Visibility and Peer Influence in Durable Good Adoption

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A big thanks to Kyle Bradbury, Jordan Malof, the Duke Energy Initiative, and the US Department of Energy

MSU Broad College of Business

November 2021

Motivation

- Social influence can play a pivotal role in the diffusion of new products and technologies (Hartmann et al 2008, Griliches 1957, Bass 1969, Mahajan et al 1990).
- Peer influence has been shown in many settings:
  - Agriculture (Foster & Rosenzweig 1995, Conley & Udry 2010).
  - Schooling (Sacerdote 2001, Graham 2008).
  - Foreclosures (Towe and Lawley 2013).
  - Hybrids (Narayanan & Nair 2011, Heutel & Muehlegger 2015).
  - Solar (Bollinger & Gillingham 2012, Graziano & Gillingham 2015).
- The underlying channels through which peer influence operates in durable good adoption can affect the ability of marketers to leverage them.

Research Questions

To what extent does the *visibility* of peer adoption decisions impact the transmission of peer influence?

Potential channels:

- Visibility
- Word-of-mouth (WOM)

Note: “Observability” is one of Roger’s Five Factors affecting product adoption, but this refers to the ability of others to assess adoptions decisions, which does not have to be through visibility per se.

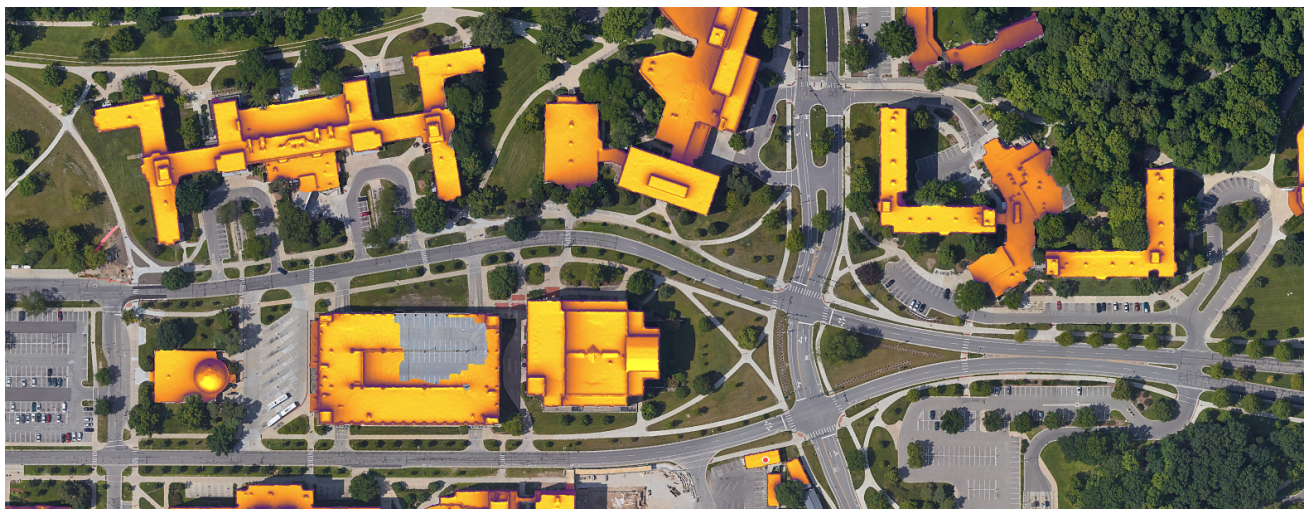
This Paper - The Role of Visibility

We estimate the social influence that results from the visibility of geographically proximate solar installations.

- We exploit the plausibly exogenous location and orientation of peers' rooftop solar panels relative to proximate roadways and visual obstructions.
- We employ satellite imagery and machine learning algorithms to precisely locate rooftop PV installations.
- We employ LiDAR imagery and a novel algorithm to precisely determine panel visibility from roadways, accounting for roof pitch, obstructions (trees, etc.), and distance.

This Paper - The Role of Visibility

Google Sunroof data provides the economic value of adopting solar PV, calculated using rooftop irradiance and utility rate data.



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County assessor data available through CoreLogic, in conjunction with InfoUSA data on home ownership, are used to identify the set of potential adopting homes.

Preview of Results

- The visibility of peer installations leads to greater influence.
- 90 degrees of visibility of peer installations within 500m:
  - Increases adoption rates by 9.35%.
  - Is equivalent to a price decline of $577.
- Non-visible adoptions by peer households only predict higher adoption probabilities within 100m.

Outline

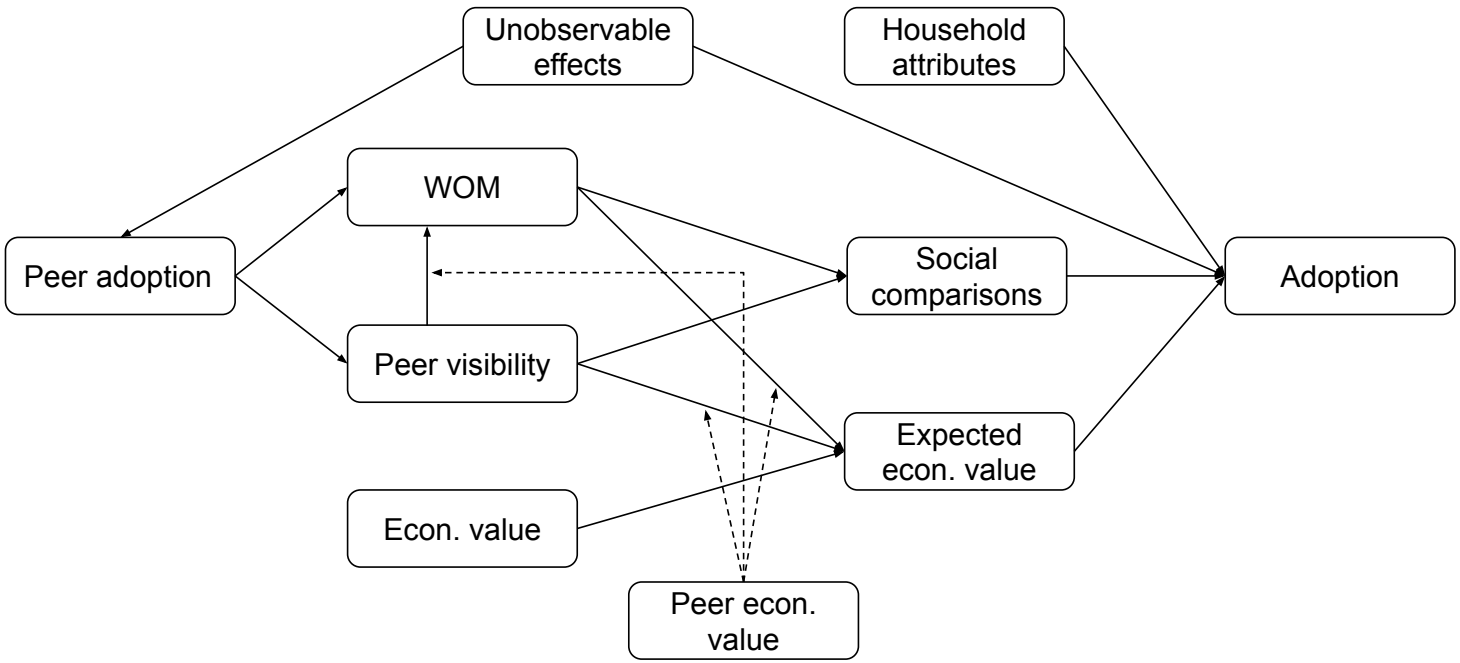
Peer Influence in Environmental Decisions

- Narayanan & Nair (2011): Installed-base effects in Prius adoption.
- Bollinger & Gillingham (2012): Installed-base effects in solar adoption.
- Kahn & Vaughn (2009): Hybrids and LEED buildings exhibit clustering behavior.
- Allcott (2010, 2014): Reducing electricity use in response to information about peer behavior.
- Ferraro & Price (2013): Norm-based messages reduce water usage.

