Residential Rent Externalities of Photovoltaic Systems: The Relevance of View*

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Abstract

We study how photovoltaic (PV) systems externally affect rents of residential dwellings. By creating a three-dimensional topographical model of our study areas in Switzerland, we model each building's view at surrounding PV installations and merge this data with rental price observations. In the hedonic difference-in-differences regressions, we provide evidence of how this view (impaired or unimpaired) on a PV system is associated with lower residential rents. This effect is stronger for the view at multiple PV systems rather than at a single one, in situations where seeing is more likely, and where PV installations are disrupting a scenic view. However, price penalties are attenuated if rental dwellings have their own PV system or if neighboring properties have large PV systems, which may benefit surrounding tenants in terms of electricity provision. Furthermore, by using municipal voting results on the Swiss Energy Act 2017 and the Swiss CO_2 Act in 2021, we show how stated preferences for sustainability are driving the external effects of PV systems on rents. We document a similar causal pathway for lived preferences measured by the number and change in electric vehicles in Swiss municipalities.

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Abstract

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Keywords: Photovoltaic Systems; Renewable Energy Infrastructure; Residential Real Estate; Rents; View Modeling.

1 Introduction

View matters in residential real estate markets. Properties with a scenic view across a picturesque lake, a stunning mountain range, an idyllic landscape, a park, or with a view over the city are rented out or sold at a premium. The transition towards a more sustainable estate market and more renewable energy supplies changes these views by integrating more and more photovoltaic (PV) systems into the built environment or rural areas. Consequently, PV installations' visual impact may affect surrounding buildings or residents by becoming a more prominent feature of the city-, town-, and landscape.

In this paper, we assess the impact of having a view at a PV system on residential rental prices. More specifically, we investigate how surrounding residential housing rents change once a PV installation starts its operation in a neighborhood. In doing so, we distinguish between various view types, which may influence estimation results. For example, we take a closer look at the external effect of a likely vs. less likely view, the view at single vs. multiple installations, and the view at small vs. large PV systems. Moreover, we analyze if residential rental price externalities of PV installations differ for buildings with a scenic view or an internal PV installation. We also explore whether houses and apartments are affected differently by the view at this small-scale energy infrastructure. Finally, we investigate to which extent stated and lived preferences for sustainability in municipalities and a municipality's solar energy production potential are driving our results on housing rent externalities of PV installations.

To test these relationships empirically, we introduce a novel approach to model the view at a PV system. By creating a three-dimensional topographical model of our Swiss study areas and employing a ray-tracing procedure, we are able to categorize the view at PV systems for buildings within an observation circle. We merge this view information with an extensive dataset on rental price observations from real estate listing services (621,010 residential rents). In doing so, we employ a broad sample of various dwelling types, controlling for a battery of housing attributes as well as year- and building-fixed effects in our hedonic difference-in-differences regressions.

Our empirical results demonstrate that the view at a PV system (external effect) leads to a depreciation in residential rental prices by an average of 1.3 % (impaired and unimpaired view). Furthermore, this negative impact is stronger for the view at multiple PV systems as well as in situations where seeing a PV installation is more likely. However, the effect is not driven by large and close PV systems. Notably, these installations might be beneficial in terms of electricity provisions for surrounding tenants. Moreover, the negative effect is also stronger for properties that offer a scenic view. Negative rental price externalities of PV installations are offset by an internal PV system of the dwelling. By using municipal voting results on the Swiss Energy Act 2017 and the Swiss CO_2 Act in 2021, we show that stated preferences for sustainability are a potential driver of negative externality effects of PV installations on residential rents. Similarly, lived preferences for going green measured by the number and change in registered electric vehicles allow for estimating a similar causal pathway of our main effect. Additionally, a municipality's solar energy production potential yields insights into the dynamics of housing rent externalities of PV systems across urban (generally higher potential), suburban, and rural areas (generally lower potential).

This study has important implications for policymakers and real estate investors. PV systems create negative externalities for surrounding rental buildings, which induce lower rents. However, this negative impact diminishes if a dwelling has an internal PV system or if it may benefit from large PV installations close by. Hence, it is likely that any negative externalities on tenants diminish if the adoption of PV systems on residential properties benefits not just renters or owners of a house but also residents close by. For example, Switzerland introduced mandatory PV installations for new buildings with large roofs or fronts (more than 300 m^2) in September 2023. However, this policy fails to address the externalities of PV systems or how electricity produced is distributed in a neighborhood. In the future, the formulation of appropriate policies to address the significant negative externalities is also required and will need to account for a PV system's visibility and not just its exposition and, thus, electricity production.

While the impact of seeing large-scale energy infrastructures such as nuclear power plants (Bauer, Braun, and Kvasnicka, 2017) or wind turbines (Skenteris, Mirasgedis, and Tourkolias, 2019) on housing is well documented, there are relatively few studies on how the housing market reacts to the installation of PV systems. In the context of large-scale PV projects, Elmallah, Hoen, Fujita, Robson, and Brunner (2023) examine the installations' effect on U.S. residential house prices. From a stacked difference-in-differences specification, the authors find that within a radius of half a mile house prices depreciate by 1.5 % compared to homes in 2-4 miles distance. This study also includes view categories such as "average view" and "all other view categories". In contrast, little is known about the link between residential rental prices and the view at small-scale PV systems. To the best of our knowledge, we are the first to provide an isolated valuation of the impact of viewing PV systems on residential rents.

The remainder of this study is organized as follows: The next section discusses related literature. Section 3 describes the data, in particular the topographic data for a three-dimensional model of our study areas in Switzerland as well as datasets on PV systems and residential rental prices. Section 4 introduces the methodology, in particular, our novel approach to model view at PV systems. Section 5 presents the results on the external effects of PV systems on residential rents, while Section 6 concludes.

2 Literature Review

Related literature mainly focuses on the impact of energy efficiency measures in terms of aggregated energy certificates on housing prices in the owner-occupied real estate as well as the residential rental market. Most of the studies confirm the existence of a green building premium in the housing market. Brounen and Kok (2011) find positive price premiums on houses labeled “green”. Kempf and Syz (1994) estimate a total green premium for certified residential dwellings of 2.45 % for the Canton of Zurich and 4.91 % for the city of Zurich. More granular studies deal with the question of how such certificates affect buildings’ energy consumption (Jakob, 2006; Brounen, Kok, and Quigley, 2012). In the housing market, studies also analyze behavioral aspects of private households when making investment decisions in renewable energy projects (Kempton and Layne, 1994; Greene, 2011; Bull, 2012; Brounen, Kok, and Quigley, 2013; Wiencke, 2013; Kahn, Kok, and Quigley, 2014; Ramos, Gago, Labandeira, and Linares, 2015).

The location of energy infrastructure is of essential interest to both local communities and policymakers (Clark and Allison, 1999). Therefore, changes in property prices as a consequence of infrastructure policies are a crucial aspect to consider during the respective decision-making process of new energy projects. Hence, research interest in the impact of energy infrastructure on property values has been vibrant. A vast body of literature has focused on the housing price impact of energy infrastructures as this field has gained momentum in the wake of the current challenges of climate change (Fuerst and McAllister, 2011). The meta-analysis of Brinkley and Leach (2019) documents that nowadays, more than half of the empirical studies in this domain are concerned with renewable energy infrastructure while in the previous century, the major focus was on transmission lines.

A growing body of literature attempts to understand the parameters that drive the public acceptance of renewable energy infrastructure projects (Hoen, Firestone, Rand, Elliot, Hübner, Pohl, Wiser, Lantz, Haac, and Kaliski, 2019). Among various parameters, the impact of the energy plant siting on housing values is of particular interest to the local communities and has resulted in many studies. Brinkley and Leach (2019) review 54 studies and conclude that the literature consistently finds positive value impacts from solar rooftops. Cost-savings attributed to low-cost energy projects can be essential drivers of price impacts according to Fuerst and McAllister (2011). The authors argue that cheap energy provided by a facility or energy efficiency within a property drives attractiveness up, especially for tenants with net rental contracts. Further, increases in rents and asset values in green buildings can be traced to other attributes associated with greater thermal efficiency and sustainability (Eichholtz, Kok, and Quigley, 2013). These findings are in line with Brändle, Füss, Schläpfer, and Weigand (2022) who document a low-carbon rent premium (or lower capitalization rates) for low-carbon residential buildings.

Existing studies on rooftop solar installations show consistently statistically significant premiums between 3 % and 7 % of sale prices (Dastrup, Zivin, Costa, and Kahn, 2012; Wen, Dallimer, Carver, and Ziv, 2018) and between 4 % and 6 % per watt premium (Hoen, Wiser, Thayer, and Cappers, 2013) after the installation of a PV system. Overall, the findings on the installation of solar rooftops consistently lead to statistically significant property price premiums (D'Alpaos and Moretto, 2019). However, Brinkley and Leach (2019) point out both lessons learned and limitations from previous studies. First, they find that visual attributes, including distance to the energy supply, are important factors that are often not included in quantitative analysis.[1] Second, the authors propose that further studies should be conducted on various types of housing and properties since the prior focus has been largely confined to residential single-family homes. Third, taking pre- and post-tests into account is important to fully understand the price impacts of PV systems. Fourth, newer energy plants are less represented in the literature and thus should be more closely examined and compared with old plants. Fifth, they doubt the generalizability of the empirical results from studies due to cultural and regional differences in communities' perceptions, planning processes, and land-use values. This last lesson is particularly important in the Swiss context because of the vibrant differences across cantons. One way to learn about the community's perception could be to look at the voting behavior on energy policies.

