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Emerging inequality in solar panel access among Australian renters

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ABSTRACT

This paper analyses progress for the adoption of solar panels, a key technology which is forecast to play a leading role in pursuit of societal sustainability goals. We assess the social change of emerging inequality for whether renters have solar panels at their dwelling. Our analysis uses four large household surveys covering the period of 2012–2020 in Australia, the leading country in the world in terms of solar photovoltaic capacity per capita. Inequality in solar-panel access among renters was hard to detect in 2012, as very few renters had access. This started to change by 2015–16 with the emergence of inequality, with the wealthiest quintile being more likely to have solar-panel access than the lowest quintile by over two percentage points. The gap had increased to 4.5 percentage points by 2019–20. It is therefore possible to forecast inequitable access to solar panels unless policies change to focus on differences *among* renters. Policies supporting the lowest wealth-quintile of renters would address inequality more effectively than other approaches.

1. Introduction

Solar photovoltaic (PV) panels are a key technology that is forecast to make a substantial contribution to sustainable energy transitions at a global scale (International Energy Agency, 2021). In addition to climate change mitigation, there are strong social elements to this technological transition. Households with solar panels generally experience lower electricity bills and are less subject to energy stress or poverty (Best and Sinha, 2021). However, renters are a key social group who are often excluded from prior research. There is a major unrealized opportunity related to the low uptake of solar panels for rental residential properties (Zander, 2020). We seek to make a unique contribution by analysing the *change* in inequality *among* renters. Understanding this *change* can motivate new policies, and enhancement of the very small number of existing policies targeting rental properties.

Research on solar-panel access for renters has wide relevance for multiple reasons, motivating studies for many countries. A key reason for relevance is the strong growth in solar-panel uptake in many countries (International Energy Agency, 2022). Studies of countries with large populations, such as the United States and India, are particularly useful given that they are directly relevant for many people in these countries (Dong et al., 2017; Irfan et al., 2021; Kurdgelashvili et al., 2019). Another key country is Australia, which is the world leader in solar PV capacity per capita by a considerable margin (International Energy Agency, 2022).

There is major policy relevance of research on solar-panel uptake. Many countries have introduced policies to support solar-panel uptake as an important way to respond to global warming risks, although there are major challenges to avoiding poor design of these policies (Bunea et al., 2020). Despite widespread policy attention for solar panels in general, rental properties are often ignored or explicitly excluded (Australian Government, 2021). An exception is the Australian state of Victoria, where a rebate and loan scheme supporting rental properties was introduced in the second half of 2019 and expanded in 2020 (Victorian Government, 2020). Equity is an important consideration of this policy, as the support is restricted based on economic criteria. The combined household income of the renters must be below A$180,000/year, thereby excluding high-income renters. Eligibility for the scheme also requires that the dwelling must be valued below A$3 million, which excludes some wealthy landlords. However, wealthy landlords who own a portfolio of many properties could qualify if any of their properties fall below the A$3 million threshold. Further analysis is therefore warranted to promote targeted policy enhancements.

This paper provides the first study on the *change* in inequality for solar-panel access by renters, as far as we are aware. This builds on the minority of solar-panel uptake studies which include any consideration of renters, and the even smaller proportion of studies that consider differences *among* renters. Greater understanding of *changes* in solar-

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panel access for renters is important to support policy enhancements for this large and sometimes disadvantaged social group.

We seek to address four main research questions to enhance understanding of solar-panel access for renters:

- Which socio-economic variables are most relevant for assessing inequality in solar-panel access for renters?
- How has inequality changed for solar-panel access by Australian renters?
- How can policies be changed to address forecasts of adverse social changes, such as unequal solar-panel access among renters?
- Is there social inequality such that solar-panel access varies across age or the type of relationship with landlords?

Section 2 discusses the literature on which our study is built. The theoretical foundations are then concisely described in Section 3. The Research methodology description in Section 4 then justifies the approaches used, which include repeated cross-sectional regressions and a pooled approach that appends the four surveys. The data are also described as covering renting households in four large Australian household surveys. Emerging inequality is shown through the results in Section 5. Low-wealth renters suffer from substantial and growing disadvantage. Other socio-economic measures are less effective in identifying inequality. We discuss specific contributions and implications in Section 6. The final section then concludes with some avenues for future research.

2. Literature review

The link between socio-economic aspects and technological diffusion is complex and important. Over the long term, there is evidence that technological diffusion can improve equality, particularly through digital technologies (Skare and Porada-Rochón, 2022). There also appears to be evidence that technology for energy efficiency may help alleviate income inequality (Dong et al., 2022). In the other direction, socio-economic drivers have also been considered for uptake of a range of technologies. For example, there are many studies investigating determinants of mobile phone technology uptake, although prior results are mixed (Aparo et al., 2022). While inequality has fallen as cumulative adoption has increased for numerous technologies in countries such as the United States (O'Shaughnessy, 2021), this does not necessarily hold for all technologies in the innovation landscape.

