Beyond the Solar Home Price Premium: Solar as a Neighborhood Amenity

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i.Introduction

Efforts to decarbonize the energy system to mitigate the effects of climate change mean that the share of renewables in the U.S. energy mix will continue to grow. In particular, solar photovoltaic (PV) technology could supply as much as 45% of U.S. electricity needs by 2050 (U.S. Department of Energy, 2021). An important aspect of many energy transition policies is concern for an equitable distribution of the benefits and costs arising from this transition. In the context of the increasing deployment of solar PV, it is important for policymakers to have an accurate estimate of the financial value of residential solar adoption, and an understanding of how that financial value is distributed across demographic groups.

Households that install solar PV can expect to receive both direct and indirect financial returns from their panels. This research focuses on one type of indirect financial return: the solar home price premium. The literature suggests that residential solar has a positive and economically significant effect on home price (Brinkley and Leach, 2019). Studies find a solar home price premium in the range of 2-5.5% or $4-6 per Watt, translating to a minimum premium of $28,000 for an average 7kWc system (see Dastrup et al., 2012; Hoen et al., 2017; Ma et al., 2015; Qiu et al., 2017; Wee, 2016). Most of the literature focuses on California and the western U.S., and although the northeast has a large amount of solar market participation, it has not been studied closely.

In this research, I first estimate the solar home price premium in Massachusetts using a hedonic model and real estate transactions data from Zillow. Next, I investigate spillover or second-order home price effects from solar PV adoption (this analysis still in progress). That is, if one homeowner installs solar panels, what is the effect on the sales price of *neighboring* homes? Neighborhood effects of solar adoption have not been studied and have important equity implications for renewable energy policy. Finally, I conduct a distributional analysis (income, ethnicity, race) for the own-home and neighborhood price premiums.

This research expands the literature on the solar home price premium to include spillovers and contributes to knowledge about the equity and justice impacts of solar diffusion, an area of burgeoning research interest (Carley and Konisky, 2020). Recent studies have shown demographic disparities in residential solar deployment (Crago, Grazier, and Breger, 2022; Lukanov and Krieger, 2019; Reames, 2020; Sunter et al., 2019). Solar adopters are most often White and high-income. If solar is both a homeowner amenity *and* a neighborhood amenity, policymakers may be failing to account for this amplified value of adoption. If neighborhood effects are significant, how can we better target solar diffusion policies like tax incentives and renewable energy credits towards marginalized and low-income communities?

Research Questions

- Can we detect a solar home price premium in our Massachusetts sample?
- Can we detect a price premium for non-solar homes with a solar neighbor, meaning solar is not just a "homeowner amenity" but also a "neighborhood amenity"? (this analysis is still in progress)
- If we do detect an own-home price premium for solar homes and/or a neighboring home price premium, how are those premiums distributed by race and income? How about by owned versus leased systems?

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ii. Literature Review: Financial Returns to Residential Solar PV Adoption

Households that install solar PV can expect to receive a variety of direct and indirect financial returns from their panels. At a minimum, solar panels produce energy that the household would otherwise have to purchase from an electric utility, resulting in a reduced monthly electricity bill. In some cases, the solar household can even sell excess energy back to the utility (known as "net metering"). Additional opportunities for direct financial returns from solar include state and federal policies like tax credits, rebates, and renewable energy certificates (RECs). The total financial value of residential solar PV varies based on system cost, location, and available incentives at the time of installation. In Massachusetts, the net present value of an average-sized (7 kWc), direct-owned system over its 25-year lifespan was $13,750 in 2014 and $22,670 in 2019

– an increase explained by falling production costs (Breger and Perides, 2020). These sums represent direct and significant financial returns to homeowners from adopting solar PV.

Solar homeowners may also derive indirect value from their panels, either internally from the "warm glow" of being environmentally friendly or externally from the public display of status, wealth, or social values (Andreoni, 1990). Research finds that some households are willing to pay a significant amount to signal their pro-environment attitudes. Households have also been shown to seek status through "conspicuous conservation" or the highly visible consumption of a "green" good like solar panels or electric cars (Dastrup et al., 2012; Sexton and Sexton, 2014). Emissions-reducing behaviors that occur inside the home (e.g. using a smart thermostat, carefully planning errands to reduce miles driven), may give homeowners that internal "warm glow" feeling, but are not easy to signal to the outside world. Solar panels are often visible from the street, an extra benefit for those who derive value from external displays of conservation behavior.