Other Papers Examining the Role of Visibility

- McShane et al. (2012): Peer adoption behavior in distant locales has less impact than proximal peer adoption behavior.
- Bollinger et al. (2020): Peer influence in water consumption are due to (visible) landscaping decisions.
- Gardete (2015): Examines product purchases as a function of line-of-sight between passengers.
- Karing (2019): Experimentally supplies bracelets indicating the vaccinations that children received.
  - Weak effect when linked to a vaccine with low perceived benefits.
  - Positive effect when linked to a vaccine with high perceived benefits.

Conceptual Model of Social Influence



Outline

CT Solar Market

- Market grew from 3 installations in 2004 to over 17,000 installations by February 2016.
- Prices declined from $8.39 per Watt (W) in 2005 to an average of $4.27/W in 2015.
- State rebates began in 2006 at $5.9/W and declined to $0.45/W by February, 2016.

Data

Potential solar adopters: occupants of single-family detached homes in Connecticut using CoreLogic (data from county assessor records)

- Home sq. ft, number bedrooms, owner-occupied, lat-lon
- 820,474 observations

Administrative data for residential PV installations in CT

- Date of approval, date of completion, address
- 17,291 in total, matched to CoreLogic data

Data

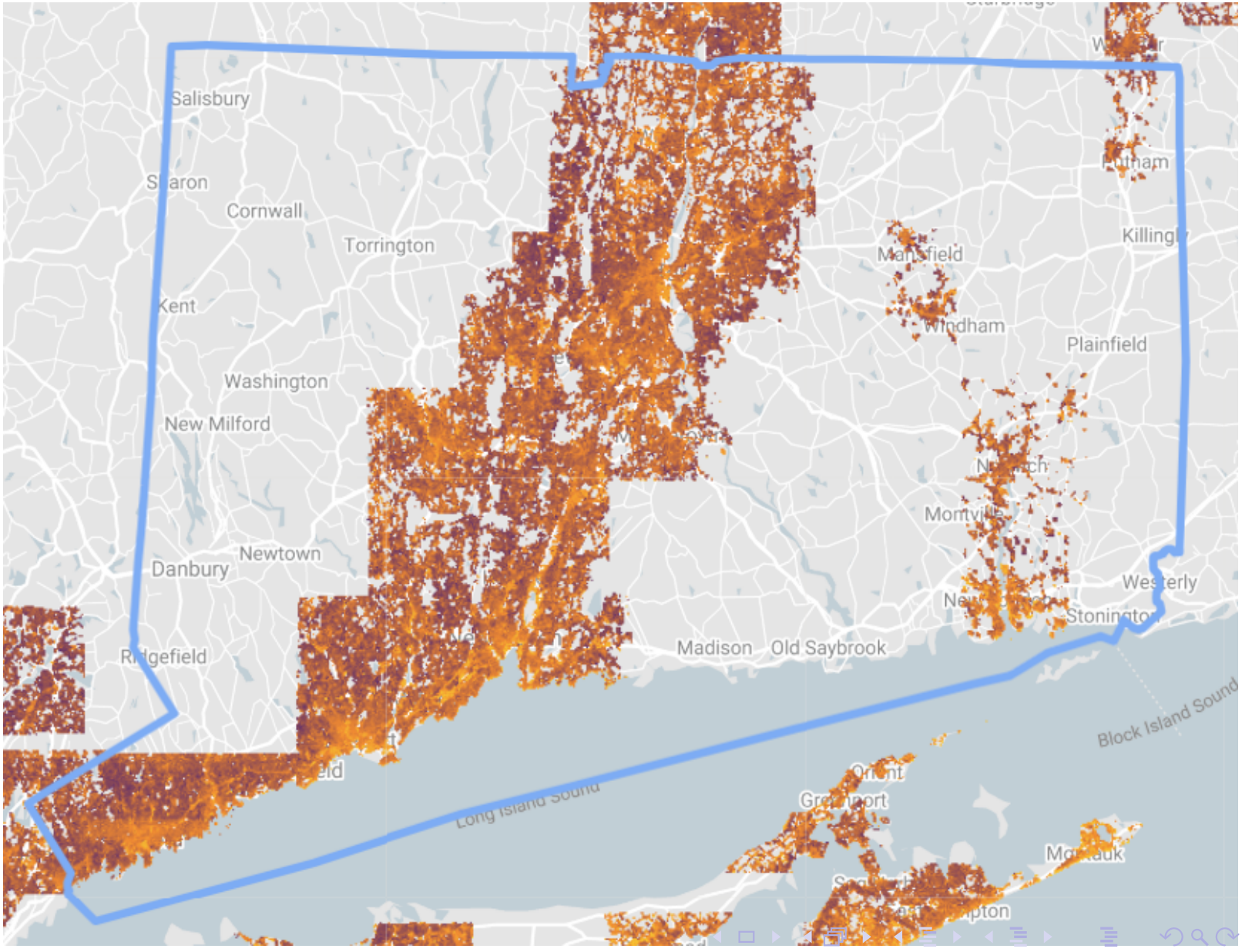
Home NPV of solar PV (Google Sunroof)

- 10,832 adoptions are in the Google Sunroof coverage are
- NPV of PV (assuming $150 monthly bill)

InfoUSA data

- Wealth, income, marital status, children, and length of residence
- 538,153 homes merge to Google Sunroof data
- This represents 660,447 households (new household after sale)
- 9,325 solar adoptions in matched sample

Google Sunroof Coverage



Google Sunroof Example

Visibility

- Identify panels X-Y from satellite imagery via convolutional neural network (CNN) (Malof et al., 2016)
- Overlay LiDAR (X-Y-Z) in vicinity of panel and identify points over panel
- Regress for pitch and azimuth
- Load road shape files
- Draw 180 rays from panel, recording all intersections with roads within 120m
- Test each point for visibility, with and without accounting for obstructions