Prior literature on solar-panel uptake which distinguishes between owned and rented properties has sometimes considered a hypothetical context. These studies of intentions can be useful for forecasting, given the forward-looking nature of stated intentions. Some examples include a study for Iran which notes that tenants have less motivation to install solar PV systems (Bashiri and Alizadeh, 2018). There is also a negative relationship between renting and installation intentions in Australia (Zander, 2021). Other avenues to build on these insights include analysis of actual uptake and consideration of differences among renters, as opposed to comparing renters and owners.

Studies which consider renters in the context of actual solar-panel uptake very commonly consider income and education (Alipour et al., 2020), but rarely consider wealth. Studies of developing countries tend to find positive influences of income and sometimes education on solar-panel uptake (Lay et al., 2013; Smith and Urpelainen, 2014), while corresponding results for developed countries are mixed (Balta-Ozkan et al., 2015; de Groote and Verboven, 2019; Fleiß et al., 2017; Graziano and Gillingham, 2015; Hughes and Podolefsky, 2015; Liang et al., 2020; Niamir et al., 2020; Schaffer and Brun, 2015). In cases where studies do consider wealth or capital variables, they tend to find positive impacts of wealth on solar-panel uptake (Araújo et al., 2019; Kurata et al., 2018). An extension is to consider wealth differences among renters.

One study considering wealth differences among renters, and how that influences solar-panel access, is an Australian study finding that greater wealth of renters promotes greater access to solar panels (Best, 2022a). While the relationship between wealth and solar-panel access is less direct than in the homeowner context, since renters rarely pay for solar panels, there is still an intuitive mechanism. Renters with more wealth have a greater capacity to access better rental properties, including those with additional attributes such as solar panels. An important extension to this research is the consideration of the *change* in the relationship between wealth and renter access to solar panels. If there is widening inequality between solar-panel access for low and high-wealth renters, then policy to address this social change would be more urgent.

3. Theoretical background

Socio-economic inequality is perhaps more likely to be apparent for solar panels owing to the high upfront cost, relative to some other cheaper technologies such as mobile phones. Social issues are therefore particularly important in understanding the diffusion and adoption of technological innovation like solar panels. This is evident in a key study that provides an expansive consideration of social aspects through integrating three psychosocial (behavioral) frameworks for solar-panel uptake (Wolske et al., 2017). These frameworks are diffusion of innovations theory, theory of planned behavior, and value-belief-norm theory. Some important social aspects for solar-panel uptake include the number of occupants and their ages (Best, 2022a), as these factors are linked to long-term decisions, such as solar-panel investment. In addition, we specifically focus on the renting context, where split incentive issues – another behavioral dimension – will be important.

Separate analysis of renters is necessary because they face additional challenges, such as the landlord-tenant split incentive problem. Split incentive issues exist when there is a split between those responsible for paying energy bills and those responsible for capital investment decisions. Split incentives have primarily been discussed in the context of impediments for energy efficient investments for renters (Gillingham et al., 2012), but a range of other energy contexts are relevant (Jaffe and Stavins, 1994).

In relation to the split incentive issue in solar installations, landlords would generally bear the upfront cost of installing the solar panels, but renters would most directly benefit with lower energy bills. The implication is that landlords may be unwilling to pay for solar panels to benefit renters, if the cost of their investment is greater than the perceived return. On the other hand, renters may be willing to pay for solar panels if the upfront cost is less than their total electricity savings over the time of their tenancy. As such, renters may not have an incentive to contribute to solar panel purchase if they only have short tenancy agreements, as is common in Australia. Furthermore, even if renters want to pay for solar-panel installation, they are generally not able to make major modifications to the residence without landlord approval. These factors make it harder for renters to access solar panels.

4. Research methodology

4.1. Method

We start with separate cross-sectional regressions for each of the surveys. Cross-sectional variation is crucial for our analysis of inequality, as we are analysing how solar-panel access differs *across* economic distributions. Household surveys are ideal for assessing inequality, as opposed to area-level data, given that household-level data explicitly links economic resources and solar outcomes for individual households. We also progress to assess *changes* over time with a pooled approach that combines the four surveys and adds extra variables such as a survey-year categorical variable. The initial cross-sectional approach is given in Eq. (1):

$$S_h = c + \delta E_h + \theta O_h + \varepsilon_h \tag{1}$$

The dependent variable (S) has a binary form with a value of one for renting households whose dwelling has solar panels and zero otherwise. Economic variables related to inequality are summarized by E for each of the h households. Control variables are included in the O vector. A constant (c) and error term (ε) are also included for a linear probability model. We also produce robustness tests using probit and logit models to account for the dichotomous nature of the dependent variable. However, results are similar including for the marginal effect magnitudes, so we retain the more convenient approach of the linear probability model.