Homeowners who adopt solar also benefit from a home price premium. The literature suggests that residential solar has a positive and economically significant effect on home price, beyond the cost of the panels themselves (Brinkley and Leach, 2019). Studies from around the world find a solar home price premium in the range of 2 to 5.5% (see Dastrup et al., 2012; Ma et al., 2015; Wee, 2016). Other studies detect a $4-6 per Watt premium, translating to a minimum premium of $28,000 for an average 7 kWc system (see Hoen et al., 2017; Qiu et al., 2017). Given that the median home sales price in the U.S. in 2021 was around $400,000, the solar home price premium represents a significant stream of value for solar homeowners (U.S. Census Bureau, 2022). The preponderance of evidence of the solar home price premium comes from California and the western U.S., which have a unique energy landscape. Investigating the existence of a price premium in Massachusetts is an important contribution to the literature, as the northeast has a large amount of solar market participation and has not been studied as closely.

Summary: Residential Solar Adoption Creates Financial Value

- Solar reduces or eliminates electricity bills
- Solar incentivizing policies like tax credits, rebates, net metering, and renewable energy certificates also produce financial returns for solar owners
- Non-monetary benefits exist, too: conspicuous conservation and warm glow
- Solar increases home value beyond the cost of the panels themselves (known as the "solar home price premium")

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iii. Empirical Strategy

a. Own-home Solar Price Premium

I will use two hedonic approaches to answer my research question. In the simple hedonic specification (following Dastrup et al., 2012), I will find the average differential in sales price of homes with and without solar panels in the same census tract selling in the same quarter after controlling for differences in observable home characteristics. The estimating equation is

$$Price_{ijt} = \alpha Solar_{it} + \beta X_i + \gamma_{kt} + \varepsilon_{ijt}$$

where $Price_{ijt}$ is the sales price of home *i* in census tract *j* in quarter *t* and $Solar_{it}$ is an indicator for the presence of solar panels. X_i is composed of home, lot, and sales characteristics. Finally, γ_{kt} are county by quarter fixed effects, accounting for housing market trends and unobserved neighborhood amenities. The parameter of interest α represents the average percent contribution of solar panels to home sales price. With this specification, I must assume that the decision to install solar and unobservable home characteristics are uncorrelated with the error term.

In the repeat sales approach, I will average the additional price increase of a home from one sale to the next when solar panels are installed between sales. The resulting equation is

$$log\left(\frac{Price_{ij(n+t)}}{Price_{ijt}}\right) = \tilde{\alpha}\Delta Solar_{i(n+t)} + \gamma_{k(n+t)} + \tilde{\varepsilon}_{ij(n+t)}$$

where $Price_{ij(n+t)}$ and $Price_{ijt}$ are consecutive sales of the same property *i* in tract *j* occurring *t* quarters apart where the subsequent sale is in period *n*. The variable $\tilde{\alpha}\Delta Solar_{i(n+t)}$ is an indicator for installation of solar between sales. $\gamma_{k(n+t)}$ includes county- and quarter-specific time effects and remaining stochastic property value effects are included in $\tilde{\varepsilon}_{ij(n+t)}$. The parameter of interest $\tilde{\alpha}$ represents the average capitalization of solar panels into home sales price when solar is installed between sales.

Summary: Two hedonic approaches

- Simple hedonic specification: What is the average percent contribution of solar panels to home sales price for homes selling in the same place (tract) and time (year and quarter)?
- Repeat sales specification: For homes that have sold repeatedly, what is the average additional sales price increase between those that installed solar between sales and those that did not?

b. Spillover Effects of Solar Home Price Premium (or "neighborhood price premium")

The empirical strategy to estimate spillover effects of the solar home price premium will mirror that of the prior section, but with a few adjustments to the specifications.

