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Original research article

Peer effects in the adoption of solar energy technologies in the United States: An urban case study

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ABSTRACT

Building upon recent literature, we combine a novel spatiotemporal variable with spatial methods to investigate and quantify the influence of the built environment and jurisdictional boundaries on spatial peer-effects (SPEs) in inner-city areas. We focus on the Hartford Capital region, using detailed data at block-group and PV system levels for the years 2005-2013. This region is part of a state, Connecticut, actively engaged in supporting PV system at residential level. Adoption of PV systems varies substantially, and state policies are mediated by town-level regulations. We initially employ typology analysis to investigate the heterogeneity of the block groups with higher adoption rates. We then use panel FE and spatial estimations to determine the existence of spill-overs of SPEs beyond town boundaries. Our estimations suggest that new PV systems have a more limited spatiotemporal influence in inner-cities. We identify spatial spill-overs from neighboring block groups even between towns, suggesting that SPEs transcend municipal barriers. We do not find significant results for built-environment, although we identify several data limitations. Our results suggest that centralized, non-voluntary support policies may have larger effects if implemented beyond town-level, and that SPEs change their determination power depending on the underlying built environment.

1. Introduction & objectives

Like many other experiential goods with high upfront capital costs [1], the diffusion of residential solar photovoltaic (PV) systems can be decisively driven by information flows between peers [2–6] and through social networks [7], particularly in young markets [8]. As the price of PV systems continues to fall, information-based drivers, and the role of non-monetary barriers may become more important in encouraging households to transition towards this low-carbon option [9,10]. Recent literature has attempted to identify non-monetary drivers influencing the diffusion of PV systems, often finding that spatial peer effects have a positive influence (see e.g. [5,3,11,12]. Similar results have been found even when treated as spill-overs between regions, that is, when neighboring regions do influence each other throughout the adoption process [13–15]. As Mills et al. [16] correctly pointed out, researchers and policymakers need to improve their understanding of non-monetary adoption factors in order to better incorporate solar systems in to utility planning, thus focusing on potential policy shortfalls in supporting the adoption of PV for late-comers.

As an extension of prior research, this work has four main objectives: *i)* to typify the profile of average adopters across different urban areas using secondary data ; *ii) to* investigate the existence and influence of spatial peer effects (SPEs) within an urban area characterized by strict jurisdictional (town) boundaries determining differences in local policies; *iii)* to understand the role of spatial barriers in influencing diffusion; and *iv*) to improve the models available for investigating the existence of SPEs, by combining a previously spatiotemporal peer-effect variable as developed by Graziano and Gillingham [3], with spatial models as previously used in the context of peer-effects by Dharshing [15], and following the methodological considerations of LeSage [17]. The introduction of spatial techniques based on Dharshing [15], mixed with a previously tested SPEs variable, provides a new, more robust insight in to the dynamics of SPEs across a diverse urban spatial setting, thus highlighting the role of space-time in the diffusion of innovation. To achieve our objectives, we focus on block-group level data from four towns within the Greater Hartford area in Connecticut, a state that has implemented several monetary and informational policies to support PV system adoption at the residential level.

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1.1. Relevant works

Our analysis builds upon the works of Bollinger and Gillingham [6], Graziano and Gillingham [3], Bronin [18], and, partly, Dharshing [15]. In their analysis of the diffusion of PV systems in California [6], identified and quantified the presence of SPEs using zip-code level data, as well as an alternative mean to the installed-base level, which was previously used in literature. Focusing on Connecticut, and conducting their analysis as block group level [3], built upon Bollinger and Gillingham's intuition about SPEs, focusing on the spatial and temporal degree of influence of these effects, developing a spatiotemporal band of proximity built off of different Euclidean distances of proximity (0.5, 1 and 4 miles), and testing it for different time lengths since the neighboring installations occurred (30 days to 24 months). The authors not only confirmed the presence of SPEs, but found that their effects decayed as time passed and distance increased, virtually fading beyond 4 miles. Further, the authors linked these results to suggest that the spatiotemporal influence of these effects may vary depending on the underlying social and built environment (e.g. use of personal vehicles), differently [11,21], which instead interpreted their similar results as the existence of a cut-off distance beyond which SPEs would rapidly disappear. Focusing on the relationship between built environment and the laws regulating the operation of diffused renewable energy technologies [18], found that the adoption of these technologies could have been hampered in urban-city areas in Connecticut, thus suggesting that support policies for adoption need to be paired with operational regulations for operating these technologies within multiple built landscapes. Finally [15], has applied spatial regressive and error models for investigating the factors influencing the diffusion of PV systems in Germany, finding that connected, although not necessarily neighboring, areas influence each other's adoptions.

