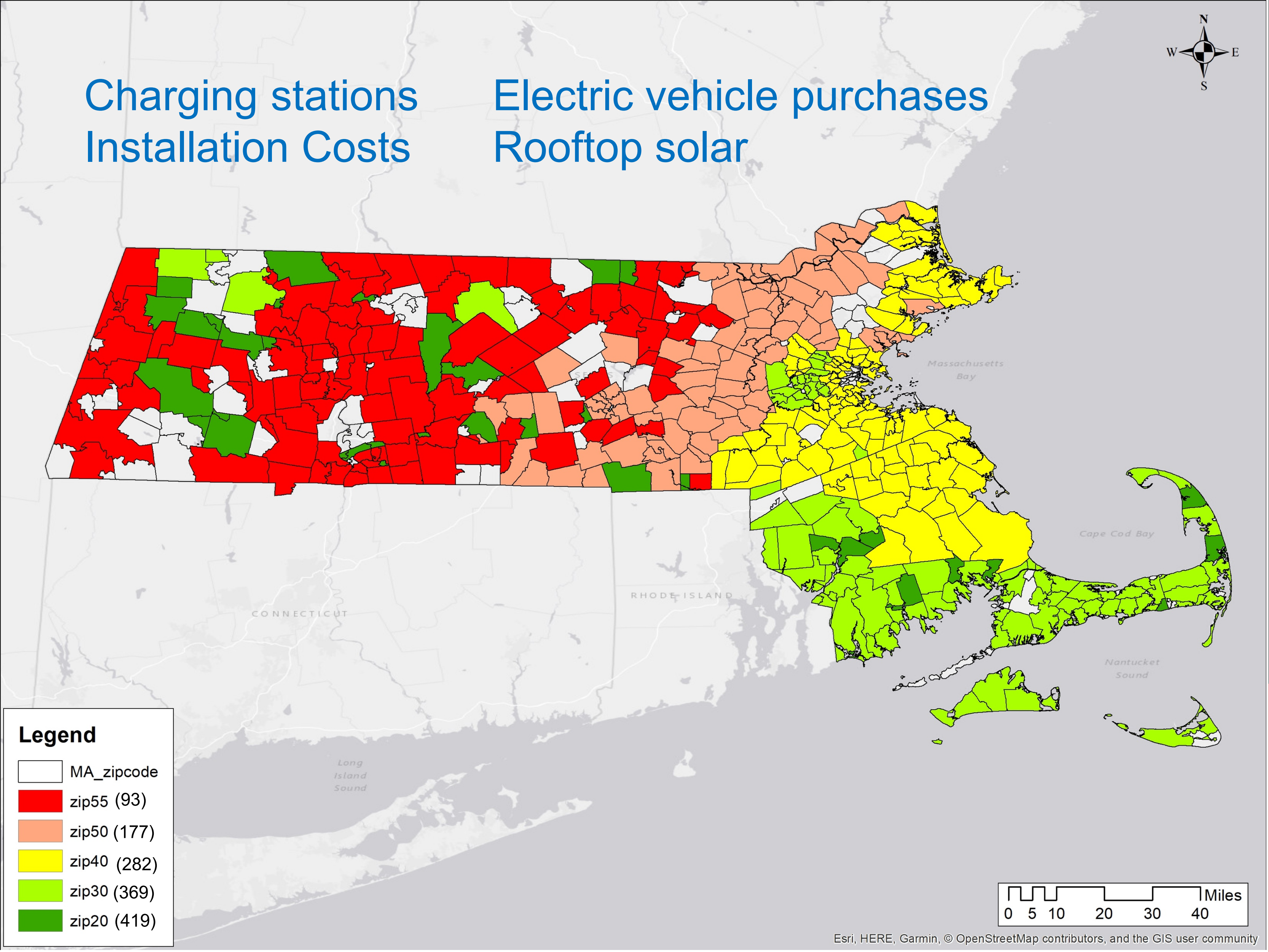
- Installation costs
  - Learning by doing

SYSTEM DYNAMICS

- Is there a way to seed the system?

- Are there feedback loops?

