

# The (Dis)amenity of Visible Solar Panels

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What do I think?

- Offset electricity bill (irradiance)
- Balanced against up-front cost
- Aesthetics
- "Warm glow"

What will the neighbors think?

- Aesthetics
- Signaling

## Economic case for solar

- Internalizing an environmental externality
  - Usually via subsidy (NEM, fed. tax credit)
  - Inefficient subsidies: second (or third) best
  - **But not always**, some are non-pecuniary
  - Non-pecuniary influences are generally more efficient
  - Internalizing your own externality is closer to a Pigouvian tax

## Dynamic settings

- S-shaped diffusion curve
  - New technology diffuses throughout the public
  - Interested in moving along the s-curve *faster*
  - Pecuniary and **non-pecuniary** levers (low cost)

## What moves or compresses the diffusion curve?

- Learn-by-doing (Bollinger and Gillingham, 2019)
- Induced innovation (Gerarden, 2022)
- Peer effects

## Peer effects

- Installed base has positive and significant effect on neighboring adoption  
(Bollinger and Gillingham, 2012)
- Visible installed base has positive and significant effect on neighboring adoption (Bollinger et al. 2022)
- **"Am I more likely to install solar if I see my neighbors have installed solar"**

## What about own visibility?

- **"Am I more/less likely to install solar if my neighbors will see my installation"**
  - Sometimes, the sunny part of your roof isn't visible from the street
  - Speaks to a non-pecuniary means of compressing the S-curve diffusion

Q1: Do households consider the visibility of their own potential solar panels when adopting?

Q2: What moderates that effect?

## Private provision of a public good (clean air, $\downarrow CO_2$ )

- "Pro-social behavior"
- "Warm glow" (Andreoni, 1990; Kotchen, 2006)

## "Signaling"

- Conspicuous conservation (Sexton and Sexton, 2014; Dastrup et al, 2011)
  - Environmental bona fides
- Identity + group norms (Akerlof and Kranton, 2000; Khan, 2007)
  - Signaling, but only when consistent with group norms

## Notably

- "Signaling" motivations rely on *visibility* of actions

How people respond when expected payoff (irradiance) is low relative to high tells us about the strength of the "warm glow"

- People who are not sensitive to the (private) payoff but who adopt regardless are consistent with "warm glow"



How people respond when the potential solar installation would be non-visible, relative to how people respond when the installation would be visible tells us about the strength of "signaling" influences relative to "warm glow" and private benefits.

- People who are seeking to "signal" would have strong preference for visible panels

How people respond to the potential solar installation's visibility when surrounded by similar group members vs. different group members tells us about the role of "signaling" environmental bona fides relative to "signaling" group membership

- People who are surrounded by a group with preference against solar are less likely to use a visible installation to signal group identity.

## Individual Household adoption decisions

- Binary adoption variable, a function of:
  - *EV*: Expected value (payoff) of adopting solar
  - Household voter affiliation
  - Visibility of the potential solar installation
  - Household characteristics
  - May be "mechanically" related to EV e.g. roof size

## Identification: Visibility is exogenous

- Determined by "side of street" and house orientation
- Endogeneity would require pro-solar-signal households select into north side of street
  - Consumers choose neighborhood, home size, local amenities before choosing on solar vis potential
- Use only <2014 builds
- Visibility, *EV*, and voter affiliation are conditionally exogenous

## Primary data sources

- Home and property characteristics (CoreLogic)
- Roof segments and irradiance (Google Project Sunroof)
- Voter registration (Ca Sec. of State)
- US Census TIGER/Line