Satellite base image: UCONN CTECO 2016

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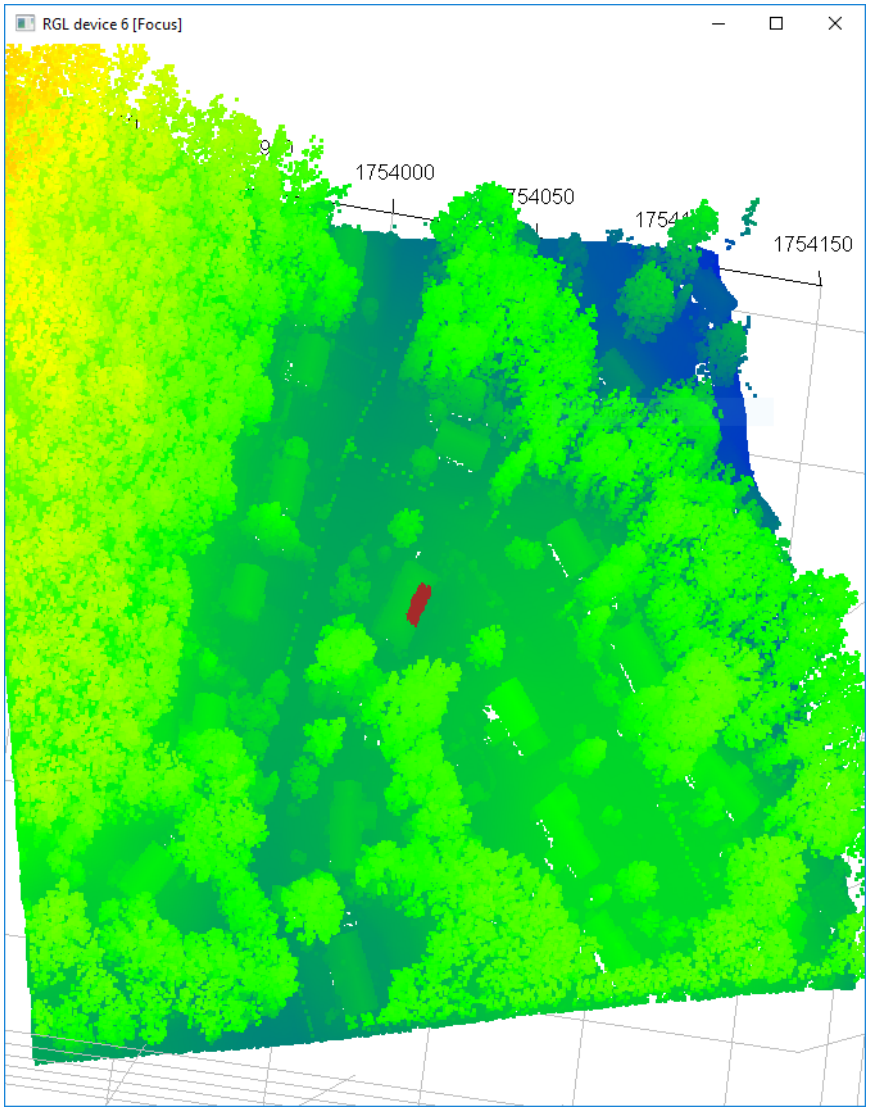

LiDAR: USGS Sandy

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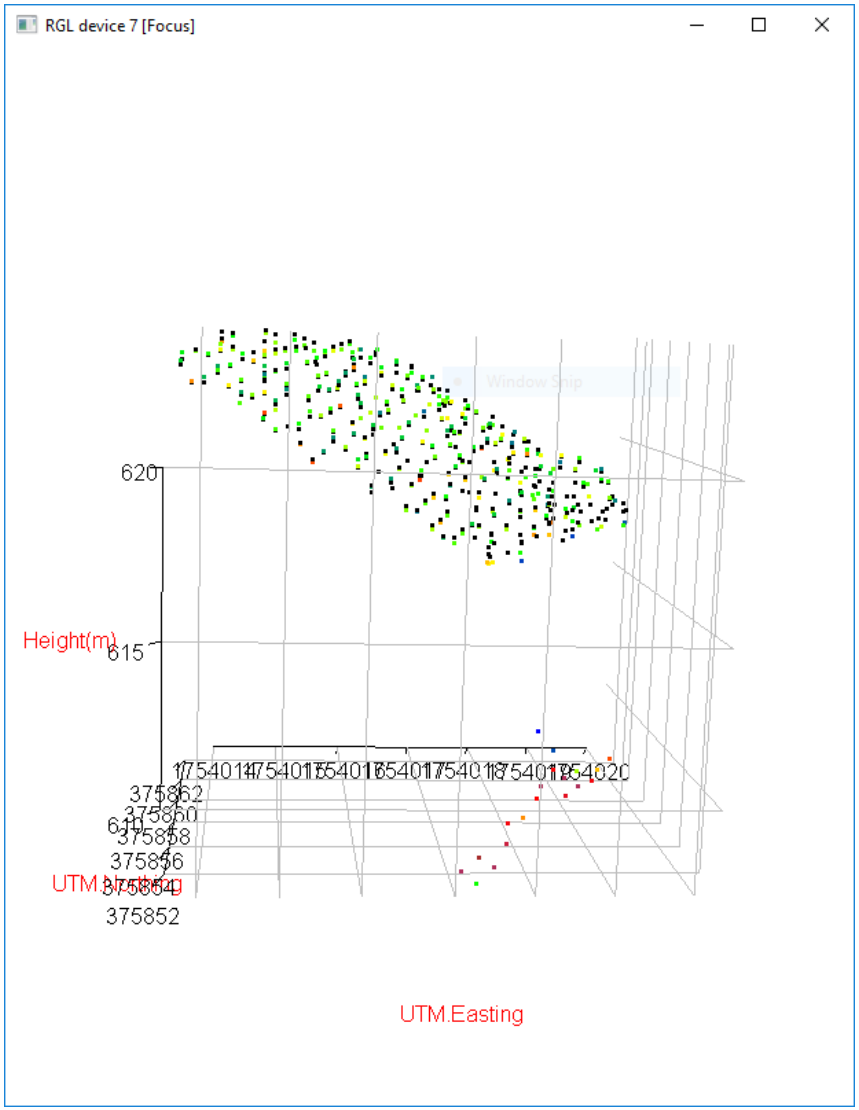