- Causal relations among components


Charging stations
Installation Costs
Electric vehicle purchases
Rooftop solar
N
W
E
S
Massachusetts Bay
Cape Cod Bay
Nantucket Sound
RHODE ISLAND
CONNECTICUT
Long Island Sound
Legend
MA_zipcode
zip55 (93)
zip50 (177)
zip40 (282)
zip30 (369)
zip20 (419)
Miles
0 5 10 20 30 40
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METHODOLOGY

- Time series properties
  - Breitung (2000), Im *et al* (2003) Levin *et al* (2002)
  - EV & Cost uncertain
  - Convert I(1) to I(0) (first difference)
- Panel causality (Dumitrescu and Hurlin, 2012)

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t}$$

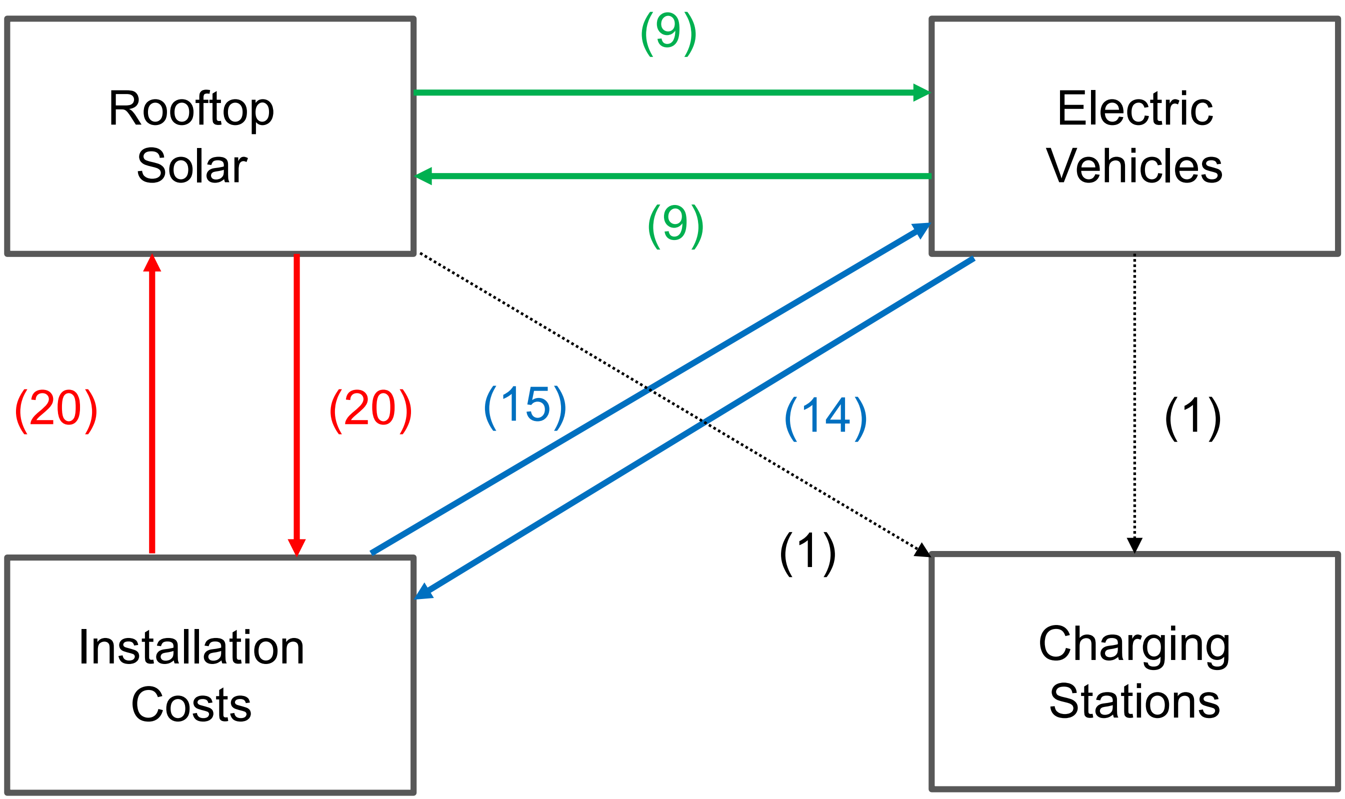
  - Fixed coefficient model $\gamma_i^{(k)}$, $\beta_i^{(k)}$ vary across individuals
  - Fixed individual effects
  - Null: homogeneous noncausality, no $x \rightarrow y$ any individual
  - Alternative heterogeneous non causality, $0 < x \rightarrow y < \mathrm{N}$
  - SBC choses lag length

$$W_{N,T}^{Hnc} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T}, \qquad W_{i,T} = \hat{\theta}_i' R' \left[\hat{\sigma}_i^2 R (Z_i' Z_i)^{-1} R' \right]^{-1} R \hat{\theta}_i = \frac{\hat{\theta}_i' R' \left[R (Z_i' Z_i)^{-1} R' \right]^{-1} R \hat{\theta}_i}{\hat{\varepsilon}_i' \hat{\varepsilon}_i / (T - 2K - 1)},$$