The pooled analysis includes the additional variable for the survey year (Y), as in Eq. (2):

$$S_h = c + \delta E_h + \lambda Y_h + \psi(E_h \bullet Y_h) + \theta O_h + \varepsilon_h \tag{2}$$

This factor variable indicates which of the four years each household was surveyed in. Further, there is an interaction between the survey-year and an economic variable (E). For example, an interaction between the binary wealth-quintile 1 and the categorical survey-year variable effectively gives four categories (one for each survey year) plus a fifth category of households who are not in wealth-quintile 1. This allows for the assessment of the *change* over time for wealth-quintile 1, relative to the wealth-quintile-1 households in a reference year. We also extend this approach to other variables related to inequality. These include other binary variables for wealth quintiles, income-quintile 1, university education of the respondent, receipt of welfare benefits by someone in the household, the youngest third of households based on age of the respondent, and a variable identifying the type of landlord such as renters who deal with a real estate agent.

4.2. Data

The paper considers four large Australian household surveys from the Australian Bureau of Statistics (ABS). These are the 2012 Household Energy Consumption (HEC) survey and three different samples from the Survey of Income and Housing (SIH) for 2015–16, 2017–18, and 2019–20. Households who do not identify as renting are then excluded. This gives four independent samples of renters: 3558 from the 2012 survey, 5223 from 2015–16, 4297 from 2017–18, and 4583 from 2019–20. When combining these four independent samples, the total is 17,661 renting households (ABS, 2013, 2017, 2019, 2022).

The common sampling approach across the surveys helps to justify appending the four surveys for some of the analysis. The households were selected by using a stratified multistage cluster approach based on a master sample of private dwellings covering about 97 % of people in Australia. Both urban and rural areas are covered but very remote areas are not included (ABS, 2022). The characteristics of households in the survey have good alignment with general population characteristics, including for key variables such as income and wealth (ABS, 2022). We also use probability weights in robustness tests, as the ABS provides different weights for households depending on how many other households they represent. These weights are not used in the main analysis given that we include many control variables and probability weights are known to have downsides in a regression context, such as through increasing standard errors (Platt and Harper, 2013).

Another feature of the surveys which allows for appending the four surveys is the similarity in variables. In most cases, the variables are identical. One minor difference is a variable which identifies households as in a State/Territory capital city or another area. In the 2012 survey, the split is between the “capital city” and the “balance of State”. In the other surveys, the split is between the “greater capital city area” and the “rest of State”. While the wording is slightly different, these definitions give similar classifications, for this control variable which is not the focus of the investigation.

A focal point of the subsequent analysis will be the *change* in solar-panel access over time and across economic distributions. An initial view of these relationships is evident with Fig. 1 and Fig. 2. Wealth quintiles are used in Fig. 1 to show that solar-panel access generally increases as the wealth of the renting household increases. However, there is some minor variation in this pattern for three surveys. For example, the 2017–18 survey has renters in wealth quintile 5 (the highest wealth) being slightly less likely to have access to solar panels than wealth quintile 4. There is also an appearance of change across the surveys. The proportions are lowest for the earliest survey (2012). There is a clear increase for the next survey in 2015–16. While the 2019–20 survey has the highest average proportions, the 2017–18 survey does not precisely follow the increasing trend, as average uptake is not clearly above the 2015–16 levels. These types of minor deviations from the general trend are reasonable based on solar-panel uptake having been relatively low for renters.

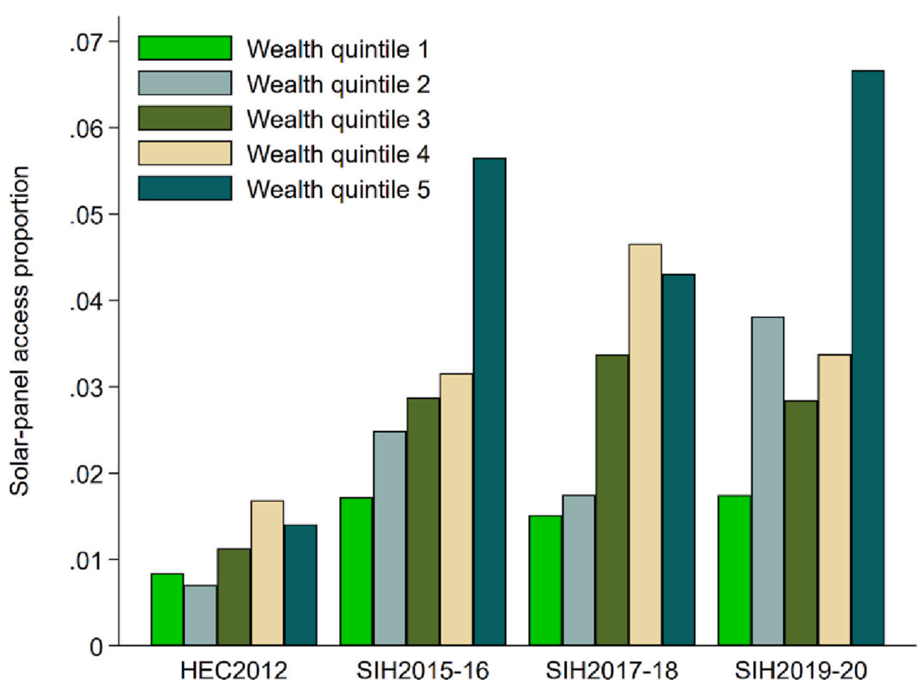

Fig. 1. Solar panel-access proportion for renters in each of four surveys, with separate proportions for each wealth quintile. Data: ABS (2013, 2017, 2019, 2022).