Green – actual

Visibility

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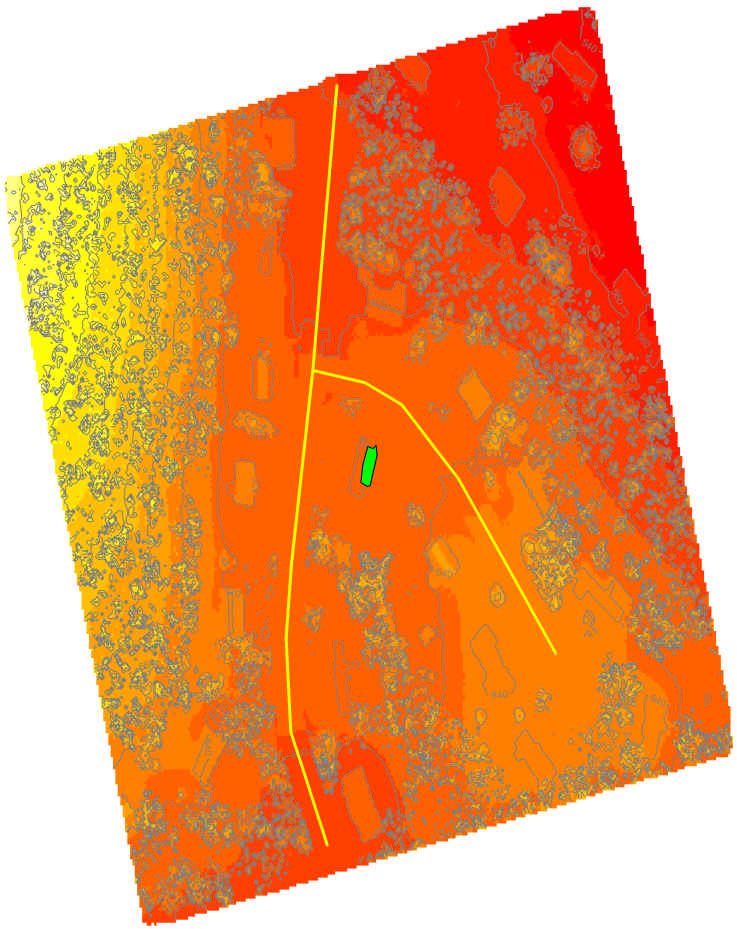

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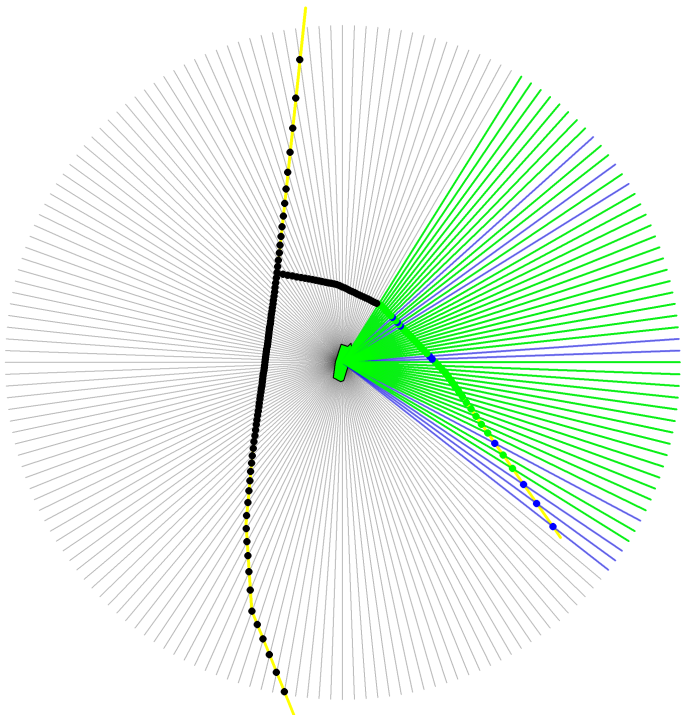

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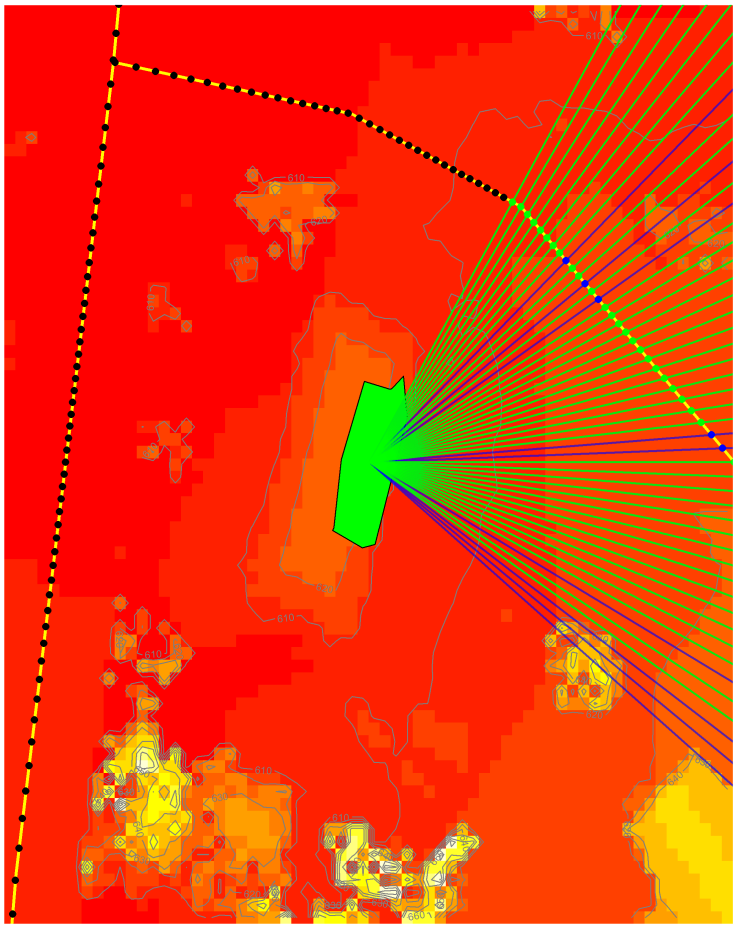
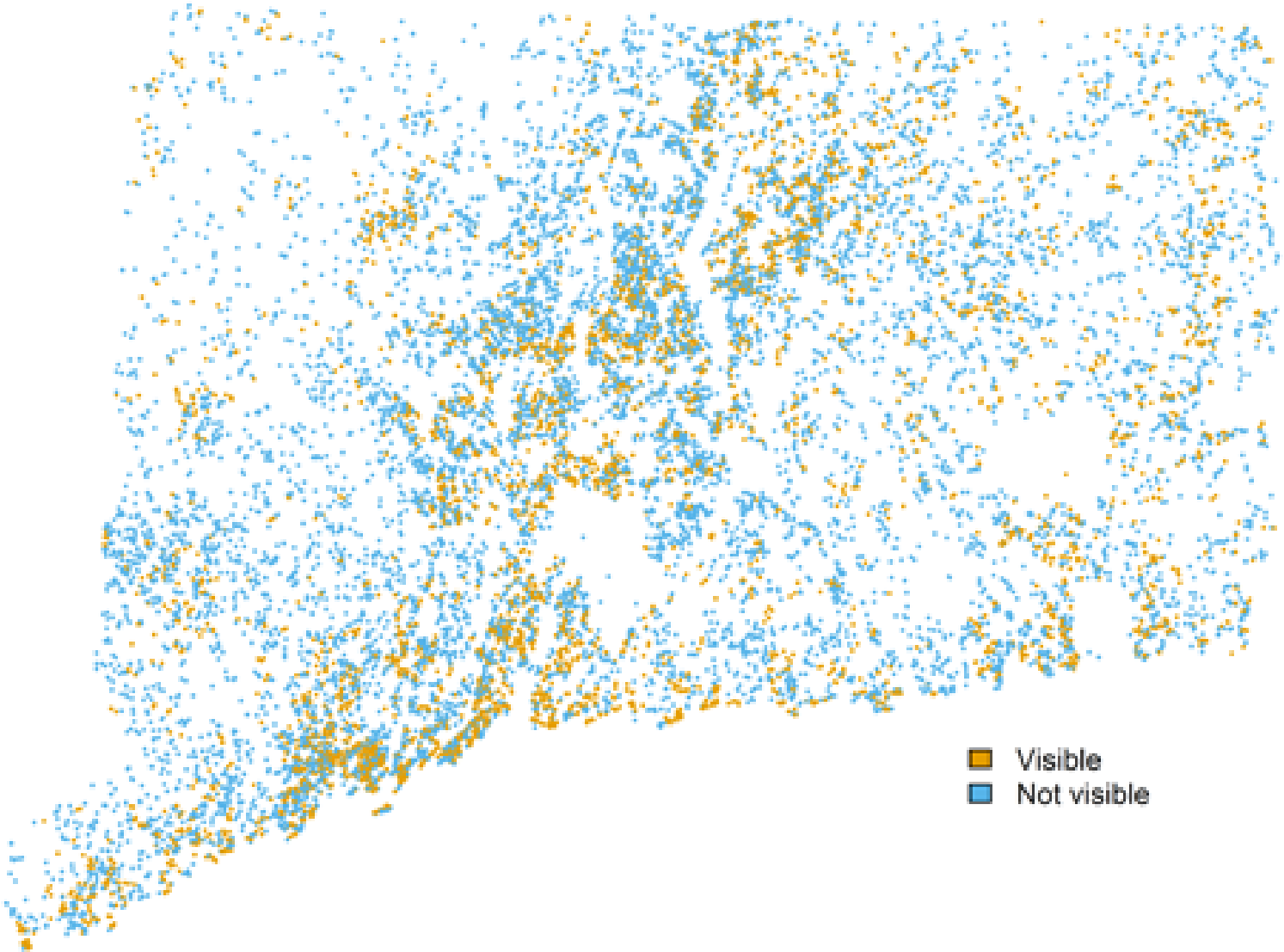