  - Distributed $\chi^2 \ (N \times K)$

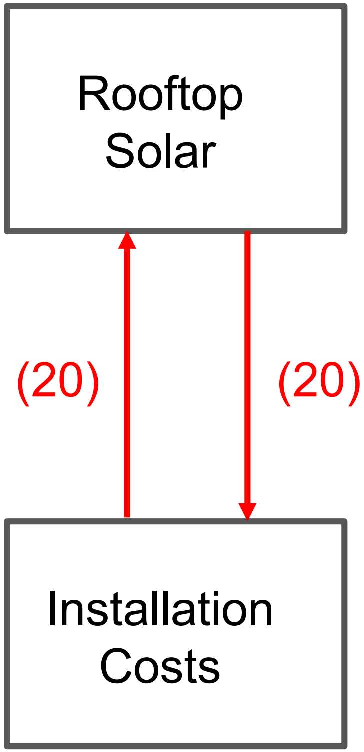
Dumitrescu, EI and C. Hurlin, 2012, Testing for Granger noncausality in heterogeneous panels, *Economic Modelling*, 29:1450-1460

RESULTS

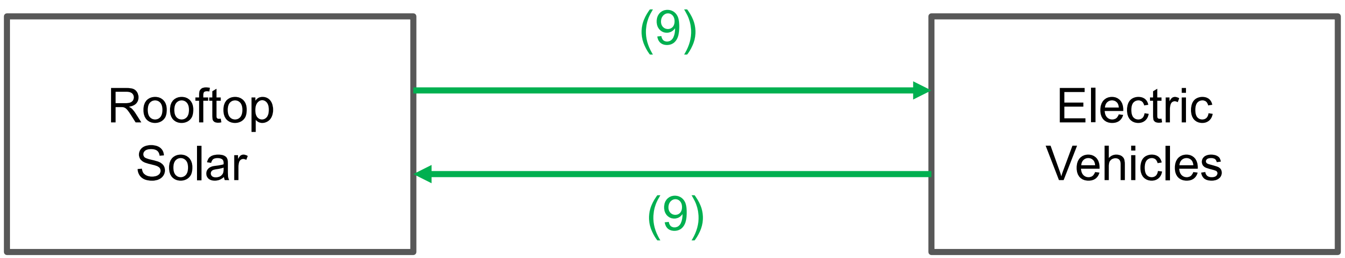

Rooftop Solar
Electric Vehicles
Installation Costs
Charging Stations
(9)
(9)
(20)
(20)
(15)
(14)
(1)
(1)

LEVELIZED COSTS & LEARNING CURVE

- $Cost \rightarrow PV$
  - Levelized cost of electricity
  - Solar \$48.8 per MWh 2018
  - Combined cycle (\$42.2 per MWh)
- $PV \rightarrow Cost$
  - Solar modules are commodities
  - 65% costs balance of system
  - Local learning



ROOFTOP SOLAR ↔ ELECTRIC VEHICLES



- Linked by environmental concerns
  - 433% increase station powered by renewable

- Highly visible technologies

INDIVIDUAL DECISIONS INFLUENCED BY MEMBERS OF THEIR COMMUNITY

- Agent-based models & threshold effects
  - Market share at which consider purchase
  - Zip codes ~43 km^2
- Norms
  - Descriptive norms those who live near-by
- Collective Efficacy
  - Group capable affect environment
- Empirical Support
  - Social norms information > cost/ benefits EV
  - More likely buy EV when neighbors do
  - Social spatial network experience with EV

POLICY IN SPACE AND TIME

- Goal: Maximize PV & EV
  - Exposure > critical threshold
  - Maximize population Exposure > critical threshold

- Need for exposure defines spatial resolution
  - Federal, state, local
  - Implement at fine scale (e.g. zip code)

- Implementation
  - Largest incentives for earlier adopters
  - Incentives decline beyond critical threshold

CURRENT POLICY FOR ELECTRIC VEHICLES

Federal EV Tax Credit Phase Out Tracker By Automaker

Updated: Current table below includes sales data from the InsideEVs Monthly Plug-in Sales Scorecard – through February 2019

Manufacturer*	Total Sales 2010 - Mar. 2019**	# To Reach 200,000	Reached / Likely to Reach 200,000
Audi	10,218	189,782	2025
BMW	85,888	114,112	2023
Fiat Chrysler Automotive (FCA)	39,855	160,145	2025
Ford Motor Company	114,247	88,753	2023
General Motors ****	211,587	-11,587	2018 Q4
Honda Motors	27,636	172,364	2025
Hyundai	9,157	190,843	2025
Jaguar	1,001	198,999	2027
Kia	13,325	186,675	2025
Mercedes-Benz	19,193	180,807	2024
Mitsubishi	7,004	192,996	2025
Nissan	132,227	67,773	2021
Porsche	10,712	189,288	2025
Tesla ***	382,573	-182,573	2018 Q3
Toyota Motor Corporation	99,918	100,082	2021
Volvo	9,841	190,159	2024
Volkswagen	14,277	185,723	2023