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[1] Zheng, Wu, Lin, Jia, and Wei (2023) are among the first to create a visual impact assessment of PV systems while estimating the potential and feasibility of the installations in a built environment (exemplary city in China). However, the authors do not investigate the price impact of such an energy infrastructure in the housing market in this context.

3 Data

To run our analysis, we collect data on seven major areas in Switzerland. These study areas comprise the agglomeration areas of Basel, Bern, Geneva, Lucerne, Schaffhausen, and St.Gallen, as well as the whole canton of Zurich. We choose these areas due to their availability of open-source government data. Moreover, our representative study areas cover 185 municipalities that inhabit approximately 30 % of the Swiss population (in 2019) while offering various different types of city- and landscape features that might influence rental price externalities of PV systems. The selection of study areas is also relatively homogenous in terms of local income levels, GDP, and sociodemographic characteristics.

3.1 Photovoltaic Systems

We utilize Open Government Data from the Swiss Federal Office of Energy to collect information on the location, output (size), and date of commissioning of PV systems in our Swiss study areas. This database on Elektrizitätsproduktionsanlagen (EPA) contains approximately 110,000 production plants in operation (various types) which are labeled with the Swiss Certificate of Origin of Electricity. In the case of PV installations, all large-scale installations with a capacity of $> 30kVA$ are included. Small-scale PV systems ($> 2kVA$) are covered if a voluntary registration for the certification of origin exists or the installation is subsidized in the form of feed-in tariffs, one-time payments, additional cost financing, or investment contributions.[2]

As the data from EPA lacks information on the placement of PV systems on buildings, we use a geo data model developed by Meteotest (Sonnendach.ch) to obtain information on the optimal rooftop exposition of individual PV installations. We assume that each PV system is placed in its optimal location on a building according to this model, which assesses the solar potential of all roof surfaces and building fronts in Switzerland.

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[2] Although the exact number is unknown, the Swiss Federal Office of Energy estimates that its database covers more than 97 % of small-scale PV systems in Switzerland due to the high share of subsidization.

3.2 3D Topographical Data

To create the 3D model of our study areas in Figure 1, we collect three datasets from the Swiss Federal Office of Topography.[3] Firstly, we utilize the precise digital elevation model from *swissAlti3D*, which describes the surface of Switzerland without vegetation and buildings. This digital terrain model is a raster dataset or an xyz-file in regular grids, where each cell of a grid contains an elevation value. Secondly, we place buildings in this elevation model based on data from *swissBuildings3D 2.0*. This is a vector dataset that represents buildings as 3D models with roof shapes and overhangs. Moreover, each object is described by various attributes (object type, usage, name, etc.). Thirdly, we use the large-scale topographic landscape model from *swissTLM3D* to position natural objects (i.e., trees and forests) and artificial objects (i.e., bridges and towers) in vector form.

[INSERT FIGURE 1 HERE]

Buildings, bridges, and towers have exact so-called polyhedral surfaces in Figure 1. In contrast, the topography is modeled with an accuracy of 5 meters. Trees and forests are positioned without an exact shape description. Therefore, we assume 5 meters of height for trees and forests.

3.3 Residential Rental Prices

The extensive dataset on Swiss rental prices (residential housing rents) is provided by Meta-Sys AG and includes all real estate advertisements in the metropolitan areas of Basel, Bern, Geneva, Lucerne, Schaffhausen, and St.Gallen as well as the entire canton of

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[3] The individual databases *swissAlti3D*, *swissBuildings3D 2.0*, and *swissTLM3D* have been continuously updated in previous years. More specifically, while the database on building shapes is updated on a yearly basis, the large-scale topographic landscape model and the elevation model of Switzerland is updated every six years.

Zurich from 2004 until 2021.[4] These listings are taken from several online real estate market platforms such as *ImmoScout24.ch* or *Homegate.ch*.[5] In total, the estimation sample includes 621,010 observations of residential rents. All housing rents in this final dataset meet the following criteria: (1) As many real estate listings are published on several platforms, a specific double-filtering process that compares all listings ensures that each observation is unique (duplicates are removed). (2) Each housing observation includes rental price and surface information.[6] (3) Listings must allow for precise geo-coding and have an exact address. (4) Residential rent observations lie within an observation circle of 500m for integrated PV systems and 2km for non-integrated PV systems.

[INSERT TABLE 1 HERE]

Table 1 shows summary statistics on residential rents. Monthly average residential rents are CHF 21.27 per m^2 with a range between CHF 9 and CHF 45.70.

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[4] The time horizon of our dataset on Swiss housing rents spans the COVID-19 pandemic. According to Balemi, Füss, and Weigand (2021), who summarize several studies on the housing market during the pandemic, the number of real estate listings dropped as mobility restrictions were hindering the property transaction process. In contrast, Dubler, Füss, and Weigand (2021) highlight the special role of the Swiss housing market during the pandemic which is characterized by rising house prices and stable rents. Due to this special nature, we include the pandemic in our sample.

[5] Advertised housing prices may slightly differ from contractual prices. However, these differences are mostly negligible, in particular for rental prices, as several studies show. Firstly, in the case of the Swiss residential market, Fleury (2018) shows that asking and contractual rents are identical in most cases. Secondly, in the case of owner-occupied housing, Haurin (1988) argues that asking and transaction prices should be similar, especially, in cases where standard houses are sold. Moreover, Han and Strange (2016) state that asking prices can be a fairly accurate price estimator as a valuable share of housing transactions have been closed with a price equal to the initial asking price. Ardila, Ahmed, and Sornette (2021) also provide strong evidence that asking and transaction prices are co-moving across different market segments and, hence, asking prices can be a suitable estimate for the developments in the Swiss real estate market.

[6] All observations include hedonic characteristics and information on local amenities. Missing hedonics (e.g., number of rooms) are set to zero (unknown/base category) and do not result in dropping an observation. The full set of hedonic and amenity variables of residential rents is listed in Table A.1 in the Appendix.

3.4 Municipal Data

We gather municipal voting results that reflect environmental awareness and stated preferences for sustainability. We are particularly interested in two referendums.[7] Firstly, on May 21, 2017, Swiss citizens agreed on the Revised Energy Act that ensures that Switzerland will have secure energy supplies in 2050. This policy includes improving energy efficiency and the promotion of renewable energies such as water, solar, wind, and geothermal power as well as biomass fuels. Secondly, on June 13, 2021, the Swiss electorate rejected the Federal Act on the Reduction of Greenhouse Gas Emissions (CO_2 Act) which aims to curb the nation's greenhouse gas emissions even further by 2030.

In addition, we retrieve other municipal characteristics from the Swiss Federal Statistical Office's website. More specifically, we collect data on the number and change in registered electronic vehicles in each municipality from 2015 until 2021 to proxy for lived preferences of sustainability in our analysis. We also gather data on the solar energy production potential of each municipality. This metric summarizes the potential energy production if all roofs and facades in a municipality were equipped with PV systems while taking local climate conditions and geographic locations into account. Consequently, solar energy production potential is positively correlated with urban density.

4 Methodology

4.1 View Modeling

To investigate the externalities of PV systems on residential rents, we use a method called "ray tracing" to model the visibility of all PV installations from each building that lies within a pre-defined buffer thereof. This four-step approach is illustrated in Figure 2.

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[7] As outlined by Stutzer and Lalive (2004) as well as Brändle, Füss, Schläpfer, and Weigand (2022), Swiss citizens are used to expressing their opinions at the poll every annual quarter. Hence, direct democratic decision elements are very common in Switzerland at the municipal, cantonal, as well as national level.

[INSERT FIGURE 2 HERE]

Firstly, the ray tracing method draws a circle around a specific PV system. Neighboring buildings are identified if they intersect the circle. If no dwelling intersects the circle, a circle with a larger diameter is drawn. Secondly, the shapes of identified buildings are used to draw a cone. The PV system is invisible for objects that lie within a cone as the view is blocked by the identified buildings. These dwellings are removed from this iteration process in a third step. Lastly, this procedure is repeated until the observation circle reaches the pre-defined cut-off distance of the PV system.[8]

Consequently, in this paper, we do not model a view as a precise statement that a PV system can be seen from a specific window of a building. Instead, our view modeling approach states if a PV installation can be seen from a specific floor of a building. In doing so, our classification or view modeling approach distinguishes dwellings with a partial view and buildings with a full/unimpaired view at the PV system. Most dwellings in our dataset have a partial view at an installation as, in many instances, only direct neighbors are able to see a PV system in full.[9] Therefore, we count the number of intersections a building has with different cones (partially seeing score). The further away a building is from a PV system, the higher this score can be, and it is more likely that the installations can actually only be seen in part from such buildings. For this reason, based on the identification of direct neighbors and the partially seeing score, we further distinguish buildings that are relatively likely or unlikely to have a (partial) view at the PV system.

Most importantly, the ray tracing method is applied to a 3D topographical model of our study areas (see Section 3.2). This setting allows classifying the view at a PV for buildings as a whole and individual floors. The ray tracing method often eliminates lower floors of a building, whereas higher floors are more likely to have a view at the PV system.

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[8] A non-integrated PV system with an assumed size of 100*100*10m (length, width, height) has an observation circle with a radius of 2km. In contrast, an integrated PV system which is placed on the most efficient location on a roof has a cut-off distance of 500m within a city and 1km outside city borders.