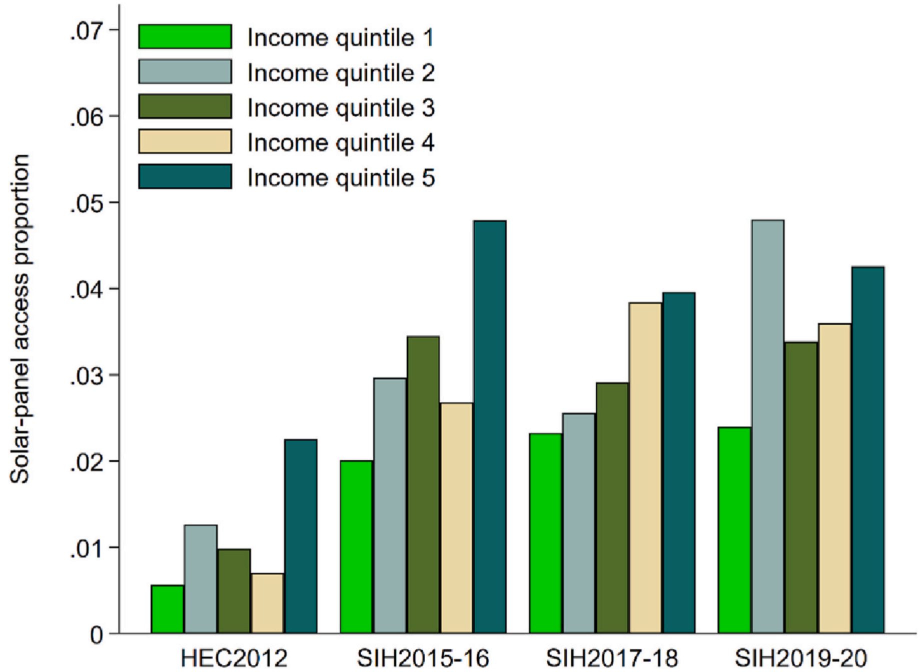

Fig. 2. Solar panel-access proportion for renters in each of four surveys, with separate proportions for each disposable income quintile. Data: ABS (2013, 2017, 2019, 2022).

Fig. 2 presents a similar picture except it uses income quintiles instead of wealth quintiles. The key conceptual difference between income and wealth is that income is a flow variable and wealth is a stock variable. In other words, income is an amount for a single time period such as a year, while wealth reflects the net accumulation of all prior inflows and outflows. There is a common theme of solar-panel access generally increasing as economic resources increase from quintile 1 to 5, but with a few exceptions. An important difference between the two figures is that Fig. 2 reveals less inequality, as the bars cover a smaller vertical range. For instance, the income quintiles in Fig. 2 have between 2 % and 5 % of renters having solar-panel access for the 2019–20 survey. In contrast, Fig. 1 with wealth quintiles has the first quintile with less than 2 % and the highest quintile as close to 7 % for the corresponding survey.

5. Results

Table 1 shows regression results for each of the four surveys. In each case, there was no evidence of a difference in solar-panel access between renters who receive welfare payments and those who do not. However, there are changes over time for other aspects related to inequality, especially for wealth.

There is an absence of evidence of inequality in solar-panel access from the 2012 survey with respect to wealth, as none of the quintiles are statistically different to the highest-wealth quintile. Starting from the second survey from 2015–16, inequality emerges such that renters in lower-wealth quintiles are less likely to have access to solar panels. The magnitude of the gap is around 2.5 percentage points for each quintile, relative to the reference of the highest-wealth quintile. There are also some corresponding negative coefficients for 2017–18, although these are closer to zero and less significant. The most recent survey from 2019–20 has stronger evidence with larger impacts which are more statistically significant. For example, the lowest-wealth quintile has solar-panel access which is 4.5 percentage points lower than the reference case of the highest-wealth quintile, with significance at the 1 % level.

Evidence of inequality in solar-panel uptake based on renter income is minor and mixed. The 2012 survey does have lower solar-panel access

Table 1
Linear probability model results explaining solar-panel uptake for each survey.