The simple hedonic approach becomes:

$$Price_{ijt} = \alpha NeighborSolar_{jt} + \beta X_i + \gamma_{kt} + \varepsilon_{ijt}$$

- $Price_{ijt}$ is the sales price of non-solar home *i* in census tract *j* in quarter *t*.
- $NeighborSolar_{it}$ is a variable for the number of solar homes in tract *j* in quarter *t* (will also MW of solar as a robustness check)
- X_i is composed of home, lot, and sales characteristics for the non-solar home *i*.
- γ_{kt} are county by quarter fixed effects, accounting for housing market trends.
- ε_{ijt} is residual idiosyncratic variation in sales price.

The repeat sales approach becomes:

$$\log\left(\frac{Price_{ij(n+t)}}{Price_{ijt}}\right) = \tilde{\alpha}\Delta \mathrm{Neighbor}Solar_{j(n+t)} + \gamma_{k(n+t)} + \tilde{\varepsilon}_{ij(n+t)}$$

- $Price_{ij(n+t)}$ and $Price_{ijt}$ are consecutive sales of the same non-solar home *i* in tract *j* occurring *t* quarters apart where the subsequent sale is in period *n*.
- $\tilde{\alpha}\Delta NeighborSolar_{i(n+t)}$ is a variable indicating the number of solar installations (or MW for robustness) in tract *j* installed between quarter *t* and quarter *n+t*.

- $\gamma_{k(n+t)}$ includes county-by-quarter time fixed effects
- $\tilde{\varepsilon}_{ij(n+t)}$ captures remaining stochastic property value effects

In order to determine how much variation the county-by-quarter fixed effects might account for, I will also estimate the following for the simple hedonic approach:

$$log(Price_{ijt}) = \gamma_{k(n+t)} + \tilde{\varepsilon}_{ij(n+t)}$$

And do the same for the repeat sales approach:

$$\log\left(\frac{Price_{ij(n+t)}}{Price_{ijt}}\right) = \gamma_{k(n+t)} + \tilde{\varepsilon}_{ij(n+t)}$$

Summary: Same two hedonic approaches, but with a twist

- Simple hedonic specification: How does the number of solar homes in a neighborhood (tract) at a certain time (quarter) affect the sales price of a non-solar home?
- Repeat sales specification: For non-solar homes that have sold repeatedly, how is their sales price affected by the number of neighboring homes (same tract) that install solar between the non-solar home's sales?

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iv. Data

Estimating the solar home price premium in Massachusetts requires the compilation of several types of data. I obtain real estate transactions from Zillow, information on solar PV installations from the Massachusetts Department of Energy Resources, and demographic data from the Home Mortgage Disclosure Act.

a. Real Estate Transactions: Zillow ZTRAX

Zillow's Transaction and Assessment Database (ZTRAX) is the largest free real estate database in the United States. The Massachusetts data in ZTRAX spans 34 years (1987-2021) and includes a wide range of property and sales information. The assessment (Zasmt) tables include property and home characteristics, while the transaction (Ztrans) tables include sales and mortgage information. I use the following variables: property address and other geographic information; date the property was built, remodeled, and sold; sales price; mortgage loan amount and lender; and various property attributes like number of bedrooms and bathrooms, square footage, presence of a pool, and type of heating and air conditioning. After merging and cleaning the Massachusetts Zasmt and Ztrans data, I am left with 3.07 million transactions, of which 1.69 million are repeat sales (defined as an address that has transacted at least twice).

b. Solar PV Installations: MA DOER SREC I and II

To identify which homes in Massachusetts have solar PV, I use data from the Massachusetts Department of Energy Resources (DOER). The solar PV in this dataset was installed 2014-2018 and qualified for the MA Solar Renewable Energy Certificate (SREC) I and II programs. Virtually all solar installed during this period was included in the SREC programs, meaning that the data represents the universe of solar installations in the state at that time (see Figure 1). The dataset contains 75,950 unique solar installations and includes applicant name, applicant address, installer name, installation type (e.g. residential, commercial), system ownership status (e.g. leased, owned), detailed system information (e.g. nameplate capacity, installation date), and financial information (e.g. SREC factor, total installed costs).