[9] Notably, in the case of direct neighbors a tree also suffices to reduce a full view at a PV system to a partial view at a given installation.

[INSERT FIGURE 3 HERE]

Figure 3 illustrates the 3D view modeling in a neighborhood of St.Gallen, Switzerland. The PV system is represented by a white dot in the center of the image. Buildings colored in green have (at least in part) a view at this specific PV system. Buildings (or parts of a dwelling) colored in yellow, red, grey, or black cannot see the PV system as their view might be blocked by buildings, trees, or other objects.

[INSERT FIGURE 4 HERE]

Figure 4 indicates that multiple PV systems can be found in most areas.[10] As a consequence, several installations of different types (integrated vs. non-integrated) and sizes may be seen from a building. These multiple relations are summarized and aggregated. For this purpose, we calculate another score for seeing large and close PV systems as well as a score for the overall number of PV installations that can be seen from any one building in our dataset, respectively.

4.2 Treatment Groups

To define treated observations for our difference-in-differences model (see Subsection 4.3), we take the date of commissioning of each PV system as the treatment date. To get a better understanding of this treatment while modeling the view at PV systems, we zoom into the area of the blue circle in Figure 4 (bottom left from center) to obtain Figure 5.

[INSERT FIGURE 5 HERE]

In Panel A of Figure 5, an observation circle with a cut-off distance of 500m is drawn around a specific PV system that just started its operation. According to the ray tracing method, several buildings (colored in yellow) are likely to have a view at the new PV

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[10] To graphically depict PV systems in our model of Switzerland, EPA coordinates have to strictly overlap with polygons of Swiss buildings. Consequently, all other mappings are omitted.

system. More specifically, as this particular PV installation is oriented southwesterly on a pitched roof, only buildings in the southwest may have a view at the installation. On the one hand, some neighboring buildings do not have a view as the dwelling with the PV system is surrounded by trees, which block the view. On the other hand, higher buildings in the south have a partial view. Panel B exclusively considers buildings and floors with an unimpaired view at a PV system. Red shading illustrates higher-up floors with a view.

[INSERT FIGURE 6 HERE]

As the number of housing price observations in buildings with an unimpaired view at a PV system is strongly reduced in Panel B, we opt to consider all buildings that have a view (impaired and unimpaired) at a PV installation as treated. Non-treated dwellings are buildings without a view at a PV system after its date of commissioning, that lie also within its observation circle. To compute the potential treatment effects of seeing a PV system on residential rents, geo-referenced rental price observations have to be mapped for buildings in the observation circle to identify treatment and control groups for our difference-in-differences setting. Figure 6 visualizes the matching of residential rents with buildings and floors that have a view at a specific PV system. While spatially matching geo-referenced housing rents (from listings data) with buildings' dimensions, the coordinates of these two different data sources are often not identical. We allow for a distance of up to 10m from the shape of a 3D building for a successful merge. If several buildings are found, the closest dwelling is selected.

Table 2 summarizes how many housing price observations have a specific type of view at a PV system. In the definition of our treatment groups, we are able to distinguish likely vs. unlikely view, view at a single vs. multiple PV systems, view at a small vs. large and close PV installation, view at a PV system from buildings with vs. without own PV installation, view at a PV system from buildings with vs. without scenic view, and view at a PV installation from apartment types vs. house types. In the latter case, the apartment types include dwellings like attics, maisonettes, lofts, penthouses, studios, or regular apartments, whereas the house types include single-family homes, detached houses, semi-detached houses, or townhouses.

[INSERT TABLE 2 HERE]

4.3 Econometric Modeling

Our econometric model aims to measure rental price effects of viewing PV systems for apartments and houses. To do so, we specify the following staggered difference-in-differences model, which includes a full set of hedonic characteristics as well as time and building fixed effects:[11]

$$ln\left(r_{ibt}\right) = \boldsymbol{X_{it}\beta} + \gamma PV_{it} + \eta_b + \lambda_t + \epsilon_{ibt}, \tag{1}$$

where, the dependent variable, $ln\, r_{ibt}$, corresponds to the natural logarithm of residential rents. The main explanatory variable, PV_{it}, is a binary indicator that equals one if a dwelling has a view at a PV system (i.e., after its installation). X_{it} comprises a set of hedonic attributes, such as the dwelling type (apartment, attic, detached house, etc.), the number of rooms (categorical), first use (newly built or fully renovated object), scenic view, and the living space (see summary statistics in Appendix Table A.1 for the scaling of the control variables). Fixed-effects at the level of individual years, t, and individual buildings, b, are denoted by λ_t and η_b, respectively. The error term is given by ϵ_{ibt}. Standard errors are clustered at the level of individual buildings.

Following the inference procedure of Callaway and Sant'Anna (2021), we estimate Equation (1) with multiple time periods and variations in treatment timing. More specifically, our difference-in-differences model is centered around heterogeneous treatments of

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[11] Usually, a PV installation is combined with a heating pump or a hybrid heating system. Heating systems are internal small-scale energy infrastructures that might additionally affect the impact of PV systems on housing rents (see e.g., Kijo-Kleczkowska, Bruś, and Więciorkowski (2022)). Notably, such effects (if any) are captured by the building fixed effects, which effectively control for differences in structural characteristics of buildings, such as the installed heating system (if time-invariant).

varying dates of commissioning of multiple PV systems. Coefficient γ on PV_{it} measures the average treatment effect on the treated (ATET) in this staggered treatment adoption, which relies on limited treatment anticipation. Most importantly, our estimation needs to meet the assumption that conditional parallel trends exist based on a never-treated control group (covariates are of minor importance in our model). To verify the validity of this assumption, we employ parallel trend tests in all re-estimations of Equation (1). Furthermore, we compute cohort-specific biennially disaggregated ATETs to explore effect heterogeneity across treatment cohorts and time periods.

Furthermore, we highlight the importance of building fixed effects in our estimation. As our data on Swiss housing rents does not represent a balanced panel dataset, the inclusion of building fixed effects in model of Equation (1) allows a more robust estimation similar to repeat cross-section data.[12] Moreover, the two-way fixed effects difference-in-differences modeling approach provides a means to address potential concerns about omitted variable bias, which could be reflected in any variable that correlates with both view at a PV system and residential rents but is not included as a regressor in our model.

5 Empirical Results

5.1 Baseline Effects of Viewing PV Systems

Regression results of estimating Equation (1) are listed in Table 3. As outlined in Subsection 4.1, we classify each building that is characterized by an impaired or unimpaired view at the PV system as a dwelling with a view. Hence, a dwelling is classified as viewing even if only a small part of the building provides a view at the infrastructure.

[INSERT TABLE 3 HERE]

The estimates in Table 3 show that scenic views significantly matter. The model

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[12] n our estimation sample, the average number of observations per building is 11 (minimum: 1, maximum: 592).

according to Equation (1) explains 35.2 % of the variance in the data with 621,010 observations, neglecting the variation explained by the full set of time and building fixed effects (adjusted within R^2). Turning to the results for residential rent externalities, the estimated coefficient γ also indicates the presence of negative externalities of PV systems indeed prevail for rental housing, as evidenced by a rental price penalty for dwellings with a view at a PV system. Having a view at a PV installation lowers rents by -1.3 % on average. This negative effect on rents is highly statistically significant.

[INSERT FIGURE 7 HERE]

Figure 7 depicts the disaggregated biennial ATET in the context of residential rents. These results are also based on our staggered difference-in-differences regression with building and time-fixed effects and illustrate the treatment effect heterogeneity by cohort and across time. Figure 8 shows a more granular graph of the estimated ATET with re-estimations cohort by cohort. Furthermore, a parallel-trends test is employed and yields an F-statistic of 1.08 with a corresponding p-value of 0.3541. Hence, the null hypothesis that treatment effects in all pre-treatment periods are zero cannot be rejected at a conventional significance level.

[INSERT FIGURE 8 HERE]

As the optimal location of PV systems on pitched roofs is generally directed to the South, critics might argue that the negative external effect of PV systems on housing rents in Table 3 is driven by apartments facing North which are usually sold or rented out at a lower price. This discount is not the driving mechanism behind our main finding, a view to the North is already priced in before the treatment date.

5.2 Effects of Different Types of View at PV Systems

Table 4 lists the results of re-estimations of several variants of our difference-in-differences model according to Equation (1).[13] More specifically, in contrast to the baseline estimation in Panel A, the results in Panels B to G consider different types of views at PV systems.

[INSERT TABLE 4 HERE]

Likely vs. less likely view at a PV: In Panel B, we split buildings, respectively, housing rent observations into two groups according to the likelihood of having an actual view at the PV system (based on the partially seeing score). The first group considers residential rent observations located in buildings that are likely to have a view at a PV. More precisely, this group includes buildings with an unimpaired view as well as buildings in the bottom quartile of the distribution of buildings with partial intersections. Hence, among dwellings with a potential partial view at PVs, this quartile is most likely to actually have a view at them. This is because the buildings in the first 25 % are closer to the installation, have few intersections with cones in the ray tracing procedure, and therefore, might provide a comparably good view at a PV system. The second group comprises buildings in the second, third, and fourth quartiles of the distribution of dwellings with a partial view, which are less likely to have a view at a PV system. These 75 % of dwellings with a potential partial view are located farther away from PV installations, have many intersections with ray tracing cones, and thus, might not provide a good view at an installation.

The difference-in-differences regression results in Panel B underscore the baseline results on the relationship between residential rents and the view at PV installations. A likely and less likely view yields a similar negative coefficient at the 1 % level of statistical significance.