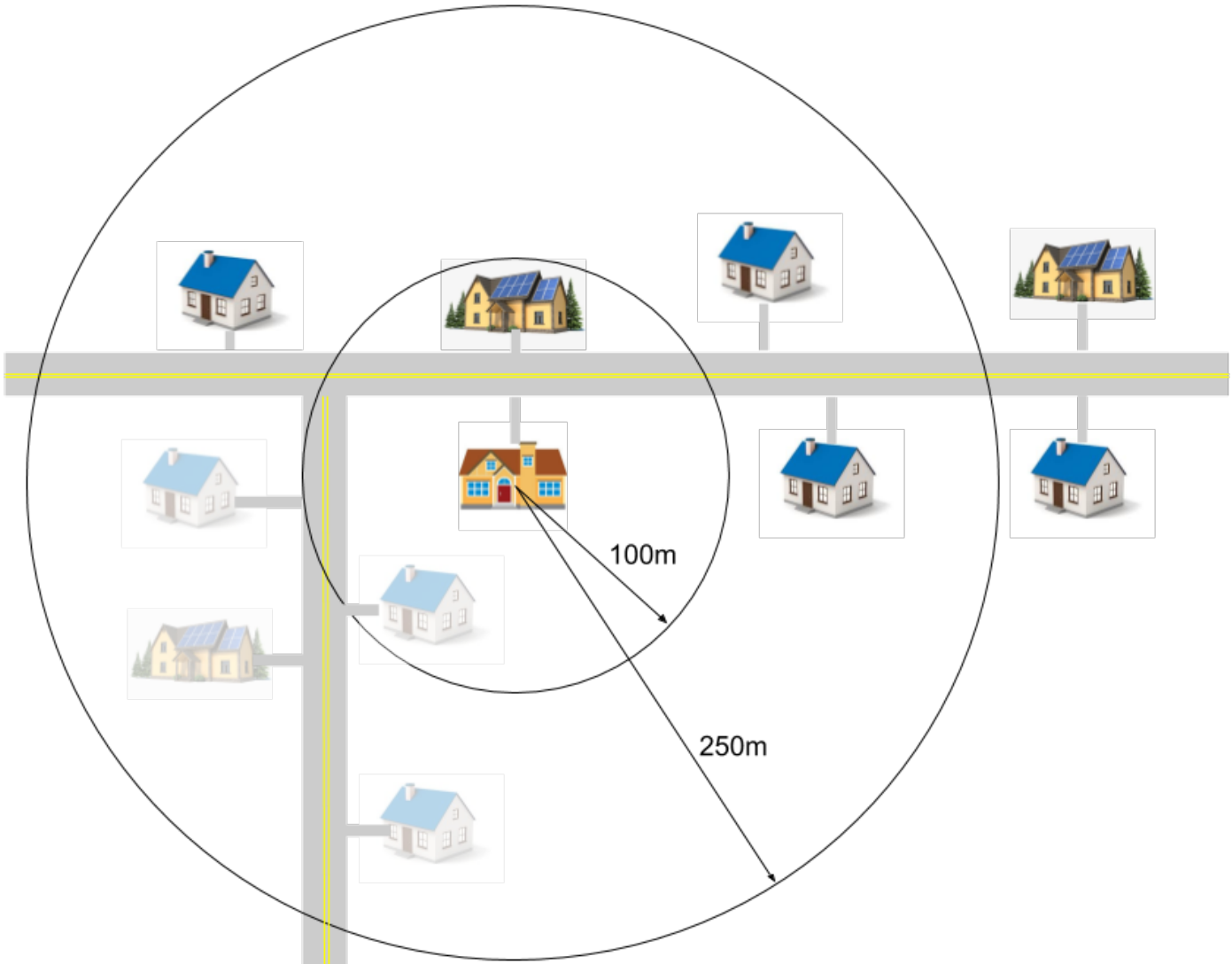
Example


18 Mohawk Cir - Google Maps
Justin
https://www.google.com/maps/@41.4107571,-73.4790974,3a,75y,295.17h,78.81t/data=!3m6!1e1!3m4!1s16MKmTgF1S8OPKkVMr2cGQ!2e0!7i...
Apps
Bookmarks
Save to Mendeley
My Projects - Overleaf
Stats Stuff
Econ Stuff
Best Practices
Bills and Shoppings
Amazon Cloud Drive...
United States Intera...
NBER Pay Stuff
18 Mohawk Cir
Danbury, Connecticut
Street View - Jul 2014
Mohawk Cir
Mohawk Circle
Seminole
Kohanza
Google
Image capture: Jul 2014
© 2016 Google
Terms
Report a problem