2. Study area

Despite being quite wealthy on aggregate, CT has widespread income inequality and poverty [20]. These differences within the state are intertwined with a highly fragmented jurisdictional landscape. A state-wide program subsidizes PV system adoption, and, upon request from towns, community programs such as Solarize CT [3]. In recent years, the residential PV program has been extended to include multi-family buildings (> 5 owners, see [21]), although sub metering is not allowed [18].

Each of the 169 towns retains wide powers in several regulatory matters, including some affecting directly residential PV systems [3]. For example towns may restrict the adoption of roof-top solar systems on certain buildings depending on their age, or the zoning (e.g. historic neighborhood), thus influencing the possibility of adoption, and creating a varied jurisdictional and socioeconomic landscape.

PV systems in CT have reached grid-parity as of 2014 meaning that the cost of electricity is at least the same as the price of electricity purchased from the grid [22], mostly thanks to the high electricity prices in the state and the generous state incentives. The incentive programs are managed at state-level, with incentive amounts and types (e.g. tax-break, cash-back, etc.) set equal for the state as a whole. Among these incentives, homeowners primarily have access to the Residential Solar Investment Program (RSIP). RSIP can be used for either accessing a PV-lease program, or a feed-in-tariff based on consumption, and funded through the Smart E-Loan program, a zero-interest program available state-wide [23]. Overall, the state is considered as a solar 'friendly' state by market watch groups, featuring in the top-10 PV states in 2018 [24,25], and featuring among the highest states for PV system count, capacity installed, and in the lower half for PV system cost [23].

Our analysis focuses on four towns in the central area of Connecticut: Hartford, the state capital, East Hartford, Glastonbury, and Manchester. All these towns are relatively old by standards in the USA, some having being incorporated as early as the 16th century. The towns form an interrelated space within the Hartford Metropolitan Statistical Area, and have strong economic ties. Nevertheless, each town is administered independently, and, even though they all enjoy the same statewide incentives, they regulate the processes through which PV systems can be licensed. Further, these towns are part of one of the most income and minority segregated regions in the country [26]. With its highly fragmented jurisdictional landscape and socio-economic characteristics, the region is able to capture some crucial feature of the whole country making it a good stepping stone on the road to fully understand the nature and dynamics of SPEs.

Residents of smaller towns usually live in single-family houses, whereas those of larger, and older, core-municipalities such as Hartford live in multi-family buildings. Due to the statewide prohibition of submetering and the lack of split-incentives (between landlord and renter of among occupants of multi-family buildings) to encourage adoption in these areas, diffusion of PV systems might be difficult even when access to the financial resources is not an issue [18]. On aggregate, the state has seen a surge of PV systems adoption in recent years. As of September 2013, 3843 residents have adopted rooftop PV systems, equating to an increase of 36.5% from December 2012 [27]. Within this context, our study area offers a wide range of socioeconomic conditions. Fig. 1 shows the extent and location of our four towns and the median household income for each town.

The four towns play different roles within the Connecticut's economy. Hartford, the capital, hosts several governmental buildings and it is one of the major international centers for insurance companies. East Hartford still hosts few large manufacturing plants. Both these towns have problems related to poverty and crime. Manchester hosts one of the largest shopping areas in the state. Finally, Glastonbury has recently developed as a wealthier, suburban community, although it still has several plots of farmland. Overall, the towns extend for about 300 sq. km of land and are home to 268,000 people, or 7.5% of the state population. None of these towns was part of the CT Solarize program during the period analyzed.

2.1. Data sources

We conduct our analysis at the (Census) block group level, selecting data at this scale when possible. Table 1 provides an overview of the sources used.

We employ a data subset from [3], selecting the block groups belonging to Hartford, East Hartford, Glastonbury and Manchester. These data are the result of interpolated values from actual observation points derived from the Census 2000 and 2010 and the American Community Surveys (ACS) – 5-year averages from 2005 to 2011. The time period covered is January 2005 through September 2013. In the interpolation process [3], accounted for the changes in block group boundaries using the newer boundaries assigned by the U.S. Census after 2008. The interpolation process was necessary to obtain a continuous dataset within the period of interest.

PV systems location and date of application to the Connecticut Energy Financial and Investment Authority (CEFIA)[1] incentive program come from the CEFIA Solar Database [27]. The dataset contains several information about adopters, including addresses and the day-month-year of installations. The dataset records each residential installation since 2004. Because of the methodology used (i.e. with lagged values), we dropped the (few) observations available for the first year. Overall, the period considered runs from January 2005 and September 2013, equal to 35 quarters. To understand the role of spatial peer effects, we build upon the work of [3], introducing the spatiotemporal variable developed by the two authors. This variable aggregates at block group level the number of PV installations within 6 and 12 months from each

[1] As of 2016, the new name of the agency is Connecticut Green Bank.