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[13] To present these estimations in a concise way, estimated coefficients of controls are henceforth not listed. However, we comment on anomalies where applicable.

View at a single vs. multiple PVs: As depicted in Figure 4. PV systems may be located in the center of the built environment. Therefore, the aspect of seeing multiple installations might influence residential rents as well. To explore this relationship, we re-estimate the difference-in-differences model, differentiating between the view at single and multiple installations. The corresponding results are listed in Panel C of Table 4. An estimated coefficient of -1.0 % for a view at a single PV and an estimated coefficient of -1.3 % for a view at multiple PVs indicate that the view at multiple PV installations does matter somewhat more for rental property.

View at a small vs. large and close PV: Additionally, we adapt our difference-in-differences setting to consider whether a PV installation is large and close in Panel D of Table 4. Corresponding results show that residential rents are significantly impacted by small PV installations in a negative way, whereas large and close PV systems show an overall positive differential (the difference outweighs the negative effect of view at a small PV installation by three percentage points and creates an overall external effect close to zero). This finding might be explained by preferences for a clear structural accent in a neighborhood rather than smaller (scattered) installations for aesthetic reasons. Furthermore, it is possible, that renters directly benefit from the electricity production of large installations nearby.

Buildings with vs. without own PV: In Panel E of Table 4, we test whether the rental price effect of having a view at a PV installation changes for dwellings that house their own PV system. Residents of buildings with an installation might be more positively inclined toward seeing other PV systems. Similar to previous estimations, there is a statistically significant negative effect of -1.3 % for residential rents in buildings without their own PV system and with a view at another installation. An internal PV system on a building that actually has a view at another PV installation compensates for this negative externality by far (a positive rental price differential of 6.7 % creates an overall rental premium of 5.4 % (-1.3 % + 6.7 %-points) compared to buildings without a view). Hence, rental housing in buildings with their own PV installations still documents higher rents when exposed to a view at a PV system.

Buildings with vs. without scenic view: Negative housing rent externalities of PV systems might affect properties with a scenic view in a stronger way. We verify this hypothesis in Panel F of Table 4. An overall negative effect of -1.1 % is documented for rental observations without a scenic view. This negative impact increases by an additional -0.8 %-points (differential) if a rental price observation features a scenic view (overall effect -1.9 %).

Apartment types vs. house types: As outlined in Section 4.2, we also form two categories for dwelling types - apartment types vs. house types. This simple differentiation in Panel G of Table 4 allows an exploration of residential rental price externalities of PV systems across two major dwelling types. PV systems have a negative impact of -1.3 % on rents for all apartment types. A comparison with our baseline estimation in Panel A shows that these two coefficients are almost identical, which suggests that the overall effect across our sample is driven by rental apartments where the small category of rental houses is not a driver of the main effect, which we do not document a significant differential for.

5.3 Preferences for Sustainability and the View at PV Systems

To examine potential causal pathways of rental price effects, we explore stated and lived preferences for sustainability in each Swiss municipality. Firstly, we link the location of residential rent observations with the stated political attitude in a respective municipality similar to Brändle, Füss, Schläpfer, and Weigand (2022). To do so, we use municipal voting results in Switzerland on the Revised Energy Act in 2017 and the Federal Act on the Reduction of Greenhouse Gas Emissions (CO_2 Act) in 2021 to investigate heterogeneous treatment effects for municipalities with a similar political attitude towards sustainability. We split residential rent observations based on quartiles of the share of yes-votes in each referendum (from the lowest to the highest support in a municipality). Secondly, we utilize data on the number and growth of electric vehicles in a municipality to measure varying degrees of peoples' lived preferences for going green in a similar split.

[INSERT TABLE 5 HERE]

Panel A in Table 5 shows that the negative effect of having a view at PV systems stems from the lowest quartile, i.e., municipalities with the lowest preference for sustainability-related policies (highest proportions of rejecters of the Revised Energy Act in 2017). In comparison to the higher quartiles (differentials), with higher environmental awareness and acceptance of this referendum, the acceptance of PV installations reduces the negative impact on residential rents step-by-step and turns it slightly positive in the fourth quartile. Moreover, these differentials are confirmed by the results in Panel B, which are derived from the CO_2 Act in 2021. The negative coefficient of -5.5 % in the first quartile of the yes-vote distribution is highly statistically significant and of similar magnitude. Again, differentials for upper quartiles diminish the effect step-by-step. We estimate a differential of 5.1 %-points in the top quartile (with the highest rate of electoral support for the CO_2 Act) in comparison to the lowest quartile.

[INSERT TABLE 6 HERE]

TABLE 6 presents results on how lived preferences for sustainability go in hand with residential rent externalities of PV systems. Panel A also shows a causal pathway of the main effect. The effects' strongest driver is the lowest quartile of observations in municipalities with the smallest absolute amount of registered electric vehicles (lowest lived preferences for going green). In this first quartile, the estimated rental price effect of having a view at a PV system is -8.3 %. With an increasing number of electric vehicles in a municipality, the differentials show a diminishing negative effect (in comparison to the first quartile). Similarly, Panel B shows a strong negative effect for the first quartile (-5.0 % for municipalities with the lowest growth in electric vehicles). Increasing lived preferences for sustainability is compensating for this negative effect, as shown by a significant differential of 4.0 %-points in the quartile of municipalities with the highest growth in electric vehicles.

Generally, our findings above underscore the importance of the degree of stated and lived preferences for sustainability regarding the public perception of renewable energy infrastructures.

5.4 Solar Energy Potential and the View at PV Systems

In a last sub-analysis, we aim to explore the relationship between residential rent externalities of PV systems and municipalities' solar energy production potential. We use this metric to again split our housing rent observations along quartiles from the lowest to the highest production potential.

[INSERT TABLE 7 HERE]

Regression results in TABLE 7 show again a causal pathway: The first quartile has a strong negative estimate of residential rental price externalities of PV systems, which diminishes in higher quartiles (differential). As outlined in Section 3.4, the metric on solar energy production potential is heavily correlated with urban density. Hence, these quartiles are an indicator of a split across urban density. Less dense areas (with low potential) have a strong negative effect due to their more rural landscape, whereas highly dense areas (with high potential) have a small or no effect due to the cityscape where PVs are more likely to blend in.

6 Conclusion and Policy Implications

The purpose of this study is to identify potential external effects of PV systems on residential rents. In particular, our analysis investigates potential positive or negative externalities of having a view at PV installations. Our empirical results demonstrate that the view (partially impaired and unimpaired) at a PV system leads to a depreciation of residential rents. This negative impact is stronger for the view at multiple PV systems as well as in situations where seeing a PV is more likely. However, the effect is not driven by large and close PV systems, possibly due to potential benefits associated with these installations, such as electricity provision for surrounding tenants. Moreover, the negative effect is also stronger for properties that offer a scenic view. Negative rental price externalities of PV installation are offset by an internal PV system of the dwelling. By using municipal voting results on the Swiss Energy Act 2017 and the Swiss CO_2 Act in 2021, we show that stated preferences for sustainability are a potential driver of negative external effects of PV installations on rents. Analogously, lived preferences for going green measured by the number and change of registered electric vehicles allow estimating a similar causal pathway of our main effect. In addition, a municipality's solar energy production potential yields insights into the dynamics of residential rental price externalities of PV systems across urban, sub-urban, and rural areas.

Our results have important implications for both policymakers and real estate investors. PV systems create negative externalities for surrounding rental buildings, which induces a lower rental income. However, this negative impact is more than outweighed if a dwelling has an internal PV system or if it may reap benefits from large PV installations in its vicinity. Hence, it is likely that any such negative externalities on tenants disappear if the adoption of PV systems on residential properties benefits not just renters or owners of a house in which those systems are installed, but also residents close by. In an exemplary policy endeavor, Switzerland recently introduced mandatory PV installations for new buildings with large rooftops or fronts (more than 300 m^2 in September 2023). However, to date this policy fails to address the externalities of PV systems and how the generated power is distributed in a neighborhood, leaving room for further improvements in the formulation of appropriate policies. In future iterations, such policies may not exclusively account for the exposition of PV installations and, thus, electricity production of PV systems but also their visibility as well as the allocation of benefits that may be reaped from such power production facilities.

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Tables

Table 1: Residential Rental Prices

This table shows descriptive statistics for the dataset on Swiss residential rents. The mean, standard deviation (S.D.), as well as the minimum and maximum values are listed. In this table, residential rents are nominal asking prices from online real estate listings and amount to 621,010 observations, respectively.

	Mean	S.D.	Min	Max
Residential rents:				
Rent (CHF/m^2/month)	21.266	6.145	9.00	45.70
log(Rent)	3.019	0.271	2.197	3.822

Table 2: Residential Rent Observations with a View at PV systems

This table shows descriptive statistics for the average amount of residential rent observations with a certain view type on PV systems. The mean, standard deviation (S.D.), and minimum and maximum values are listed. All variables that summarize the view are binary indicators. The number of observations amounts to 621,010.