	2012	2015–16	2017–18	2019–20
Welfare recipient	−0.000	−0.001	−0.001	0.002
	(0.005)	(0.007)	(0.008)	(0.008)
Ref: Quintile 5				
Wealth quintile 1	0.006	−0.024**	−0.015	−0.045***
	(0.007)	(0.010)	(0.010)	(0.012)
Wealth quintile 2	0.001	−0.024**	−0.017*	−0.025**
	(0.006)	(0.010)	(0.010)	(0.012)
Wealth quintile 3	0.004	−0.024**	−0.006	−0.039***
	(0.006)	(0.010)	(0.010)	(0.011)
Wealth quintile 4	0.006	−0.026***	0.006	−0.034***
	(0.007)	(0.009)	(0.010)	(0.010)
Ref: Quintile 5				
Income quintile 1	−0.012	0.009	0.011	0.005
	(0.009)	(0.011)	(0.013)	(0.013)
Income quintile 2	−0.010	0.006	−0.000	0.019*
	(0.007)	(0.010)	(0.010)	(0.011)
Income quintile 3	−0.013*	0.005	−0.003	0.004
	(0.008)	(0.009)	(0.010)	(0.009)
Income quintile 4	−0.017**	−0.013	0.002	0.002
	(0.007)	(0.008)	(0.010)	(0.009)
University	0.012**	0.006	−0.006	0.000
	(0.005)	(0.006)	(0.006)	(0.007)
Controls	Yes	Yes	Yes	Yes
Observations	3558	5223	4297	4583
Adjusted R^2	0.021	0.027	0.027	0.026

Notes: Controls include (i) dwelling and occupant variables: dwelling structure, number of bedrooms, landlord type, number of people, respondent age terciles; (ii) location variables: state/territory of usual residence, capital city status.
* Shows statistical significance at the 10 % level.
** Shows statistical significance at the 5 % level.
*** Shows statistical significance at the 1 % level.

for some income quintiles relative to the highest-income quintile, although statistical significance only exists in two cases. Most of the other income coefficients across the surveys are insignificant, and one is even positive and significant in the 2019–20 survey, although only at the 10 % level. These results suggest that inequality in solar-panel access based on renter income has not been substantial and there is no clear evidence of change, in contrast to the wealth coefficients. This is important, given that the policy in Victoria is designed based on an income threshold for renters.

A binary variable for university education has a positive and significant impact for the 2012 survey, all else equal, but not for other years. This may suggest that greater education was a driver of solar-panel access in the early years when knowledge of solar-panel benefits was perhaps more concentrated. Given the widespread uptake of solar panels (predominantly for owned homes) and the frequent advertising for solar panels, education or knowledge may be less important in more recent years. The benefits of solar panels are now well known in Australia, with provision of simple information on the cost-savings or payback period on many government websites. The changed outcome for university education in Table 1 may provide one possible explanation for the mixed results of education's impact in prior studies, of a lessening impact as information becomes more readily available. The mixed results for the broader context including homeowners, where only some studies find a significant education influence, are summarized in numerous places such as prior literature reviews (Alipour et al., 2020).

Many control variables are also included for the regressions in Table 1 but are not shown to focus primarily on variables related to inequality and to save space. These other variables have intuitive coefficients that match some prior studies. This includes positive and significant coefficients when the landlord has a familial relationship with the renter, compared to the reference case of a real estate agent being involved with the landlord relationship (Best, 2022a). Larger rented dwellings, based on having more bedrooms, are also more likely to have solar panels. Attached and semi-detached dwellings are less likely to have solar panels than detached dwellings. There are positive coefficients for the number of people in the household, consistent with larger family size being a driver of solar uptake (Irfan et al., 2021), although the coefficients are not significant in the Australian rental context. The additional coefficients can be viewed with the available Stata code.

Other regression metrics are reasonable given the context and are comparable to prior literature. For instance, the low values for the *R*-squared are similar to other large household-level studies, which tend to have much lower values than for aggregated studies. Examples for the United States include an *R*-squared value of 0.06 for a study controlling for homeownership (Mildenberger et al., 2019) and 0.03 for a renter sample (Best, 2022b). *R*-squared values tend to be lower for renter-only or owner-only samples given that they avoid explaining the owner-renter gap in solar-panel uptake. Another metric is the variance inflation factor, which averages below two for each column in Table 1, suggesting that multicollinearity is not a problem.

A range of robustness results support the main findings. Probit and logit models both support the story that solar-access inequality has emerged and expanded with respect to wealth but not income. The marginal effects from these models give some similar magnitudes to the main results using linear probability models. Results with probability weights also support the main findings. Positive education impacts are evident with each of the robustness tests for the 2012 survey, with insignificant coefficients for other surveys, as is the case for the main results. Another robustness test is dropping households from Victoria from the sample, since policy support from late 2019 could theoretically have influenced the results in the last survey. However, results are similar with this slightly smaller sample. This could be anticipated since the policy support has led to very few solar installations for rental properties (Woods, 2021).