I merge this data with the real estate data from ZTRAX by matching on address. Of the nearly 80,000 solar installations in the MA DOER dataset, I can match 8,286 observations with ZTRAX. This means that nearly 90% of solar homes in Massachusetts have been owned by the same individual since at least 1987, a fact that has important equity implications since long-term home ownership is likely linked with wealth. Of those home sales matched with solar installations, I observe 6,746 homes that have sold at least twice (a “repeat sale”) and installed solar between sales (important for my repeat sales empirical strategy). These repeat transactions where solar is installed between sales seem to be distributed proportionally to total sales by county (see Table 1). I plan to obtain DOER data for the years 2019 and 2021 to increase the number of repeat solar sales included in my analysis.

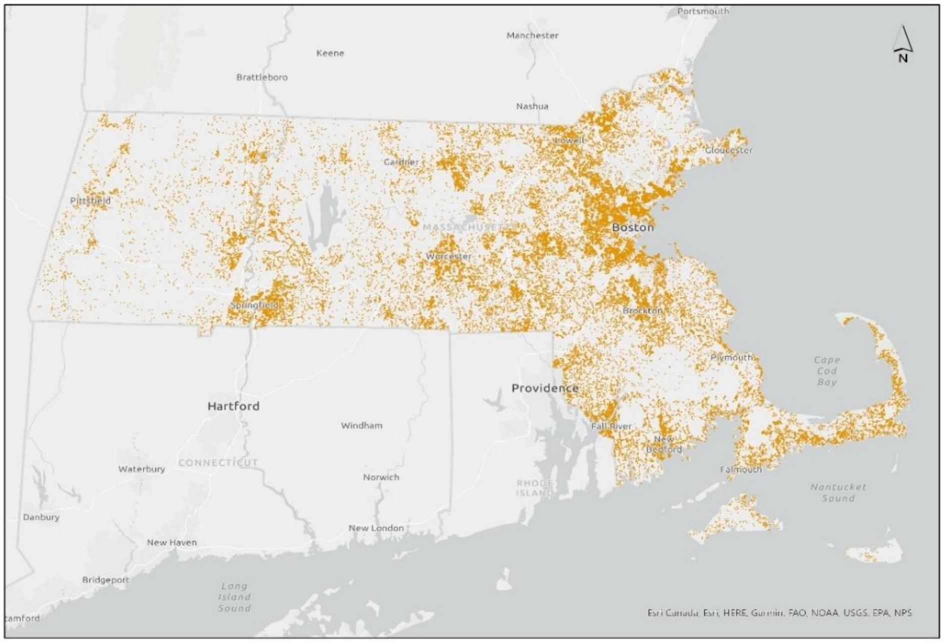

Figure 1. Massachusetts Solar Installations, 2014-2018

Table 1. Total Sales, Solar Sales, and Repeat Solar Sales by County, 1987-2021

County	Total Sales	Solar Sales	Repeat Solar Sales
Barnstable	201,163	254	192
Berkshire	63,172	154	121
Bristol	224,589	840	658
Dukes	11,367	10	4
Essex	356,120	996	818
Franklin	28,667	94	72
Hampden	203,844	488	400
Hampshire	57,827	318	249
Middlesex	665,897	1,733	1,447
Nantucket	10,710	2	1
Norfolk	327,241	755	612
Plymouth	263,601	817	661
Suffolk	274,537	211	156
Worcester	375,983	1,614	1,355
Total	**3,064,718**	**8,286**	**6,746**

c. Demographics: Home Mortgage Disclosure Act

To conduct a distributional analysis of the solar home price premium, I need to know household-level demographics. However, Zillow omits names and other identifying information from ZTRAX. The MA DOER solar installation data does contain some identifying information (e.g. applicant name), but also does not include demographics. Following Bayer et al. (2016), I find a solution using the Home Mortgage Disclosure Act (HMDA). HMDA is a U.S. federal law requiring certain financial institutions to make mortgage data publicly available to monitor discriminatory lending practices. HMDA requires the collection of the race and income of mortgage applicants, which allows me to conduct my distributional analysis at the household level. I match the ZTRAX database with HMDA on the following variables: the year a home sold, the census tract and block group where the home is located, the mortgage loan amount, and the mortgage lender's name. I am able to match about 30% of my observations with HMDA (Note: Bayer et al., 2016 matched 55%; Billings, 2019 matched 48-57%). I observe sales and solar data plus demographics for 903,212 homes after this matching process. Of those homes, 1,456 have solar, and 437 are repeat solar sales. I lose all observations in Barnstable and Franklin counties in this merge (see Table 2 – need to check this out further).