	Mean	S.D.	Min	Max
View at a PV system	0.589	0.492	0	1
Likely view at a PV system	0.157	0.364	0	1
Unikely view at a PV system	0.432	0.495	0	1
View at a single PV system	0.103	0.304	0	1
View at multiple PV system	0.486	0.500	0	1
View at small PV system	0.535	0.499	0	1
View at large and close PV system	0.054	0.226	0	1
View at a PV system w/o own PV	0.584	0.493	0	1
View at a PV system with own PV	0.005	0.073	0	1
View at a PV system w/o scenic view	0.419	0.513	0	1
View at a PV system with scenic view	0.170	0.376	0	1
View at a PV system from all apartment types	0.574	0.491	0	1
View at a PV system from all house types	0.015	0.124	0	1

Table 3: External Effects of PV Systems on Residential Rents – Baseline

This table lists the results of the staggered difference-in-differences regression for the estimation of the external effects of PV systems on residential rents. View at a PV system is defined as any view (i.e., partially impaired and unimpaired). The dependent variable is the natural logarithm of residential rents. Cluster-robust standard errors (at the building level) are reported in parenthesis. The number of building fixed effects is 57,969. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

	Residential Rents	
View at a PV system	-0.013***	(0.002)
Dwelling type (base category: unspecified type)		
Single-family house	0.024*	(0.014)
Detached house	-0.010	(0.006)
Semi-detached house	0.010	(0.012)
Townhouse (corner)	-0.001	(0.014)
Townhouse (single-family)	0.007	(0.010)
Apartment	-0.010**	(0.006)
Attic	0.142***	(0.006)
Maisonette	0.013**	(0.006)
Loft	0.054***	(0.008)
Penthouse	0.023***	(0.006)
Studio	-0.069***	(0.010)
Dwelling characteristics		
log(living space)	-0.388***	(0.005)
First use	0.067***	(0.002)
Scenic view	0.020***	(0.001)
Rooms (base category: unknown # of rooms)		
1	-0.115***	(0.004)
2	-0.026***	(0.003)
3	0.019***	(0.002)
4	0.055***	(0.003)
5	0.099***	(0.003)
6	0.174***	(0.006)
7 and more	0.244***	(0.009)
Constant	4.582***	(0.022)
Year fixed effects	Yes	
Building fixed effects	Yes	
Observations	621,010	
Adjusted within R^2	0.352	

Table 4: External Effect of PV Systems on Residential Rents – View Types

This table lists the results of various staggered difference-in-differences regressions for the estimation of the external effects of PV systems on residential rents. The view at PV systems is defined in multiple ways (Panels A-G). The dependent variable is the natural logarithm of residential rents. All regressions include the full set of control variables. Cluster-robust standard errors (at the building level) are reported in parenthesis. The number of building fixed effects in Panels A-G is 57,969. The adjusted within R^2 for all regressions reported is approximately 0.35. Δ denotes a differential. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

	Residential Rents
Panel A: Baseline	
View at a PV system	-0.013*** (0.002)
Panel B: Likely vs. less likely	
Likely view at a PV system	-0.015*** (0.003)
Less likely view at a PV system	-0.012*** (0.002)
Panel C: Single vs. multiple	
View at single PV system	-0.010*** (0.003)
View at multiple PV systems	-0.013*** (0.002)
Panel D: Heterogenous treatment effects Small vs. large and close	
View at a small PV system	-0.014*** (0.002)
View at a large and close PV system Δ	0.017*** (0.005)
Panel E: Heterogenous treatment effects Buildings with vs. w/o own PV system	
View at a PV system w/o own PV	-0.013*** (0.002)
View at a PV system with own PV Δ	0.067** (0.028)
Panel F: Heterogenous treatment effects Buildings with vs. w/o scenic view	
View at a PV system w/o scenic view	-0.011*** (0.002)
View at a PV system with scenic view Δ	-0.008*** (0.001)
Panel G: Heterogenous treatment effects Apartment types vs. house types	
View at a PV system from apartment	-0.013*** (0.002)
View at a PV system from house Δ	-0.003 (0.004)
Year fixed effects	Yes
Building fixed effects	Yes
Observations	621,010

Table 5: External Effect of PV Systems on Residential Rents – Stated Preferences

This table lists the results of staggered difference-in-differences regressions for estimating the causal pathway of the external effect of a PV system on residential rents. Quartiles at the municipality level are based on voting results of the Revised Energy Act in 2017 as well as the CO_2 Act in 2021 (yes-votes) reflecting the municipal population's stated preferences for sustainability. Δ denotes a differential with the respective first quartile. The dependent variable is the natural logarithm of residential rents. All regressions include the full set of control variables. Cluster-robust standard errors at the building level are reported in parenthesis. The number of building fixed effects in Panel A is 57,725, while Panel B includes 57,964. The number of observations in Panels A and B differs due to the fusion of municipalities between 2017 and 2021. The adjusted within R^2 for all regressions reported is approximately 0.35. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

	Residential Rents
Panel A: Heterogenous treatment effects Revised Energy Act 2017	
View at a PV system (yes-votes (Q1))	-0.059*** (0.004)
View at a PV system (yes-votes (Q2): Δ)	0.016*** (0.004)
View at a PV system (yes-votes (Q3): Δ)	0.028*** (0.004)
View at a PV system (yes-votes (Q4): Δ)	0.064*** (0.004)
Year fixed effects	Yes
Building fixed effects	Yes
Observations	619,890
Panel B: Heterogenous treatment effects CO_2 Act 2021	
View at a PV system (yes-votes (Q1))	-0.055*** (0.008)
View at a PV system (yes-votes (Q2): Δ)	0.000 (0.009)
View at a PV system (yes-votes (Q3): Δ)	0.015* (0.009)
View at a PV system (yes-votes (Q4): Δ)	0.051*** (0.008)
Year fixed effects	Yes
Building fixed effects	Yes
Observations	620,937

Table 6: External Effect of PV Systems on Residential Rents – Lived Preferences

This table lists the results of staggered difference-in-differences regressions for estimating the causal pathway of the external effect of a PV system on residential rents. Quartiles at the municipality level are based on the number of electric vehicles in a municipality as well as changes in registered electric vehicles (in %) from 2015 until 2021 reflecting the municipal population's lived preferences for sustainability. Δ denotes a differential with the respective first quartile. The dependent variable is the natural logarithm of residential rents. All regressions include the full set of control variables. Cluster-robust standard errors at the building level are reported in parenthesis. The number of building fixed effects in Panels A and B is 57,685. The adjusted within R^2 for all regressions reported is approximately 0.35. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

	Residential Rents	
Panel A: Heterogenous treatment effects Number (#) of registered electric vehicles 2015		
View at a PV system (# electric vehicles (Q1))	-0.083***	(0.012)
View at a PV system (# electric vehicles (Q2): Δ)	0.042***	(0.013)
View at a PV system (# electric vehicles (Q3): Δ)	0.039***	(0.012)
View at a PV system (# electric vehicles (Q4): Δ)	0.074***	(0.012)
Year fixed effects	Yes	
Building fixed effects	Yes	
Observations	619,894	
Panel B: Heterogenous treatment effects Change (%) in registered electric vehicles 2015-2021		
View at a PV system (change in electric vehicles (Q1))	-0.050***	(0.010)
View at a PV system (change in electric vehicles (Q2): Δ)	0.015	(0.015)
View at a PV system (change in electric vehicles (Q3): Δ)	0.004	(0.010)
View at a PV system (change in electric vehicles (Q4): Δ)	0.040***	(0.010)
Year fixed effects	Yes	
Building fixed effects	Yes	
Observations	619,894	

Table 7: External Effect of PV Systems on Residential Rents – Solar Energy Potential

This table lists the results of staggered difference-in-differences regressions for estimating the causal pathway of the external effect of a PV system on residential rents. Quartiles at the municipality level are quartiles based on the solar energy production potential for roofs and facades in each municipality (lowest to highest). Δ denotes a differential with the respective first quartile. The dependent variable is the natural logarithm of residential rents. All regressions include the full set of control variables. Cluster-robust standard errors at the building level are reported in parenthesis. The number of building fixed effects in Panel A is 57,853. The adjusted within R^2 is approximately 0.35. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

	Residential Rents
Panel A: Heterogenous treatment effects	
Solar energy production potential (roofs and facades)	
View at a PV system (potential (Q1))	-0.082*** (0.014)
View at a PV system (potential (Q2): Δ)	0.006 (0.014)
View at a PV system (potential (Q3): Δ)	0.037*** (0.014)
View at a PV system (potential (Q4): Δ)	0.074*** (0.014)
Year fixed effects	Yes
Building fixed effects	Yes
Observations	620,416

Figures

Figure 1: Topographical Data Visualization

This figure visualizes 3D data from the Swiss Federal Office of Topography for a neighborhood in the city of St.Gallen, Switzerland. More precisely, this graph combines a vector dataset of 3D buildings (including shapes and overhangs), a large-scale topographic landscape model of Switzerland (including trees and forests), as well as a precise digital elevation model that describes the surface of Switzerland without vegetation and buildings.