Table 2 has results with a pooled sample where the four surveys are combined in a single sample. An additional categorical variable to identify the survey year is included. In addition, this survey-year variable is linked to one of the wealth-quintile categories to assess inequality changes over time. In particular, the wealth-quintile one (WQ1) variable is linked with the survey-year variable to give a categorical variable with five levels. The reference level is households in wealth-quintile one in the 2019–20 survey. Changes over time for wealth-quintile one can then be assessed with coefficients for each of the other three survey years. The final level is households who are not in wealth quintile one. Column (1) shows that these households in other wealth quintiles were more likely to have solar-panel access, based on a regression without control variables.

Table 2
Linear probability model results explaining solar-panel uptake for the pooled sample.*

	(1)	(2)	(3)	(4)	(5)
Ref: WQ1&19–20					
WQ1&2012	−0.009	0.020***	0.020***	0.022***	0.023***
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
WQ1&2015–16	−0.000	0.006	0.006	0.009	0.009
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
WQ1&2017–18	−0.002	0.004	0.004	0.004	0.004
	(0.006)	(0.008)	(0.008)	(0.007)	(0.007)
Not in WQ1	0.015***	0.024***	0.020***	0.012**	0.012**
	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)
Ref: 2012					
2015–16		0.023***	0.023***	0.024***	0.024***
		(0.004)	(0.004)	(0.004)	(0.004)
2017–18		0.023***	0.023***	0.024***	0.024***
		(0.004)	(0.004)	(0.004)	(0.004)
2019–20		0.029***	0.029***	0.034***	0.034***
		(0.004)	(0.004)	(0.004)	(0.004)
Controls	No	No	Yes	Yes	Yes
Observations	17,661	17,661	17,661	17,661	17,661
Adjusted R^2	0.002	0.005	0.005	0.023	0.025

Notes: WQ1 is wealth quintile one. Column (3) has economic controls: the inverse hyperbolic sine transformation of wealth and of income, along with a binary variable for receipt of welfare benefits. Column (4) also has the dwelling and occupant controls (matching Table 1). Column (5) also has the location controls (matching Table 1).
* Shows statistical significance at the 10 % level.
** Shows statistical significance at the 5 % level.
*** Shows statistical significance at the 1 % level.

Column (2) of Table 2 controls for the survey year, and shows seven coefficients, consistent with an interaction approach. There are positive and significant coefficients for each survey-year variable, relative to the reference year of 2012, indicating the increase in solar-panel access over time. The interpretation of the combined wealth-year variables now changes in column (2), given the inclusion of the survey-year variables. The wealth-year variables now show the difference between the change in solar-panel access for wealth-quintile one and the change for the other quintiles. For example, there was a change in solar-panel access by 2.9 percentage points between 2012 and 2019–20 for households *not* in wealth-quintile one. For wealth-quintile one it was 0.9 percentage points. The difference of two percentage points is the coefficient for WQ1&2012 in column (2). This shows a widening of inequality since solar-panel access for wealth-quintile one grew more slowly than the other quintiles which have higher access.

Columns (3) to (5) show that the inequality findings are robust to the inclusion of numerous control variables. This includes economic controls in column (3), dwelling and occupant controls in column (4), and location controls in column (5). The column (5) coefficient magnitude of 2.3 percentage points for wealth-quintile one in 2012 is similar to previous columns. It shows that wealth quintile one was in a more favourable (relative) position in 2012, compared to the reference of 2019–20, when controlling for many other variables. This again suggests that inequality has expanded between 2012 and 2019–20.

Table 3 gives results that focus on each of the five wealth quintiles. The reference variable in this case is wealth-quintile x in 2012, where x stands for each of the five quintiles, one at a time. The first column shows that renters in wealth quintile one (i.e. $x = 1$) were in a better relative position in 2012, compared to subsequent years where there were negative and significant coefficients. A key point with the interpretation is that this is a conditional association while including the

Table 3
LPM results explaining solar-panel uptake; pooled sample; five quintiles displayed.

	$x = 1$	$x = 2$	$x = 3$	$x = 4$	$x = 5$
Ref: WQx&2012					
WQ*x*&2015–16	−0.014**	−0.003	−0.003	−0.008	0.028***
	(0.006)	(0.007)	(0.007)	(0.008)	(0.009)
WQ*x*&2017–18	−0.019***	−0.011*	0.003	0.015*	0.012
	(0.007)	(0.007)	(0.008)	(0.009)	(0.009)
WQ*x*&2019–20	−0.023***	0.010	−0.010	−0.010	0.033***
	(0.007)	(0.008)	(0.008)	(0.008)	(0.010)
Controls	Yes	Yes	Yes	Yes	Yes
Observations	17,661	17,661	17,661	17,661	17,661
Adjusted R^2	0.025	0.025	0.025	0.026	0.027

Notes: WQ*x* is wealth quintile *x*, where *x* varies across the five columns. LPM is linear probability model. The full control set is used, including the survey wave variable, as in Table 2-column (5).
* Shows statistical significance at the 10 % level.
** Shows statistical significance at the 5 % level.
*** Shows statistical significance at the 1 % level.

survey-year variables (as specified in the notes on the controls under Table 3). As an example, wealth-quintile one had an increase in solar-panel access by 0.7 percentage points from 2012 to 2017–18. This was lower than the increase of 2.3 percentage points over the same period for the other quintiles. This is a difference of 1.6 percentage points. The regression coefficient changes slightly to 1.9 percentage points in Table 3 due to the inclusion of other control variables. There are also positive and significant coefficients for the highest-wealth quintile (5). This suggests that higher-wealth renters have experienced improved access to solar panels since 2012 to a greater extent than other wealth quintiles. Most of the other coefficients are insignificant when viewing the other columns.