Panel Locations



Peer Groups



Household/Home Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Ever installs	0.0188	0.1360	0	1	538161
Value of potential installation ($1000 NPV)	6.522	4.468	-28.238	15.254	538161
Visibility of installations (90°)	0.3193	0.4935	0	2.8222	7088
Visibility of installations ignoring obstructions (90°)	0.8358	0.7925	0	3.7778	7088
Visibility of installations with non-zero visibility (90°)	0.6359	0.5326	0.0222	2.8222	3559
Visibility of installations ignoring obstructions with non-zero visibility (90°)	1.3928	0.6258	0.0222	3.7778	3559
Home value ($100,000)	2.4837	3.3867	0	354.76	538153
House size (1000 sq. ft.)	1.8501	0.9606	0	56.7780	538153
Lot size (acres)	0.7693	2.2603	0	224.28	538153
Homes within 100m	14.14	09.21	1.00	134	538153
Homes within 250m	68.02	0.4469	1.00	280	538153
Homes within 500m	218.44	142.26	1.00	919	538153
Independent	0.3340	0.4716	0	1	53815
Democrat	0.3076	0.4615	0	1	538153

Observation Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Install indicator (1E-3)	0.1669	12.92	0	1000	55872419
Peer installations 100m	0.0080	0.0945	0	5	55872419
Peer installations 250m	0.0207	0.1624	0	6	55872419
Peer installations 500m	0.0327	0.2138	0	8	55872419
Peer installation NPV 100m ($10,000)	0.0022	0.0504	-0.8553	4.1888	55872419
Peer installation NPV 100m ($10,000)	0.0061	0.0876	-0.8553	6.0015	55872419
Peer installation NPV 100m ($10,000)	0.0099	0.1158	-0.8553	7.2711	55872419
Peer installation visibility 100m (90°)	0.0031	0.0604	0	5.8444	55872419
Peer installation visibility 250m (90°)	0.0079	0.1021	0	8.5556	55872419
Peer installation visibility 500m (90°)	0.012	0.1313	0	11.7556	55872419
Wealth ($1,000,000)	3.2321	1.0282	0.374	9.9180	55872419
Income ($100,000)	1.1399	0.7698	0.05	5	55872419
Married	0.7168	0.4505	0	1	55872419
Has children	0.2453	0.4303	0	1	55872419
Length of residence	17.9451	12.2042	1	58	55872419

Notes: Value is the NPV of a standard-sized installation.

Outline

Model

Let the utility of adopting solar at time t be given by:

$$u_{it} = EV_{it} + Z_{it}\tilde{\gamma} + H_i\beta$$

- EV_{it} is the expected economic value of adopting solar relative to the option value of waiting.
- Z_{it} include cumulative peer adoption variables that may affect utility through social comparisons.
- H_{it} is a vector of household attributes that affect adoption.
- Let $EV_{it} = \alpha V_i + Z_{it}\gamma + \xi_m + \eta_t$, in which V_i is the economic value of installing solar reported in the Google Sunroof data.

Model

The empirical hazard rate is a function of this utility:

$$\log(\lambda_{it}) = \alpha V_i + Z_{it}\gamma + H_i\beta + \xi_m + \eta_t$$

- ξ_m and η_t are geographic & time fixed effects
- Z_{it} includes:

$\sum_{s=1}^{t-1} \sum_{j \in \mathbb{G}_i^d} y_{js}$ Cumulative number of peer installations.

$\sum_{s=1}^{t-1} \sum_{j \in \mathbb{G}_i^d} V_{js}$ Cumulative economic value of peer installations.

$\sum_{s=1}^{t-1} \sum_{j \in \mathbb{G}_i^d} Vis_{js}$ Cumulative angle of visibility of peer installations.

Estimation

Let $X_{it} = \{V_i, Z_{it}, H_i\}$ and $\theta = \{\alpha, \gamma, \beta\}$, The likelihood of the data can be written as:

$$\mathbb{L}(X_{it}; \theta) = \prod_i \prod_{t=1}^{T} \lambda_{it} \exp\left(-\lambda_{it}\right), \tag{1}$$

To estimate the model, we solve the first-order conditions for maximization of the pseudo log-likelihood:

$$\mathbb{E}\left[\log(\mathbb{L}(X_{it}; \theta))\right] = \mathbb{E}\left[\sum_i \sum_{t=1}^{T} \log(\lambda_{it}) - \lambda_{it}\right] = 0 \tag{2}$$

Outline

Three Major Challenges in Identifying Peer Effects

There are three main challenges in identifying causal peer effects (Manski 1993, Hartmann et al. 2008):

1. Endogenous group formation (homophily).
    - Self-selection of peers.
2. Correlated unobservables.
    - Other localized factors that affect you and your peers.
3. Simultaneity (i.e., Manski's 'reflection' problem).
    - You affect your peers just as they affect you.

Our Strategy

1. Address *simultaneity*
   - Use lags in peer adoption (4-6 month)
2. Address *correlated unobservables*
   - Census tract or block and month fixed effects
3. Addresses *self-selection of peers – homophily*
   - Our central object of interest is the *difference* between the effect of visible and non-visible installations, i.e. the effect of peer visibility.
   - Is *visibility* exogenous (conditional on fixed effects)?
     - Location of panel determined by south-facing exposure
     - Most purchases long before solar (and solar vis) would be salient
     - Take extra care to assess potential correlates

Identification of the Effect of Peer Adoption Visibility

The ideal experiment is to take solar adopting households that are similar in all respects (including the characteristics of their peers) and randomly assign their installations to be visible or not.

Visibility is driven by:

- Roof orientation, roof pitch, and distance to roadways
  - May correlate with variables such as income, which may also affect adoption.
- Obstructions
  - Implies a correlation between visibility (obstruction) and the economic value (shading by obstruction) of a solar installation.
  - Economic value must be included as a covariate.

Covariate Correlations with Visibility

VARIABLE	Visibility (90°)	Visibility not accounting for obstructions (90°)
Visibility not accounting for obstructions (90°)	0.7060	
Installation NPV ($10,000)	0.1048	0.1255
Home value ($100,000)	-0.1007	-0.0885
House size (1000 sq. ft.)	-0.1643	-0.1855
Lot size (acres)	-0.0895	-0.1113
Number of peer homes 100m (100s)	0.2313	0.3125
Number of peer homes 250m (100s)	0.2461	0.3340
Number of peer homes 500m (100s)	0.2363	0.3193
Wealth ($1,000,000)	-0.1797	-0.1645
Income ($100,000)	-0.1469	-0.1495
Married	-0.0123	-0.0391
Has children	0.0124	-0.0046
Independent	0.0243	0.0275
Democrat	0.0141	0.0094