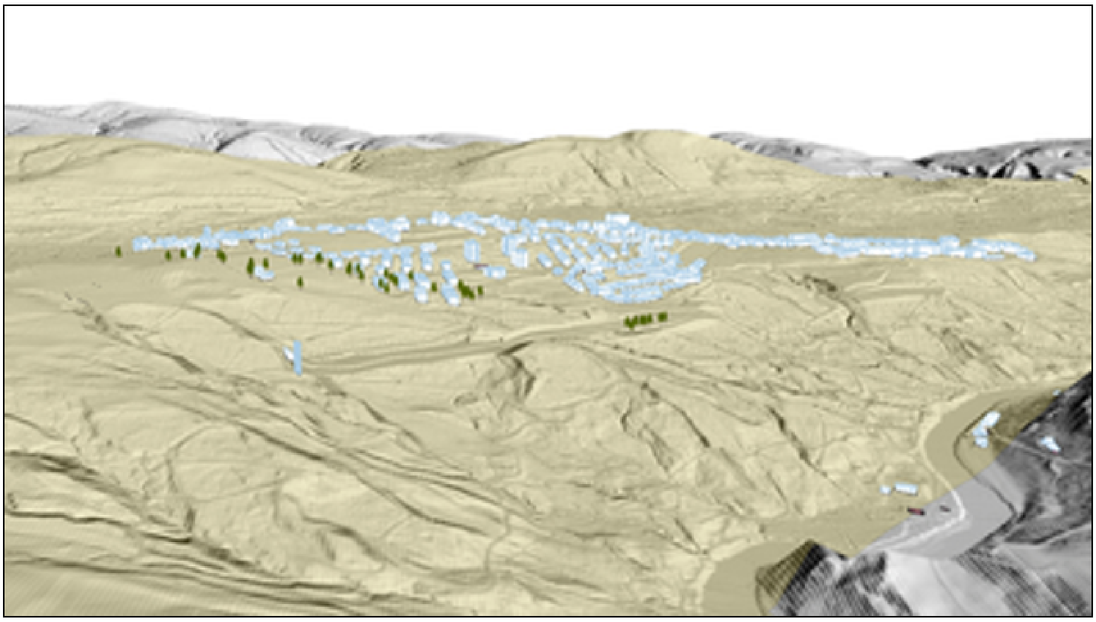


Figure 2: View Modeling – Ray Tracing Method

This figure illustrates the process of modeling view at PV systems by the ray tracing procedure. This method includes four steps which are recursively applied in circles with increasing diameters.

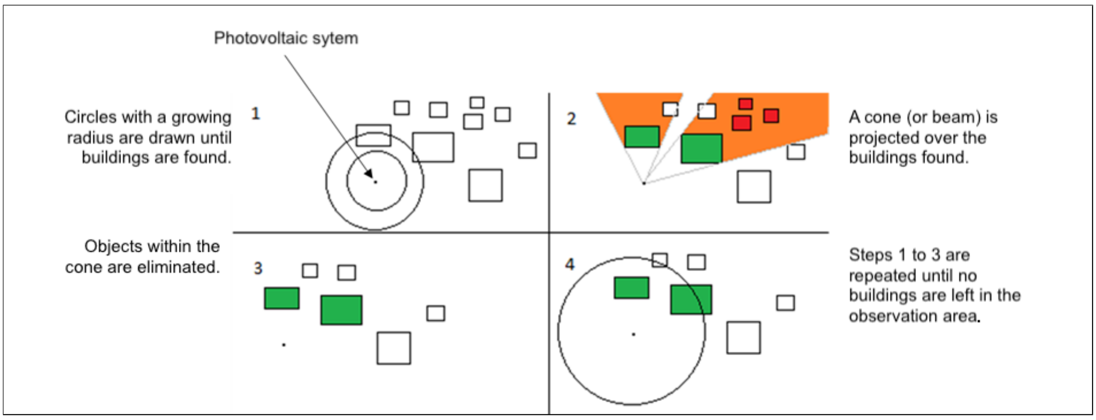


Figure 3: View Modeling – 3D View at a Specific PV System

This figure illustrates the view at a PV system (white dot) in an exemplary neighborhood in the city of St.Gallen, Switzerland. View at PV systems is based on the ray tracing method. Neighboring buildings (or sections of a dwelling) with a view at the installation are colored in shades of green. Neighboring buildings (or sections of a dwelling) without a view at the PV system are colored orange, yellow, grey, or black. Red areas indicate public land used for roads or sidewalks.

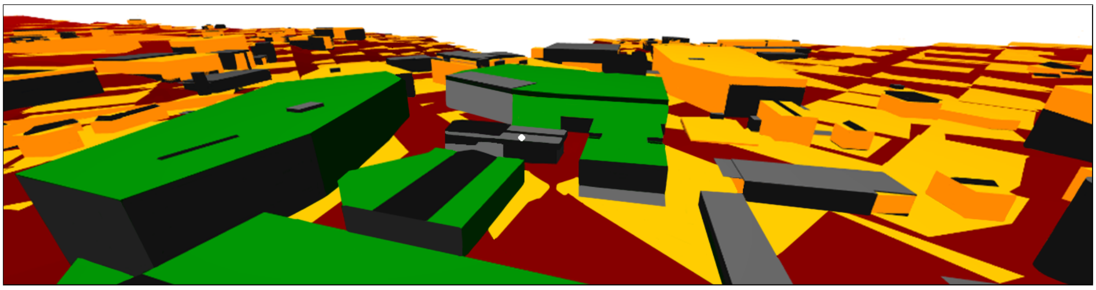


Figure 4: Mapping PV Systems of Different Size

This figure plots the location of PV systems in the city of St.Gallen, Switzerland in December 2021. The size of each installation is indicated by varying shades of red.

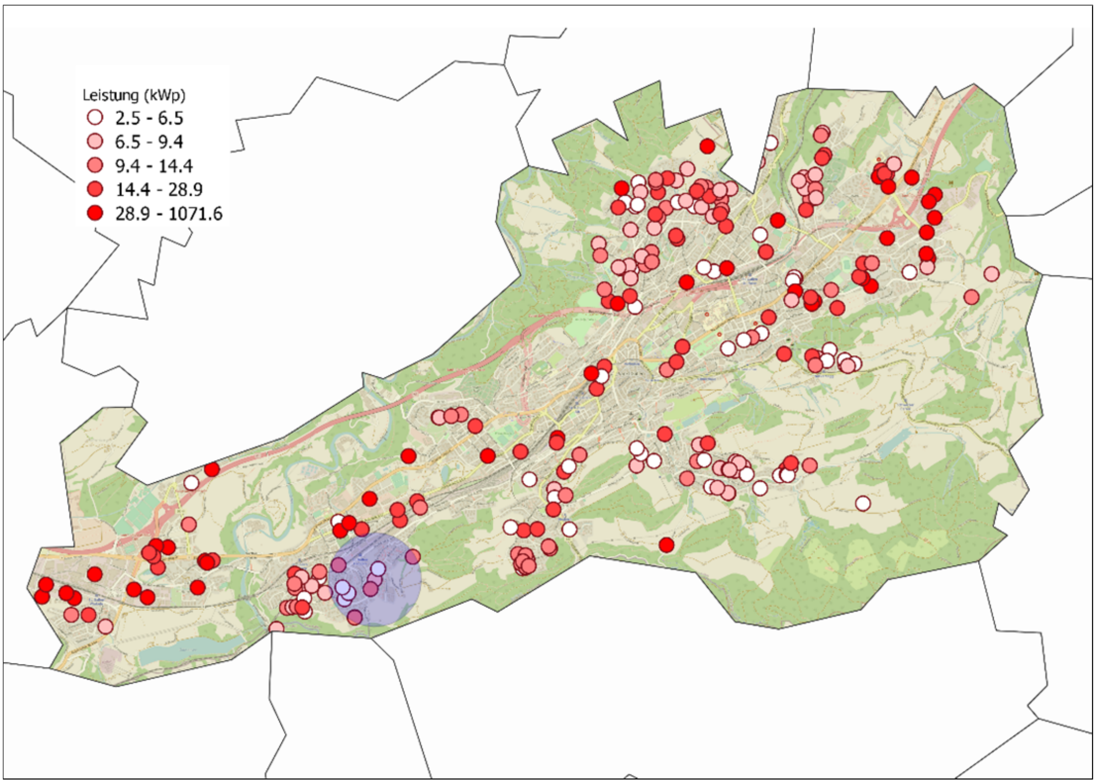
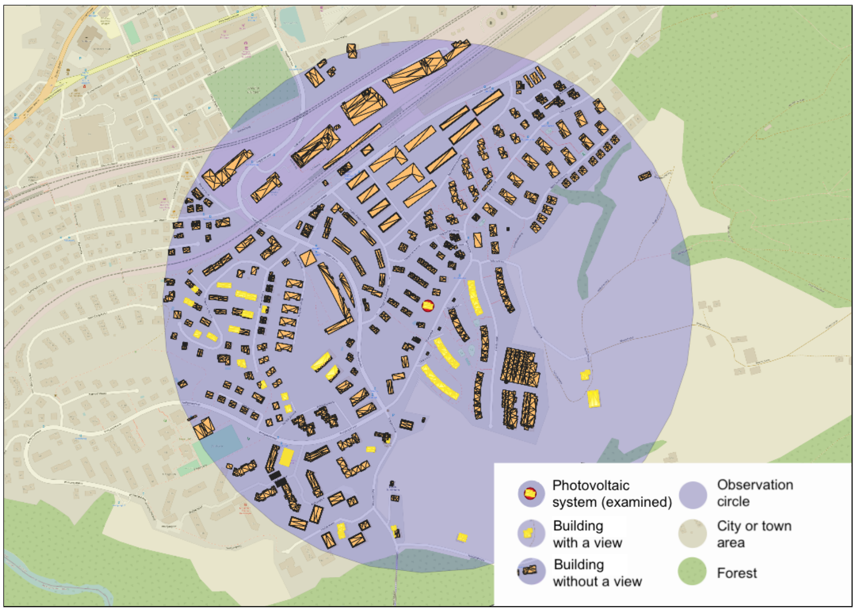


Figure 5: Buildings with a View at a Specific PV Installation

This figure illustrates buildings with a view at a specific PV system in an exemplary neighborhood in St.Gallen, Switzerland. More specifically, Panel A shows buildings with a view (at least partially) at a specific PV system within a 500m observation circle. Panel B shows buildings that have an unimpaired view at the PV installation from a certain floor. Red roofs illustrate higher-up floors that have a full view at the PV system.