Table 4 compares different variables for their ability to identify inequality. The coefficients are from a single regression in Table 4, in contrast to earlier tables where separate columns are used for separate regressions. The widening inequality based on wealth is shown in the first column for wealth quintile one. The negative coefficients show that wealth-quintile one, which generally has the lowest access, experienced lower increases compared to other quintiles following 2012. There are also negative coefficients for income quintile one, although only one is significant at the 10 % level. This coefficient gives some evidence that low income (being in income quintile one) is associated with less growth in solar-panel access compared to other income quintiles over the 2012 to 2019–20 period.

There is also some evidence of changes in influences of other related variables. The negative coefficients in the column for education with the binary university variable shows that university education has become less important over time. This is consistent with the results in Table 1, where the positive influence of education in 2012 disappeared for the subsequent surveys. Most of the coefficients are insignificant in the final three columns, although there is some evidence of changes for renters in age tercile one and who have a real estate agent as the landlord. In both cases, the average change in solar-panel access for these households was less than for others. These results suggest that the gap between solar-panel access for households with a young respondent (tercile one) and other households has become greater from 2012 to 2019–20. Likewise, the gap from lower solar-panel uptake for renters dealing with a real estate agent has become more pronounced relative to renters with other arrangements.

6. Discussion

6.1. Summary

In this novel study on the change in inequality of solar-panel access for renters, we find that inequality has emerged and is widening over time. This change in inequality is most pronounced when focusing on the net wealth distribution. Equitable policy approaches could therefore focus on net wealth rather than other socio-economic aspects such as income, education, welfare receipt, age, or social relations with landlords.

The stronger link between wealth and solar-panel access, rather than between income and solar-panel access, may be explained with reference to inequality and indirectly through payment mechanisms. The greater inequality in the wealth distribution, compared to the income distribution, allows for more precise identification of disadvantaged households who are less likely to be able to access solar panels. Wealthier renters might be more likely to match with wealthier landlords, particularly where there are social connections. This is potentially important, as landlords looking to invest in solar panels would either require savings or upfront finance, which is more likely through leveraging other existing assets. Current income for short time periods (without accumulated wealth) may be insufficient without savings or a demonstrated ability to save. The stronger general impact on solar-panel uptake from wealth, rather than income (Best and Chareunsy, 2022), may therefore indirectly apply to the rental context.

The results showed that inequality in solar-panel access for Australian renters emerged after 2012. This inequality is evident and robust when focusing on the net wealth of households, but not other variables such as the receipt of welfare benefits, which is also a form of income flow. We also found that the importance of education for promoting solar-panel access was only a temporary phenomenon. Widespread information and knowledge may mean that most people have been aware of the benefits of solar panels in recent years, possibly leading to no detectable difference in motivation for solar-panel access between education groups, when controlling for other variables.

Table 4
A single regression explaining solar-panel uptake; pooled sample; other interactions.

	y = WQ1	y = IQ1	y = Uni	y = Welfare	y = AT1	y = REA
Ref: y&2012						
y & 2015–16	−0.012*	−0.012	−0.007	0.001	−0.006	−0.005
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
y & 2017–18	−0.019**	−0.006	−0.017**	−0.000	−0.006	−0.000
	(0.007)	(0.009)	(0.008)	(0.008)	(0.007)	(0.007)
y & 2019–20	−0.023***	−0.016*	−0.014*	−0.001	−0.012*	−0.014*
	(0.008)	(0.009)	(0.008)	(0.008)	(0.007)	(0.008)

Notes: Coefficients from a single regression with 17,661 observations are shown. The adjusted R^2 is 0.020. WQ1 = Net wealth quintile one (household-level); IQ1 = income quintile one (household-level); Uni = University degree (for the respondent); Welfare = Pension or benefit recipient; AT1 = age tercile 1 (for the respondent); REA = real estate agent as landlord. The control set is mostly the same as Table 3 but excludes some variables to avoid repetition with the additional interactions. This means that binary variables for university education and welfare receipt are excluded, as are categorical variables for age and landlord.
* Shows statistical significance at the 10 % level.
** Shows statistical significance at the 5 % level.
*** Shows statistical significance at the 1 % level.