Table 2. HMDA Sample: Total Sales, Solar Sales and Solar Repeat Sales by County, 1987-2021

County	Total Sales	Solar Sale	Solar Repeat Sale
Barnstable	0	0	0
Berkshire	19,818	20	5
Bristol	71,071	160	42
Dukes	2,726	0	0
Essex	128,783	215	78
Franklin	0	0	0
Hampden	52,144	58	13
Hampshire	19,675	54	10
Middlesex	242,316	310	98
Nantucket	2,046	0	0
Norfolk	116,767	162	41
Plymouth	77,116	137	39
Suffolk	33,540	41	10
Worcester	137,210	299	101
Total	**903212**	**1456**	**437**

v. Analysis

a. Own-home solar price premium: Simple Hedonic Approach

Before beginning my analysis, I clean and restrict my data along a few dimensions. The original dataset has some extremely high-value properties (mostly condominiums, apartment complexes, or data entry errors) that skew the mean and median sales price upwards. I create a cleaned dataset with the following restrictions:

- Land use code = “single family residence”
- Sales price > $50,000 to exclude non-arms-length transactions and other low-value outliers
- Sales price < $800,000 (twice the Massachusetts median for 2014-2018)
- Bedrooms < 10

The summary statistics in Table 3 below provide preliminary evidence that the sales price of solar homes is greater than that of non-solar homes. Except for 2016, both the mean and median sales prices of solar homes are higher than non-solar homes.

Table 3. Summary of Sales Price by Solar Status by Year

Year	Solar	Obs	Median	Mean	Stdev	Min	Max
2014	1	6	$ 459,500	$ 414,500	$ 163,150	$ 206,000	$ 575,000
	0	50,260	$ 300,000	$ 328,097	$ 164,963	$ 50,100	$ 800,000
2015	1	126	$ 340,000	$ 360,295	$ 136,018	$ 80,000	$ 775,000
	0	54,975	$ 305,000	$ 333,225	$ 164,955	$ 50,065	$ 800,000
2016	1	450	$ 310,000	$ 356,190	$ 145,232	$ 58,000	$ 800,000
	0	57,981	$ 334,450	$ 337,152	$ 166,350	$ 50,018	$ 800,000
2017	1	864	$ 350,000	$ 373,921	$ 143,658	$ 52,000	$ 795,000
	0	60,133	$ 329,200	$ 352,487	$ 168,577	$ 50,020	$ 800,000
2018	1	1,172	$ 365,000	$ 386,887	$ 149,648	$ 57,133	$ 800,000
	0	57,962	$ 345,500	$ 368,595	$ 170,667	$ 50,500	$ 800,000
2019	1	1,363	$ 370,000	$ 393,580	$ 150,384	$ 60,000	$ 800,000
	0	56,043	$ 361,000	$ 381,747	$ 169,474	$ 50,050	$ 800,000
2020	1	1,534	$ 405,000	$ 422,367	$ 154,923	$ 54,000	$ 800,000
	0	54,560	$ 399,000	$ 411,599	$ 171,228	$ 50,515	$ 800,000
2021	1	1,086	$ 445,000	$ 459,149	$ 159,237	$ 55,000	$ 800,000
	0	35,154	$ 430,000	$ 441,410	$ 173,003	$ 50,960	$ 800,000

In the simple hedonic approach, I regress sales price on a solar indicator and home characteristics (number of bedrooms and effective age of home), then account for county and year-quarter fixed effects. I find that the effect of installing solar on home sales price, or the solar home price premium, is about $4,800 in Massachusetts (Table 4).