Panel A: Impaired and Unimpaired View within Observation Circle



Panel B: Unimpaired View within Observation Circle

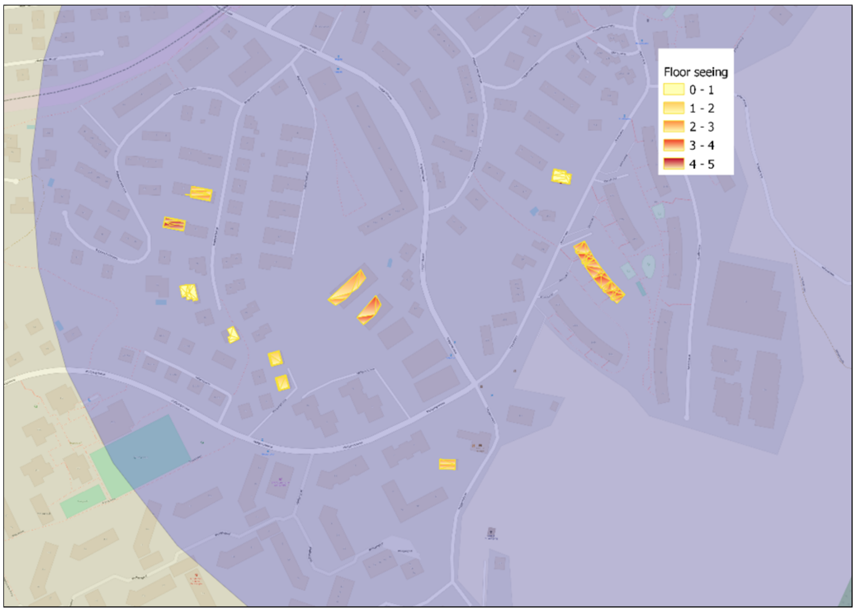


Figure 6: Residential Rents and Buildings with a View at a Specific PV Installation

This figure visualizes merging housing rent data with buildings or floors that have a view at a specific PV system. Residential rent observations are depicted by blue dots while buildings with a view are colored in yellow. Only rental price observations within the observation circle are considered.

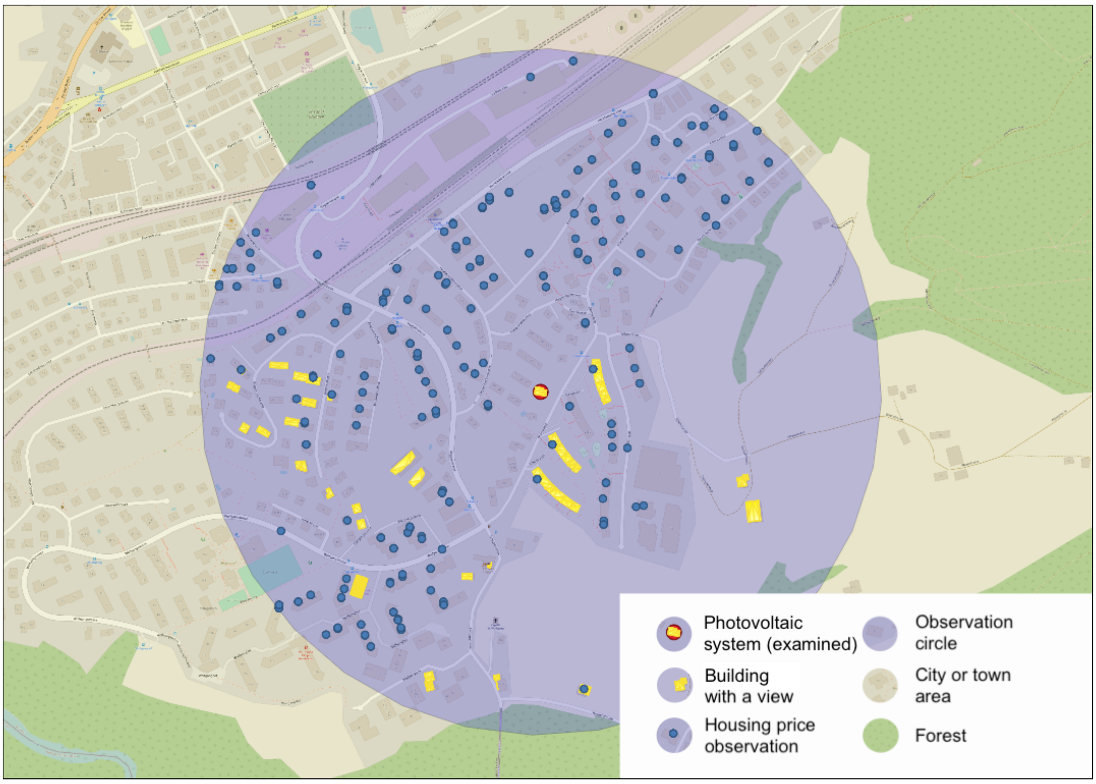
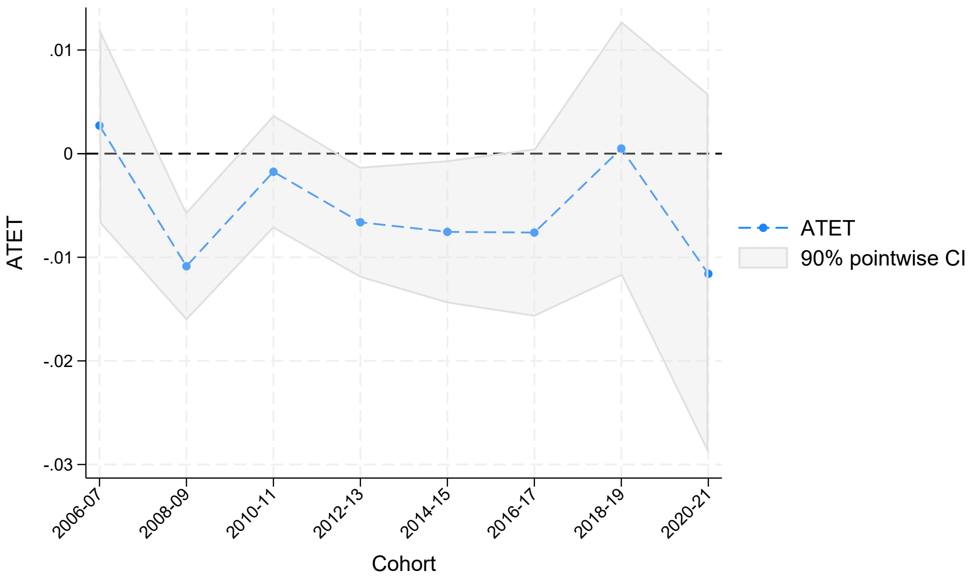


Figure 7: Biennial ATET Plots

This figure illustrates biennial ATET plots from the staggered difference-in-differences regression to capture the external effects of PV systems on residential rents. View at a PV system is defined as impaired and unimpaired view. Panel A is aggregated by cohort while Panel B is aggregated over time. Never-treated observations serve as the control group in both panels.