Changes in solar-access inequality, based on renter wealth, are concentrated in the top and bottom quintiles. The lowest-wealth quintile has experienced less growth in solar-panel access since 2012, while the top-wealth decile experienced greater growth. This has led to the widening inequality in solar-panel access for Australian renters. For the middle three quintiles, there is an absence of strong evidence that relative access changes have been different to other quintiles. However, there is a hint that the adverse changes for the lowest wealth quintile may extend to the second quintile. Also, the greater growth at the top may extend into the second-highest wealth quintile.

The comparison of many related variables helps to show that net wealth is a good variable to identify inequality in solar-panel access and its changes. In contrast, other variables generally do not identify growing inequality. However, there is some evidence that solar-panel access growth for younger respondents is slower than for older respondents. Also, some evidence exists that renters dealing with a real estate agent are disadvantaged with respect to solar-panel access, when compared to other renters. This speaks to the power relations between landlords and renters that may be a contributing factor.

6.2. Theoretical contributions

We draw on a diverse set of theoretical aspects which form the foundation for our empirical contribution. We extend consideration of split-incentive issues (Gillingham et al., 2012) into the solar-panel access context. These split-incentive issues are likely to be more impactful when social relations between landlords and renters are lacking (Best, 2022a). This is one of the numerous social aspects that can be important for solar-panel access (Wolske et al., 2017). Another theoretical pillar is the core economic aspect of wealth effects, as higher levels of wealth support additional consumption and investment. Even though landlords are generally responsible for the initial cost of solar-panel installation, there is an indirect wealth effect as wealthier renters have the capacity to match with wealthier landlords (Best, 2022a).

6.3. Theoretical implications

A prominent theoretical implication is that more than one theoretical framework is likely to be necessary. Theoretical frameworks tend to focus on a subset of issues, such as psychosocial theories like the diffusion of innovations theory or value-belief-norm theory, or economic theories like wealth effects. Our analysis highlights the importance for technology diffusion theories to specifically consider social relations related to landlord type. But in addition, our analysis also indicates the importance of theoretical frameworks to incorporate key economic concepts.

6.4. Limitations

A limitation of the study relates to the relatively low uptake of solar panels for rental properties. Even by 2019–20 in the top quintile based on wealth, the proportion of renters with solar-panel access was only 7 %. This motivates further studies on Australia. A further limitation is that results for Australia may not generalize to apply to other countries. However, we assess ubiquitous issues like split-incentive issues and wealth effects which are likely to be evident to varying extents in most contexts. Future studies can quantify the extent of impacts across countries.

6.5. Practical implications

Our research has pronounced policy implications. Other studies focusing on the gap between renters and owners motivate policy attention for renters (Best, 2022a; Zander, 2020). Our contribution is directed toward the design of policies for renters. Our results suggest that policies need to be targeted toward low-wealth renters, to avoid the persistence of inequality in solar-panel access. In particular, we identify the bottom quintile of households based on net wealth as the main group who are experiencing adverse access changes compared to other households. If an exclusionary approach is used by policymakers, then the top quintile of renters based on net wealth could be excluded, since growth for this group has outpaced other households historically. This policy suggestion can be contrasted to an existing approach used by the Victorian Government, where high-income households are excluded. Our results show that inequality based on income had not been substantial.

7. Conclusion

This paper contributes by assessing novel and important research questions for solar-panel access by renters. After assessing a range of socio-economic aspects, we find that net wealth is better for identifying solar-access inequality than other socio-economic variables. Further, there have been substantial changes for inequality relating to net wealth. Our finding of widening inequality motivates attempts to change policy approaches to avoid worsening inequality among renters. This is important as some renters are already disadvantaged, before even considering further disadvantage from lacking access to technological innovations. There is also inequality with respect to social variables like age and social relations with landlords, but there is limited evidence of changes over time with respect to these social aspects.

Future research can build on the strengths and limitations of this study. One beneficial aspect of fundamental importance is the use of actual household-level data. This is well-suited to inequality analysis as it can jointly identify individual households who are renters and their economic resources. Future research can also be extended across many other countries and technologies. The rental sector is a large and growing proportion of households in many countries, motivating greater understanding of the situation with respect to solar panels on rented rooftops. Issues that exist for solar panels will likely share some similarities with technologies such as home batteries and electric vehicles. This expectation is based on the fundamental mechanism of wealth promoting access to energy technologies, since wealthier households can access properties with better attributes.

Future research for many countries could consider the potential impacts of relational aspects which are likely to be relevant for solar-panel access by renters. For instance, if renters have a familial or friendship relationship with their landlord, they may be more likely to achieve access to solar panels. These relations may be a partial substitute for wealth in promoting solar-panel access, especially where landlords have characteristics which correlate with higher solar-panel uptake. Interesting research exists in other contexts such as for the importance of social relations for energy demand or home renovations (Ambrosio-Albala et al., 2020; Bolton et al., 2023; Hargreaves and Middlemiss, 2020). For example, Hargreaves and Middlemiss (2020) provide a typology of relevant social relations which could be used for understanding many household decisions such as energy use, solar-panel uptake, and responses to policy interventions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The code is available. The data need to be obtained from the data provider.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2023.122749.

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