Table 4. Solar Home Price Premium - Simple Hedonic Approach (Full State)

Model: reghdfe sales_price solar bedrooms effective_year_built, absorb(county y_q)

```
HDFE Linear regression                            Number of obs   =  1,786,893
Absorbing 2 HDFE groups                           F(   3,1786738) =  101234.15
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.4717
                                                  Adj R-squared   =     0.4717
                                                  Within R-sq.    =     0.1453
                                                  Root MSE        =  1.189e+05
```

sales_price	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
solar	4833.841	1483.943	3.26	0.001	1925.364	7742.317
bedrooms	47194.74	107.892	437.43	0.000	46983.28	47406.21
effective_year_built	772.6157	2.546169	303.44	0.000	767.6253	777.6061
_cons	-1385695	4972.67	-278.66	0.000	-1395441	-1375949

Absorbed degrees of freedom:

Absorbed FE	Categories	- Redundant	= Num. Coefs
county	14	0	14
y_q	139	1	138

Next, I break down the results by county. As shown in Figure 2 and Table 5, there are some spatial differences in the solar home price premium. Essex, Middlesex, and Norfolk counties – three contiguous counties in the greater Boston area – all have negative and significant relationships between solar and sales price. Counties in more rural central and western Massachusetts have positive and significant solar home price premiums ranging from $10,000-$48,000. Plymouth and Barnstable counties on the South Shore and Cape Cod also have positive and significant premiums. Suffolk county (Boston), Berkshire, and Bristol have positive but insignificant premiums. Massachusetts' two island counties Dukes (Martha's Vineyard) and Nantucket are omitted due to insufficient solar observations.

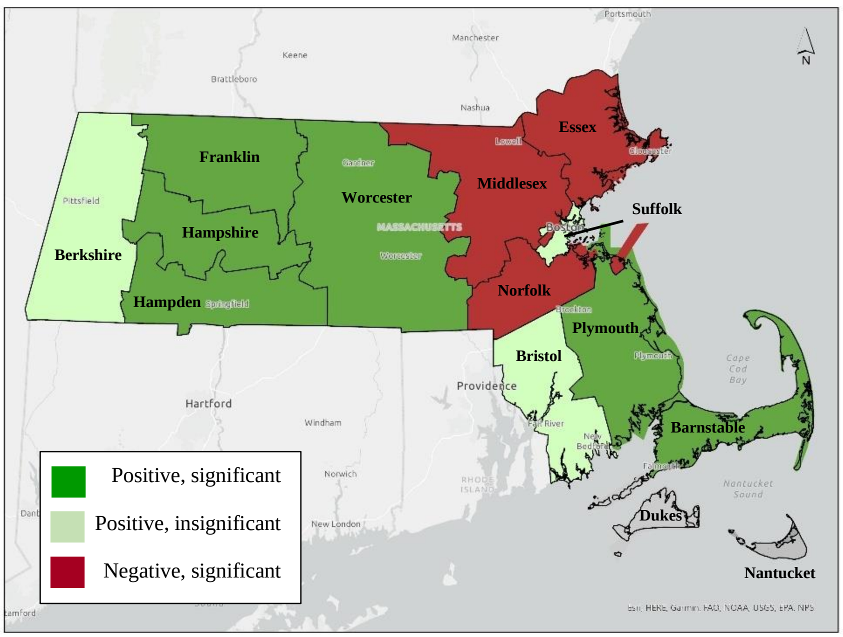

Figure 2. Solar Home Price Premium - Simple Hedonic Model Results by County

Table 5. Solar Home Price Premium - Simple Hedonic Approach (County-level)