VARIABLE	(1)	(2)	(3)	(4)
Installation NPV ($10,000)	0.1388***	0.1255***	0.0777***	0.0684***
	(0.0242)	(0.0254)	(0.0195)	(0.0191)
Home value ($100,000)	-0.0002	0.0015	0.0005	0.0012
	(0.0027)	(0.0038)	(0.0023)	(0.0026)
House size (1000 sq. ft.)	-0.0274**	-0.0361***	-0.0044	-0.0051
	(0.0088)	(0.0088)	(0.0063)	(0.0064)
Lot size (acres)	-0.0015	-0.0015	0.0001	0.0000
	(0.0010)	(0.0010)	(0.0009)	(0.0010)
Number of peer homes 100m (100s)	0.3000+	0.2893	-0.1186	-0.0927
	(0.1779)	(0.1930)	(0.1457)	(0.1556)
Number of peer homes 250m (100s)	0.0932	0.1016	-0.0408	-0.0622
	(0.0613)	(0.0664)	(0.0440)	(0.0476)
Number of peer homes 500m (100s)	0.0061	-0.0156	0.0170	0.0144
	(0.0214)	(0.0223)	(0.0150)	(0.0166)
Wealth ($1,000,000)	-0.0320**	-0.0230*	-0.0088	-0.0045
	(0.0112)	(0.0113)	(0.0081)	(0.0088)
Income ($100,000)	-0.0155	-0.0174	-0.0109	-0.0160+
	(0.0109)	(0.0118)	(0.0089)	(0.0095)
Married	0.0349*	0.0363*	0.0302*	0.0267*
	(0.0171)	(0.0169)	(0.0135)	(0.0126)
Has children	0.0157	0.0148	0.0031	0.0060
	(0.0133)	(0.0136)	(0.0104)	(0.0104)
Length of residence	0.0007	0.0006	-0.0000	0.0000
	(0.0006)	(0.0006)	(0.0004)	(0.0004)
Independent	0.0078	0.0039	0.0040	-0.0010
	(0.0145)	(0.0147)	(0.0103)	(0.0108)
Democrat	0.0056	0.0071	0.0031	-0.0000
	(0.0160)	(0.0157)	(0.0112)	(0.0117)
Visibility not accounting for obstructions (90°)			0.436	0.443
			0.010	0.010
Census tract FE	Y	N	Y	N
Census block FE	N	Y	N	Y

Outline

Effect of Peer Installations

	100m		250m		500m	
VARIABLE	(1)	(2)	(3)	(4)	(5)	(6)
Installation NPV ($1000)	0.1691***	0.1619***	0.1692***	0.1619***	0.1695***	0.1621***
	(0.0080)	(0.0072)	(0.0803)	(0.0803)	(0.0080)	(0.0072)
Peer installations	0.1007*	0.0635	0.0417	-0.0140	-0.0476	-0.0980+
	(0.0463)	(0.0473)	(0.0603)	(0.0629)	(0.0549)	(0.0579)
Peer installation NPV ($1000)	0.0029	-0.0006	-0.0039	-0.0030	-0.0011	-0.0000
	(0.0052)	(0.0057)	(0.0026)	(0.0028)	(0.0028)	(0.0029)
Peer installation visibility (90°)	0.1235	0.1048	0.1059*	0.1025*	0.0960**	0.0935**
	(0.0955)	(0.0966)	(0.0472)	(0.0483)	(0.0333)	(0.0348)
Census tract FE	Y	N	Y	N	Y	N
Census block FE	N	Y	N	Y	N	Y
Month FE	Y	Y	Y	Y	Y	Y
N	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07

Increasing the visibility of peer installations within 500m from 0° to 90° increases a household's monthly adoption probability by 9.80%

Marginal Effect of Peer Installations (1×10^{-6})

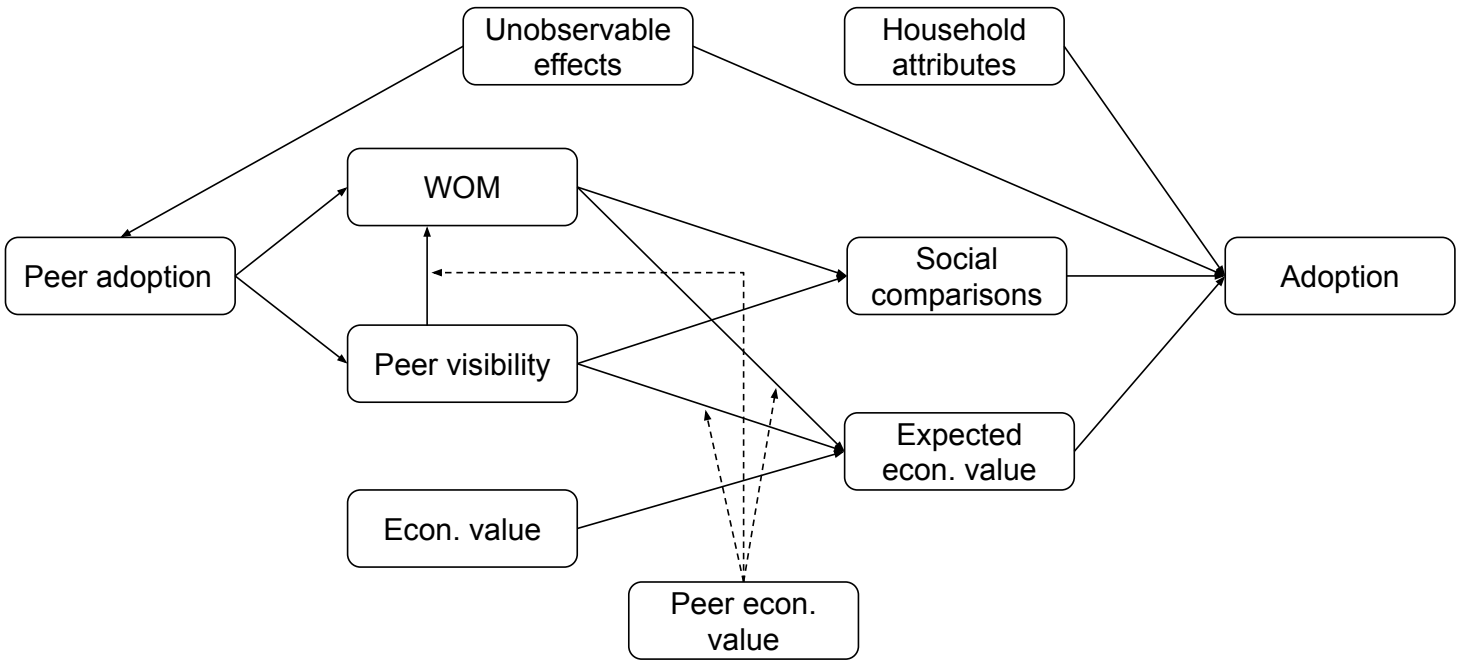
	100m		250m		500m	
VARIABLE	(1)	(2)	(3)	(4)	(5)	(6)
Installation NPV ($1000)	29.84***	29.43***	29.85***	29.42***	29.91***	29.46***
Peer installations	17.78*	11.54	7.36	-2.54	-8.39	-17.80+
Peer installation NPV ($1000)	0.51	-0.10	-0.68	-0.54	-0.19	-0.00
Peer installation visibility (90°)	21.80	19.05	18.69*	18.63*	16.94**	16.99**
Census tract FE	Y	N	Y	N	Y	N
Census block FE	N	Y	N	Y	N	Y
Month FE	Y	Y	Y	Y	Y	Y
N	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07

For every visible peer installation within 500m that is visible at the average level of 57.2 degrees (conditional on being partially visible), a household's monthly probability of adoption increases by 1.08×10^{-5}, an increase of 6.5% over the baseline adoption rate of 1.67×10^{-4}, the same effect as a price decline of $367.