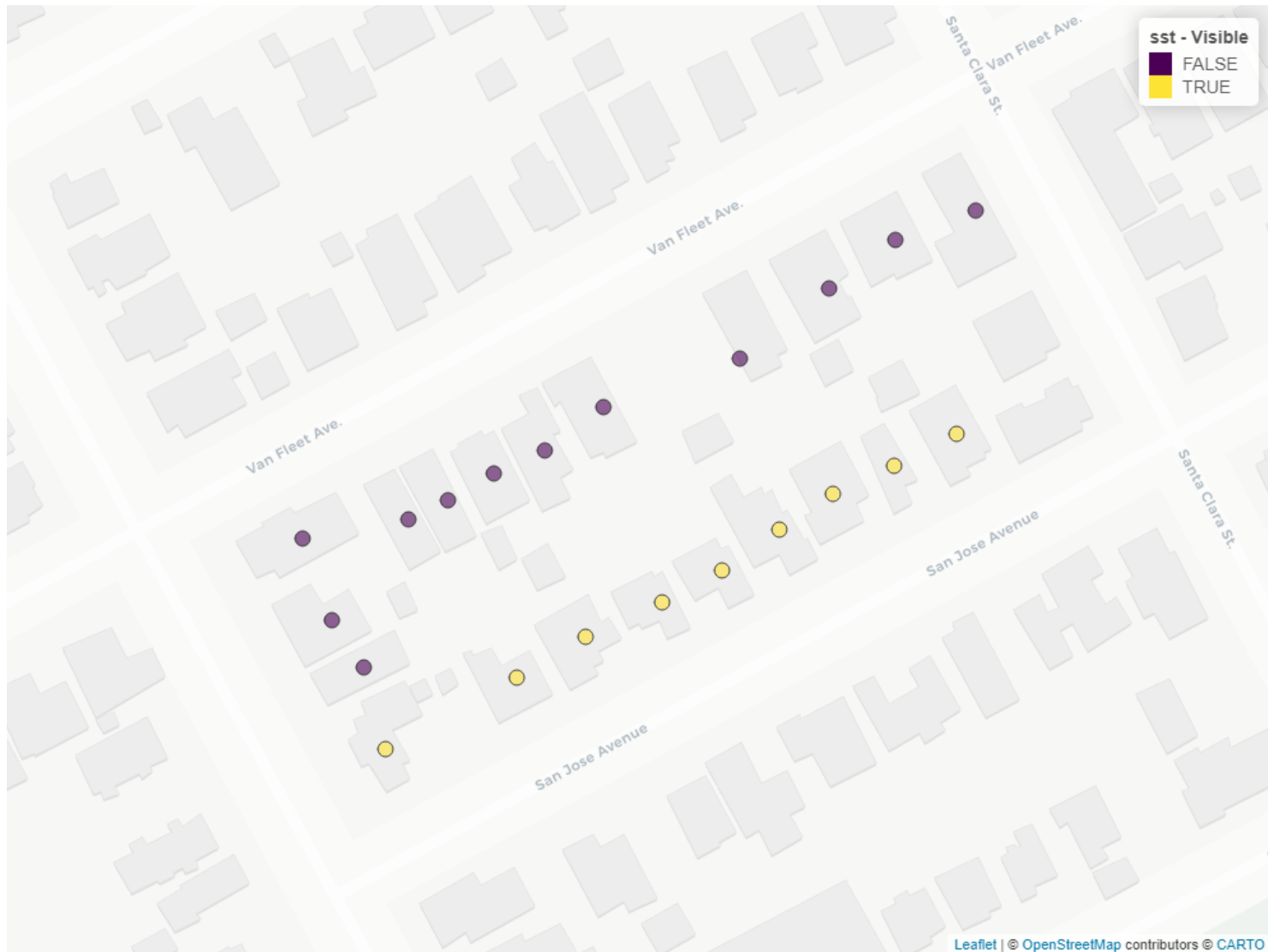
## Sample construction

- All single-family detached homes in 8 counties in CA
- Year of construction < 2014
- Matched to Google Sunroof (97.8%)
- Limit to census blocks with "suburban" densities (between 5 and 50 households)
  - $N = 994,000$

## Measures of visibility

### Location relative to street: for each home...

1. From Google Sunroof, find the centroid of the sunniest roof segment
2. Find the *nearest* point on the closest street
3. Find the "compass" angle defined by the street point, north, and the roof point
4. Define as decreasing (negative) when moving away from north
  - North is 0
  - South side is -180
  - East and West are both -90
5. Define "visible" as greater than -45



$$\mathit{adopt}_i = \beta_0 + \beta_1 \mathit{Visible}_i + \beta_2 \mathit{EV} + \beta_3 \mathit{Rep}_i + \\ \beta_4 \mathit{Visible}_i \times \mathit{Rep}_i + \beta_5 \mathit{EV}_i \times \mathit{Rep}_i + \mathbf{X}_i \Gamma + \theta_{c(i)} + \varepsilon_i$$

- *Visible* is binary visibility measure
- *EV* is Google Sunroof expected value (in 1,000's)
- *Rep* is indicator for Republican registration
- $\mathbf{X}_i$  are home characteristics
  - Home size (sqft)
  - Number of stories
  - Lot size
- $\theta_{c(i)}$  are fixed effects at census block level x street name

$\beta_1$  and  $\beta_4$  tell us about value of signaling (and aesthetics) between political affiliations

$\beta_2$  and  $\beta_5$  tell us about value of solar payoff vs. "warm glow" between political affiliations: sensitivity to payoff indicates private benefits rather than "warm glow".