	Barnstable			Berkshire		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	27098	9024	0	12219	9910	0.218
bedrooms	45216	413	0	38720	612	0
year built	230	14	0	897	14	0
_cons	-309418	26856	0	-1673485	27657	0
	Hampshire			**Middlesex**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	24286	5846	0	-2571	3976	0.518
bedrooms	43486	589	0	57167	272	0
year built	492	12	0	522	6	0
_cons	-880169	24228	0	-873120	12378	0
	Bristol			**Dukes**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	714	3628	0.844	0	(omitted)	
bedrooms	33680	308	0	35289	1992	0
year built	1064	7	0	18	59	0.754
_cons	-1952362	13544	0	239386	116290	0.04
	Essex			**Franklin**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	-6065	4380	0.166	48880	8430	0
bedrooms	50891	331	0	25441	623	0
year built	909	7	0	521	13	0
_cons	-1625599	13486	0	-921294	25321	0
	Hampden			**Nantucket**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	10462	3531	0.003	0	(omitted)	
bedrooms	31044	248	0	33361	2896	0
year built	1038	7	0	-956	68	0
_cons	-1956803	13022	0	2148237	135159	0
	Norfolk			**Plymouth**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	-8923	5291	0.092	13344	4679	0.004
bedrooms	60641	337	0	46313	339	0
year built	805	8	0	553	8	0
_cons	-1443261	16388	0	-959658	15678	0
	Suffolk			**Worcester**		
	Coef.	Std. err.	p>|t|	Coef.	Std. err.	p>|t|
solar	13780	11561	0.233	15108	2686	0
bedrooms	21349	518	0	53637	254	0
year built	-1	14	0.932	1105	5	0
_cons	223547	27446	0	-2104224	10674	0

b. Own-home solar price premium: Repeat Sales Approach

In the repeat sales approach, I consider sales of the same home over time. I regress the log of the change in sales price from one sale to the next on an indicator for solar being installed between sales. I also account for spatial and seasonal trends by using county and quarter fixed effects. I find that installing solar between home sales is associated with a 12.6% increase in sales price (Table 6). For a home that sold for the Massachusetts median value of $400,000 (2014-2018), this amounts to a $50,000 premium.

Table 6. Solar Home Price Premium – Repeat Sales Approach

Model: reghdfe ln_delta_price solar_repeat_sale, absorb(county quarter)

```
HDFE Linear regression                            Number of obs   =    817,306
Absorbing 2 HDFE groups                           F(   1, 817288) =     334.22
                                                  Prob > F        =     0.0000
                                                  R-squared       =     0.0156
                                                  Adj R-squared   =     0.0156
                                                  Within R-sq.    =     0.0004
                                                  Root MSE        =     0.4919
```

ln_delta_price	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
solar_repeat_sale	.1262031	.0069032	18.28	0.000	.112673	.1397332
_cons	.304462	.0005458	557.81	0.000	.3033923	.3055318

Absorbed degrees of freedom:

Absorbed FE	Categories	- Redundant	= Num. Coefs
county	14	0	14
quarter	4	1	3

c. Distributional Analysis

No studies to date have paired household-level race, ethnicity, and income with solar installation data. Although the process of merging demographic data from HMDA with my existing ZTRAX and solar database greatly restricts the number of solar homes I observe (8,286 to 1,456), I am still able to glean some interesting demographic insights. The percentage of solar households by race generally matches with Massachusetts averages, with a slight underrepresentation of nonwhite homeowners (see Table 7). When we consider homes with solar panels that are *owned* rather than leased, we see a stark underrepresentation of Black homeowners (2.8% compared to the state average of 7.2%). Homeowners that also own their solar panels receive financial returns 300% higher than those who lease (Crago, Grazier, and Breger, 2022). This is because, with leasing, the solar developer rather than the homeowner receives any credits, tax incentives, and subsidies from the panels. The underrepresentation of Black solar panel owners is evidence of racial inequity in financial returns to solar adoption.

I also observe differences in household income between solar and non-solar homes. Median household income in both Massachusetts and my HMDA sample is about $78,000, while for solar households it is $99,000 and for solar *owning* households it is $129,000 (see Table 8). Prior research has shown that solar homes are more likely to be located in high-income census block groups (see Sunter and Kammen, 2019 and Crago, Grazier, and Breger, 2022). My research provides direct, household-level evidence that solar adopters have higher median income than non-adopters, and that solar owners have higher median income that lessees, again highlighting inequity in financial returns to solar adoption.