Robustness Checks

- Only measure visibility to the nearest street segment.
- Include peers not on same street.
- Weigh peer variables by inverse distance.
- Include the measure of unobstructed visibility (leverages only the variation from obstructions).
- Linear probability analogues for every specification.
- Placebo test.

Conceptual Model of Social Influence



Moderating Effect of Peer Installation NPV on Visibility

	100m		250m		500m	
VARIABLE	(1)	(2)	(3)	(4)	(5)	(6)
Installation NPV ($1000)	0.1691***	0.1619***	0.1691***	0.1618***	0.1694***	0.1620***
	(0.0080)	(0.0072)	(0.0080)	(0.0072)	(0.0080)	(0.0072)
Peer installations	0.1009*	0.0640	-0.0212	-0.0782	-0.0529	-0.1023+
	(0.0457)	(0.0467)	(0.0534)	(0.0580)	(0.0529)	(0.0565)
Peer installation NPV ($1000)	0.0029	-0.0006	0.0031	0.0042	-0.0004	0.0005
	(0.0053)	(0.0057)	(0.0057)	(0.0063)	(0.0025)	(0.0027)
Peer installation visibility (90°)	0.1127	0.0614	0.2128*	0.2117*	0.1579***	0.1498**
	(0.2085)	(0.2219)	(0.0913)	(0.0917)	(0.0447)	(0.0468)
Peer installation visibility X NPV (90° X ($1000))	0.0012	0.0048	-0.0231	-0.0236	-0.0234**	-0.0216*
	(0.0217)	(0.0231)	(0.0173)	(0.0178)	(0.0091)	(0.0088)
Census tract FE	Y	N	Y	N	Y	N
Census block FE	N	Y	N	Y	N	Y
Month FE	Y	Y	Y	Y	Y	Y
N	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07	5.29e+07

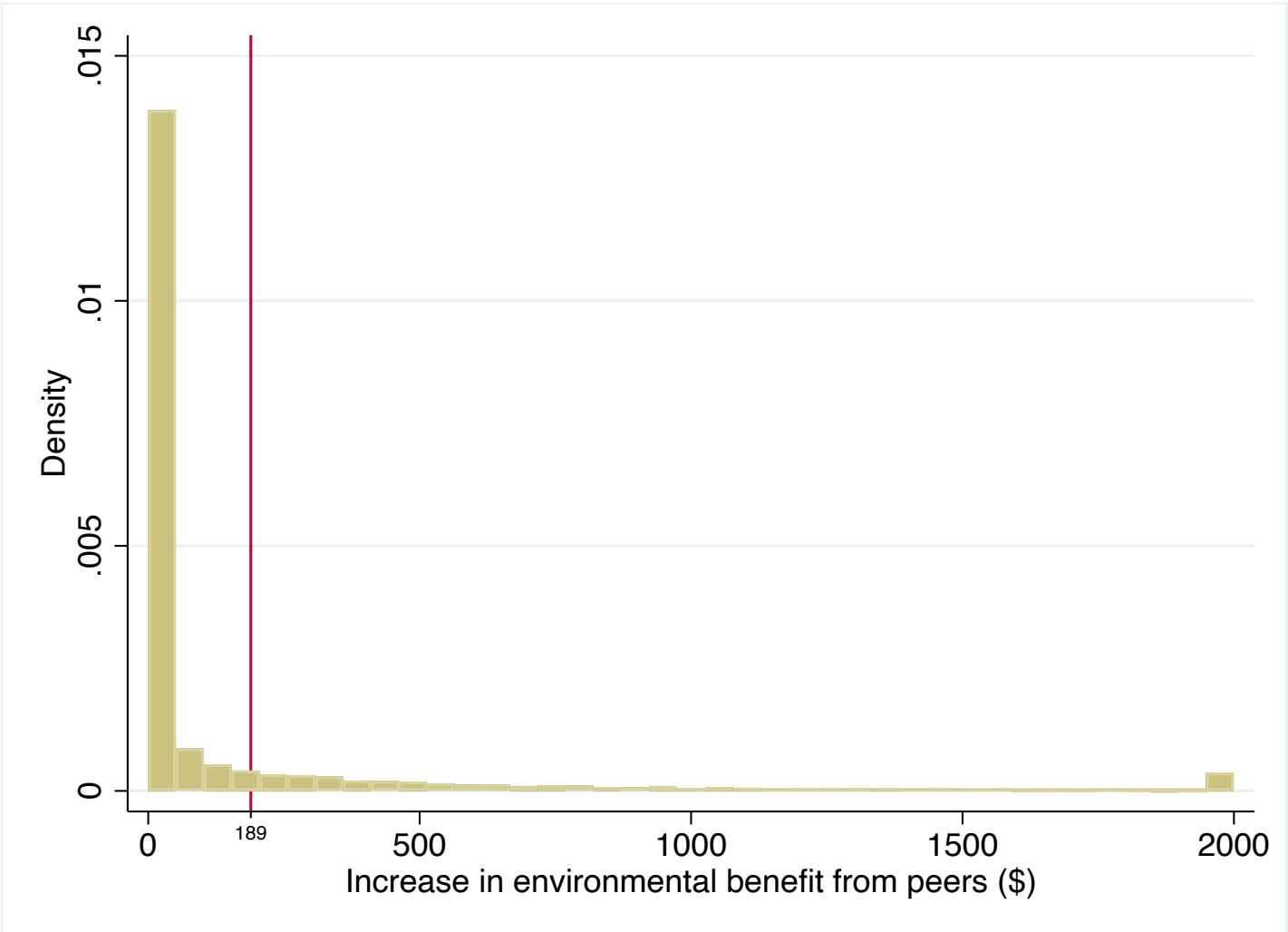
Economic Value of Peer Installations

- The information contained in the amount of sunlight a peer installation receives affects adoption rates.
- This interaction effect between peer economic value and visibility for peers within 500m suggests that social learning can occur due to peer visibility.
- We cannot not rule out that visibility leads to WOM at these larger distances.

Implications

- Previously documented peer effects in solar diffusion for spatially proximate households operating at larger geographies (Bollinger & Gillingham 2012, Graziano & Gillingham 2014) likely do so as a result of their visibility.
- The environmental benefits that can result from this social spillover are large.
  - Annual environmental benefit from averted greenhouse gas emissions is $76 per installation-year (for a 4 kW installation) in Connecticut (Sexton et al. 2018).
  - Using a monthly discount factor of 0.99, which is equivalent to an annual rate of 0.886, a single installation yields an environmental benefit (net present value) of $669.

Value of Targeting



Red vertical line indicates mean.

Concluding Remarks

- By leveraging exogenous variation in the visibility of peer installations, we assessed the extent to which the visibility channel leads to peer effects.
- We constructed a novel dataset in order to do this:
  - Neural networks to identify panel locations
  - LiDAR data to construct three-dimensional maps of houses and potential obstructions
  - GIS data to identify roads.
- Non-visible peer solar installations only correlate with adoption within 100m (some of this effect may not be casual).
- Visible peer installations affect adoption at greater distances, allowing for much greater effects on diffusion.

Thank You

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