Dependent Variable: Model:	(1)	Adopt x 100 (2)	(3)
<i>Variables</i>			
Visible	-0.369*** (0.101)	-0.295*** (0.106)	-0.285*** (0.105)
Expected Value	0.874*** (0.049)	0.874*** (0.049)	0.782*** (0.050)
Registered Rep	0.743*** (0.080)	0.827*** (0.092)	-2.44*** (0.402)
Visible × Registered Rep		-0.343* (0.180)	-0.357** (0.180)
Registered Rep × Expected Value			0.446*** (0.074)
<i>Fixed-effects</i>			
GEOID20-PROPERTY_STREET_NAME	Yes	Yes	Yes
<i>Fit statistics</i>			
Observations	994,454	994,454	994,454
R <sup>2</sup>	0.21455	0.21455	0.21577
Within R <sup>2</sup>	0.00382	0.00383	0.00537

*Clustered (GEOID20-PROPERTY\_STREET\_NAME) standard-errors in parentheses*  
*Signif. Codes: \*\*\*: 0.01, \*\*: 0.05, \*: 0.1*



Include measure of the "Republican-ness" of the area

$$\begin{aligned} adopt_i = & \beta_0 + \beta_1 Visible_i + \beta_2 EV + \beta_3 Rep_i + \\ & \beta_4 Visible_i \times Rep_i + \beta_5 Rep_i \times EV_i + \\ & \beta_6 Visible_i \times AreaRep_i + \beta_7 AreaRep_i \times Rep_i + \\ & \mathbf{X}_i \Gamma + \theta_{c(i)} + \varepsilon_i \end{aligned}$$

- $AreaRep_i$  is the fraction of households registered Republican in  $\{Block, Blockgroup\}$  of  $i$

$\beta_6$  tells us about how people *signal* in relation to the "types" around them

$\beta_7$  tells us how people internalize the area around them

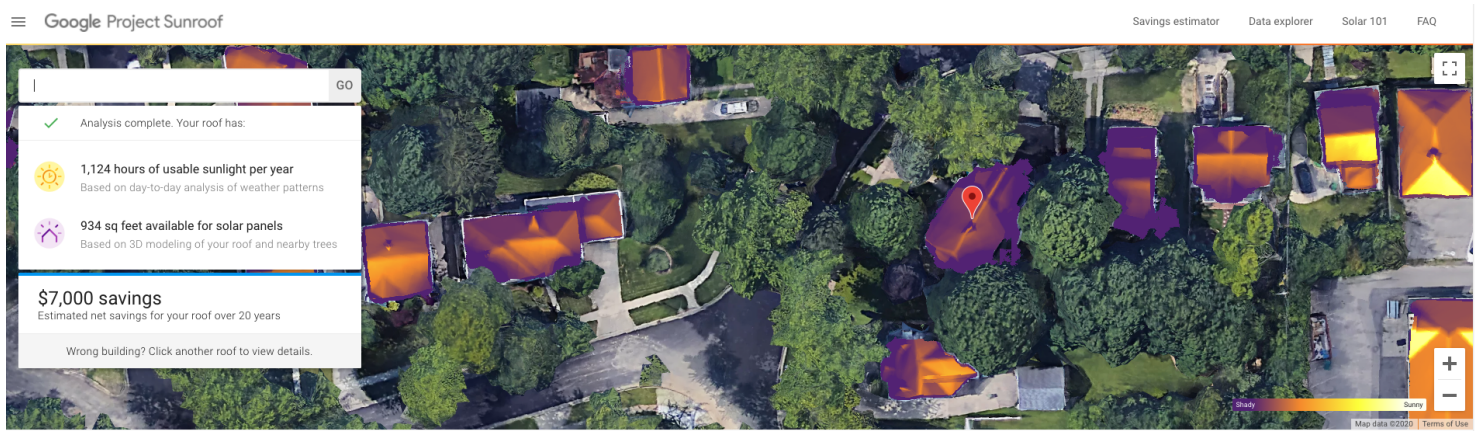
Dependent Variable: Model:	(1)	Adopt x 100 (2)
<i>Variables</i>		
Visible	-0.093 (0.147)	0.082 (0.190)
Registered Rep	-2.83*** (0.427)	-2.88*** (0.426)
Expected Value	0.784*** (0.050)	0.786*** (0.050)
Visible × Block average Rep	-0.974 (0.617)	
Block average Rep × Registered Rep	1.37** (0.543)	
Visible × Registered Rep	-0.262 (0.188)	-0.288 (0.183)
Registered Rep × Expected Value	0.437*** (0.074)	0.426*** (0.075)
Visible × Block-group average Rep		-1.77** (0.892)
Block-group average Rep × Registered Rep		2.12*** (0.728)
<i>Fixed-effects</i>		
GEOID20-PROPERTY_STREET_NAME	Yes	Yes
<i>Fit statistics</i>		
Observations	994,454	994,454
R <sup>2</sup>	0.21578	0.21578
Within R <sup>2</sup>	0.00538	0.00539

*Clustered (GEOID20-PROPERTY\_STREET\_NAME) standard-errors in parentheses*  
*Signif. Codes: \*\*\*: 0.01, \*\*: 0.05, \*: 0.1*

## Limitations

- Cannot disentangle aesthetics from signaling
- Do not directly observe "type" or "identity" and proxy with voter affiliation
- Cannot distinguish between Conspicuous Conservation and Identity/group norms without assumptions on role of surrounding voter affiliation.
  - Neighbors may not define group

# Google Project Sunroof (#sunroof) MICHIGAN STATE UNIVERSITY



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