Table 7. HMDA Sample: Demographics of Solar Households and *Owned* Solar Households Compared to the Massachusetts State Averages for the Sample Period (2014-2018)

	Massachusetts Average*	**Solar Household**		**Solar = Owned**	
	%	n	%	n	%
Race					
White	79.2	1,130	77.6	203	79.9
Black or African American	7.2	80	5.5	7	2.8
American Indian and Alaska Native	0.2	5	0.3	0	0.0
Asian	6.1	84	5.8	16	6.3
Native Hawaiian or Pacific Islander	0	4	0.3	1	0.4
Not provided	-	153	10.5	27	10.6
Ethnicity					
Hispanic or Latinx	12.6	147	10.1	16	6.3
Not Hispanic or Latinx	87.4	1,173	80.6	216	85.0
Not provided	-	136	9.3	22	8.7

* Massachusetts Average 2014-2019 (U.S. Census Bureau)

Table 8. HMDA Sample: Mean and Median Household Income for Overall Sample, Solar Households, and *Owned* Solar Households

	Massachusetts Average*	Overall Sample	Solar Household	Solar = Owned
Mean	-	$ 106,533	$ 124,168	$ 172,849
Median	$ 78,772	$ 78,000	$ 99,000	$ 129,000

* Massachusetts Average 2014-2019 (U.S. Census Bureau)

d. Neighborhood Price Premium

Analysis to be conducted.

vi. Possible Mechanisms for Solar Home Price Premium Spillover Effects

Summary: Why might solar increase the value of neighboring homes?

- Signal of a "green" community
- Signal of neighborhood home quality and energy efficiency
- Signal of a wealthy or white community

If it is true that the sales price of a non-solar home increases when a neighboring home installs solar panels, what might be the mechanism for this effect? I posit that the presence of solar PV on a neighbor's home serves as a signal to prospective home buyers about some aspect of the neighborhood. A neighbor's solar panels could be perceived as a signal of a "green" community, a signal of neighborhood home quality, or a signal of an area's wealth or racial composition.

Willingness to pay to signal pro-environmental values has been found in the case of hybrid vehicles (Kahn, 2007; Sexton and Sexton, 2014). Another study finds that solar panels visible from the road have a positive effect on neighbors' adoption decisions for up to 500 meters (Bollinger et al., 2012). It is plausible that solar panels add to the "green" or environmentalist *bona fides* of a neighborhood, thus increasing desirability (and sales price) for those who value living in an environmentally conscious community.

In addition to being a visible signal of "green"-ness, solar panels may also give prospective home buyers information on hidden attributes of home quality. Homeowners sometimes bundle several energy efficiency improvements together: they might repair the roof, add extra insulation to the walls, and install solar at the same time. Solar on the outside of a newer build could signal that the developer invested in energy efficient appliances throughout the home. If a prospective home buyer perceives a neighboring home's solar as a signal of home quality, they may extrapolate that quality to other homes in the neighborhood, especially if those homes were built around the same time or by the same developer.

Finally, solar could be a signal of a neighborhood's wealth or racial composition. Prior research finds that solar panels are more prevalent in higher income and less racially diverse areas (see Crago et al., 2022; O'Shaughnessy et al., 2020; Reames, 2020; Sunter et al., 2019). If prospective home buyers perceive the presence of solar panels as a signal of a neighborhood's wealth or racial composition, and if they value living in wealthy or low-diversity neighborhoods more than other areas, then it is possible that solar panels contribute a premium to that neighborhood's home sales prices.

vii. Contributions and Policy Implications

This research makes three important contributions to the economics literature. First, it expands the literature on the solar home price premium, moving from first-order effects on own home price to second-order effects on neighboring homes. Second, it adds to the research on peer effects and willingness-to-pay to live in a "green" community. Third, it contributes to knowledge about the equity and justice impacts of solar diffusion, an area of burgeoning research interest (Carley and Konisky, 2020). Recent studies have shown disparities in residential solar deployment by race, income, and ethnicity (Crago et al., 2022; Lukanov and Krieger, 2019; Reames, 2020; Sunter et al., 2019). Solar adopters (and financial beneficiaries) are most often White and high-income. If solar is both a homeowner amenity *and* a neighborhood amenity, policymakers may be failing to account for this added value. If neighborhood effects are significant, how can we better target solar diffusion policies like tax incentives and renewable energy credits towards minority and low-income communities?

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