Panel A: Cohort-Aggregated Biennial ATET



Panel B: Time-Aggregated Biennial ATET

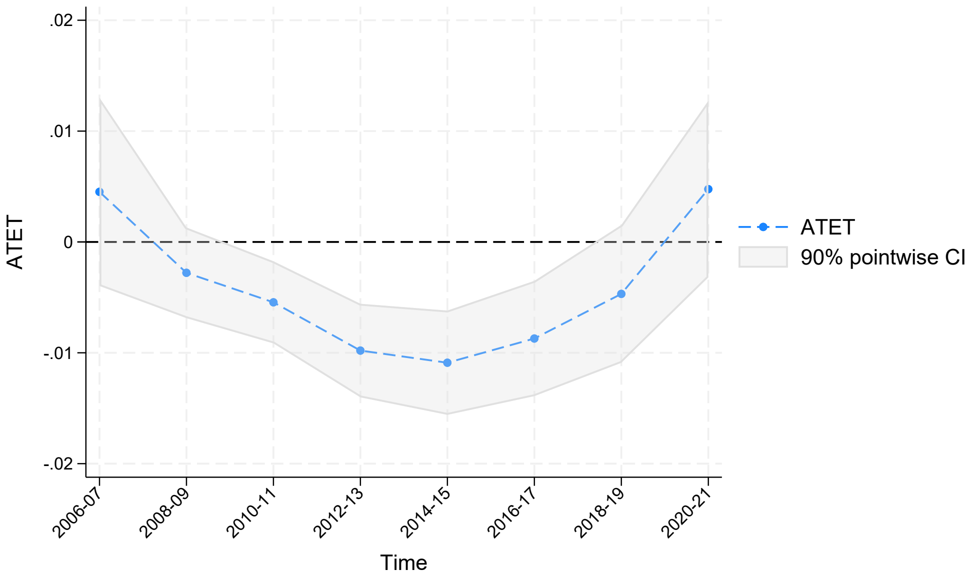
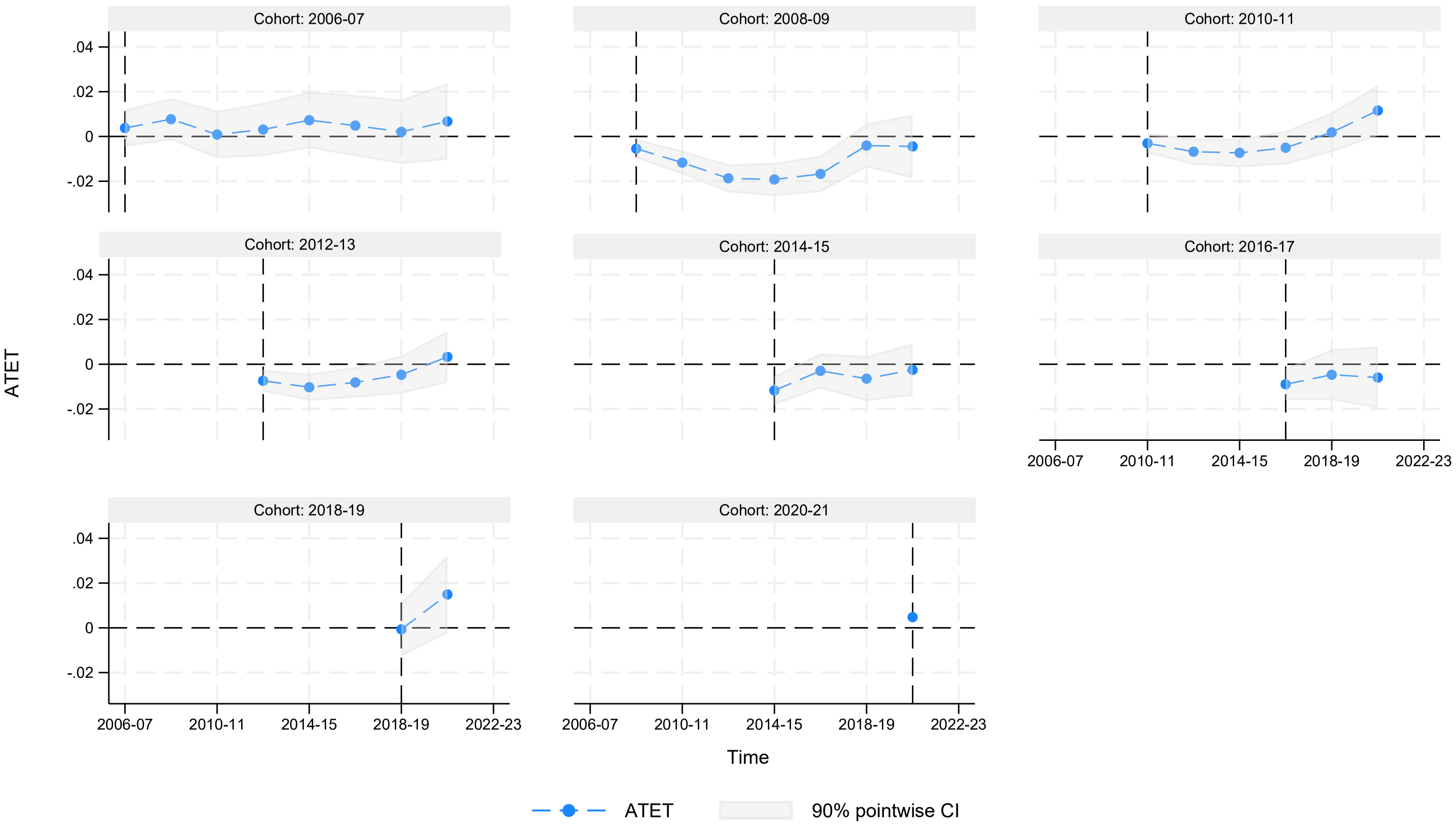


Figure 8: Biennial ATET Plots by Cohort

This figure illustrates biennial ATET plots from the staggered difference-in-differences regression to capture the external effects of PV systems on residential rents by cohort. View at a PV system is defined as impaired and unimpaired view. Never-treated observations serve as the control group.



Appendix for

Residential Rent Externalities of Photovoltaic Systems: The Relevance of View

Abstract

We study how photovoltaic (PV) systems externally affect rents of residential dwellings. By creating a three-dimensional topographical model of our study areas in Switzerland, we model each building's view at surrounding PV installations and merge this data with rental price observations. In the hedonic difference-in-differences regressions, we provide evidence of how this view (impaired or unimpaired) on a PV system is associated with lower residential rents. This effect is stronger for the view at multiple PV systems rather than at a single one, in situations where seeing is more likely, and where PV installations are disrupting a scenic view. However, price penalties are attenuated if rental dwellings have their own PV system or if neighboring properties have large PV systems, which may benefit surrounding tenants in terms of electricity provision. Furthermore, by using municipal voting results on the Swiss Energy Act 2017 and the Swiss CO_2 Act in 2021, we show how stated preferences for sustainability are driving the external effects of PV systems on rents. We document a similar causal pathway for lived preferences measured by the number and change in electric vehicles in Swiss municipalities.

JEL Classification: Q40, R11, R32.
Keywords: Photovoltaic Systems; Renewable Energy Infrastructure; Residential Real Estate; Rents; View Modeling.

Table A.1: Summary Statistics

This table shows descriptive statistics for the dataset on Swiss residential rents. The mean, standard deviation (S.D.), minimum, and maximum values are listed. Residential rents in this table are asking prices from online real estate listings, comprising 621,010 observations. Furthermore, each observation can be precisely located in Switzerland.

	Mean	S.D.	Min	Max
Rent (CHF/m^2/month)	21.266	6.145	9.00	45.70
log(Rent)	3.019	0.271	2.197	3.822
Dwelling type (dummies)				
Unspecified type	0.001	0.033	0	1
Single-family house	0.001	0.027	0	1
Detached house	0.019	0.183	0	1
Semi-detached house	0.003	0.050	0	1
Townhouse (corner)	0.001	0.032	0	1
Townhouse (single-family)	0.004	0.062	0	1
Apartment	0.842	0.364	0	1
Attic	0.028	0.165	0	1
Maisonette	0.043	0.204	0	1
Loft	0.012	0.109	0	1
Penthouse	0.040	0.196	0	1
Studio	0.006	0.078	0	1
Dwelling characteristics				
Living space (m^2)	80.327	34.379	6	663
log(living space)	4.294	0.442	1.792	6.497
First use (dummy)	0.087	0.282	0	1
Scenic view (dummy)	0.281	0.449	0	1
Internal PV system	0.009	0.094	0	1
Rooms (dummies)				
Unknown	0.019	0.138	0	1
1	0.111	0.314	0	1
2	0.223	0.416	0	1
3	0.347	0.476	0	1
4	0.227	0.419	0	1
5	0.057	0.231	0	1
6	0.012	0.108	0	1
7 and more	0.005	0.070	0	1
Years (dummies)				
2004	0.028	0.164	0	1
2005	0.044	0.205	0	1
2006	0.051	0.221	0	1
2007	0.057	0.231	0	1
2008	0.055	0.228	0	1
2009	0.058	0.233	0	1
2010	0.059	0.236	0	1
2011	0.056	0.230	0	1
2012	0.063	0.243	0	1
2013	0.055	0.227	0	1
2014	0.059	0.236	0	1
2015	0.056	0.229	0	1
2016	0.060	0.238	0	1
2017	0.064	0.245	0	1
2018	0.058	0.233	0	1
2019	0.058	0.235	0	1
2020	0.063	0.243	0	1
2021	0.058	0.233	0	1

Table A.2: Biennial ATET by Cohort

This table lists the biennial ATET from the staggered difference-in-differences regression to capture the external effects of PV systems on residential rents by cohort. View at a PV system is defined as impaired and unimpaired view (baseline). Never-treated observations serve as the control group. The number of observations amounts to 621,010. Cluster-robust standard errors (at the building level) are reported in parenthesis. **, and * denote statistical significance at the 5 %, and 10 % level.

	Residential Rents	
Cohort: 2006-07		
2006-07	0.004	(0.005)
2008-09	0.008	(0.006)
2010-11	0.001	(0.006)
2012-13	0.003	(0.007)
2014-15	0.007	(0.008)
2016-17	0.005	(0.008)
2018-19	0.002	(0.009)
2020-21	0.007	(0.010)
Cohort: 2008-09		
2008-09	-0.005*	(0.003)
2010-11	-0.012**	(0.003)
2012-13	-0.019**	(0.004)
2014-15	-0.019**	(0.005)
2016-17	-0.017**	(0.005)
2018-19	-0.004	(0.006)
2020-21	-0.004	(0.009)
Cohort: 2010-11		
2010-11	-0.003	(0.003)
2012-13	-0.007	(0.004)
2014-15	-0.007	(0.004)
2016-17	-0.005	(0.005)
2018-19	0.002	(0.005)
2020-21	0.012	(0.007)
Cohort: 2012-13		
2012-13	-0.007*	(0.003)
2014-15	-0.010**	(0.004)
2016-17	-0.008	(0.004)
2018-19	-0.005	(0.005)
2020-21	0.003	(0.007)
Cohort: 2014-15		
2014-15	-0.012**	(0.004)
2016-17	-0.003	(0.005)
2018-19	-0.006	(0.006)
2020-21	-0.002	(0.007)
Cohort: 2016-17		
2016-17	-0.009*	(0.004)
2018-19	-0.005	(0.007)
2020-21	-0.006	(0.008)
Cohort: 2018-19		
2018-19	-0.001	(0.007)
2020-21	0.015	(0.011)
Cohort: 2020-21		
2020-21	0.005	(0.010)