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Wealth effects on household solar uptake: quantifying multiple channels

Rohan Best [a*], Rabindra Nepal [b], Noura Saba [c]

* Corresponding author; email: rohan.best@mq.edu.au.

[a] Department of Economics, Macquarie University, Sydney, Australia

[b] School of Business, Faculty of Business and Law, University of Wollongong, Australia; rnepal@uow.edu.au

[c] Department of Economics, Macquarie University, Australia; noura.saba@mq.edu.au

Abstract

Increased clean energy production from household solar panels is a potentially vital component of a sustainable energy transition and decarbonisation that can reduce carbon dioxide emissions from many countries. This paper investigates multiple channels of wealth effects on household solar-panel uptake. There is evidence of impacts of both financial and non-financial assets on solar-panel uptake, but the evidence for financial assets is much more robust. Compared to the highest-asset quartile, proportional solar-panel uptake is three percentage points lower for the second-highest quartile of households based on financial assets, all else equal. This gap grows to six percentage points for households in the lowest quartile for financial assets. The results are robust across many models using probit, logit and linear probability formats. Knowledge of the relative magnitudes of impacts of wealth channels is important for policymakers who are considering supporting solar-panel uptake, particularly following the COVID-19 pandemic, when efficiency of public spending will be crucial. Our results reveal that means testing for solar policy support should be based on financial-asset thresholds, rather than non-financial assets or income. These are globally important policy lessons in creating a viable climate change adaptation strategy through solar electrification.

Keywords: solar; household; wealth; asset; liability; COVID-19

1. Introduction

A crucial component of cleaner production involves sourcing clean energy, given that emissions from fuel combustion comprise around 80% of human-induced emissions of carbon dioxide globally (IEA, 2017). In addition to the contribution of emissions in raising risks of climate change, there are also extremely adverse effects of air pollution on human health (Coady et al., 2017). There are millions of deaths each year from air pollution (WHO, 2016).

The massive amount of global solar exposure provides an opportunity for cleaner production of energy that could theoretically satisfy global energy demand with less adverse environmental impacts than energy from fossil fuel combustion (Kabir et al., 2018). While only one of many energy types, solar panels have great potential through allowing for the use of the abundant solar input directly into the energy production process. Clean energy transitions are central for sustainability improvements, with solar panels predicted to play a key role in this transition, accounting for over 20% of emission mitigation potential for the energy sector up to 2050 (IRENA, 2019). Small-scale solar photovoltaic (PV) systems are set to take ‘centre stage’ and are expected to double in capacity in the 5 years to 2024 at a global scale (IEA, 2019).

1.1 Capital inputs for clean energy production

Clean energy transitions can face constraints when key capital inputs are lacking in clean production processes. Economic theory focuses on physical capital as one of the main inputs to production but there are also other types of capital that are important. Green intellectual capital is one such input that involves organizations having knowledge of effective approaches for clean production (Yusliza et al., 2020; Yusoff et al., 2019). Financial capital is another crucial component for energy, due to the capital-intensive nature of energy, especially sustainable energy types (Best, 2017). Capital costs are particularly important for solar PV and relate to a range of costs beyond the solar module, such as the cost of cables and mounting (Elshurafa et al., 2018).

1.2 Household solar uptake as a substitute for industrial-scale production

The modern context for energy production has evolved to include households as producers of clean energy when solar panels are installed on residential rooftops. Residential solar PV systems, which can be either off-grid or connected to electricity grids, can be substitutes for industrial-scale production of energy (Akinsipe et al., 2020; Rigo et al., 2019). Distributed energy generation from solar panels avoids the waste of physical losses in electricity distribution from centralised industrial-scale production, potentially adding to the efficiency of the distributed approach in some cases (Pepermans et al., 2005). Socioeconomic factors are contributors to uptake of residential solar panels, which can enhance environmental outcomes by displacing industrial-scale energy generation that can lead to large quantities of carbon dioxide emissions (Jan et al., 2020). While the inputs into household production may differ slightly to industrial-scale contexts, the fundamental importance of capital inputs into clean energy production remains.

1.3 The influence of household wealth

There are several channels through which capital can influence solar panel uptake and the subsequent production of clean energy. Households with accumulated savings may use these resources to purchase solar panels (Petrovich et al., 2019). Having illiquid assets, such as housing assets, could also promote solar panel uptake. This can be explained by demand effects, where households are more likely to spend on consumption and investment when perceiving themselves wealthier (Campbell and Cocco, 2007). There is also a collateral channel, as higher wealth can make loan acquisition more easily achievable (Cooper and

Dynan, 2016). These wealth effects are likely to be more important than income effects, given the relatively high upfront cost of solar panels.

There are some studies of solar intentions that mention that upfront costs and financial aspects of solar panel investment are perhaps the most important determinants (Balcombe et al., 2013; Fleiß et al., 2017; Zander et al., 2019). Studies of the impact of wealth on actual solar uptake could complement hypothetical studies.

Despite the importance of capital constraints and solar uptake more broadly, the large literature on solar panel adoption only includes wealth or capital variables in a small number of cases. Capital variables are not always covered in literature review analysis, reflecting that studies of actual solar uptake often omit these variables (Alipour et al., 2020 (see Figure 9); Müller and Trutnevyte, 2020).

For the small number of studies that include capital, housing values are the most commonly included control variable. Of the vast literature on solar uptake, housing values were used as explanatory variables in only a small number of cases, in contrast to common use of income (Alipour et al., 2020). Recently, there have been increasing numbers of examples of studies that control for housing assets (Kucher et al., 2020; Palm and Lantz, 2020; Schelly and Letzelter, 2020).

Capital variables beyond housing assets are not included in nearly all studies of actual solar uptake. One exception that does consider multiple components of wealth is a study in Ethiopia, which includes some natural capital variables like the number of cattle, and a binary variable for households having savings (Guta, 2018). Accumulated savings have also been considered in a hypothetical context (Petrovich et al., 2019). Overall net wealth has been found to be a key contributor to solar uptake (Best et al., 2019a). Detailed analysis of wealth components could make a major contribution to prior literature, given the lack of prior studies, and the opportunity for influencing policy design.

1.4 Wealth constraints and government spending following the COVID-19 pandemic

Identifying types of constraints on solar panel uptake by households allows governments to address these constraints through policy and subsidy schemes. The most significant barrier is likely to be capital costs (Balcombe et al., 2013). Therefore, wealth constraints are likely to be paramount. Government subsidies would be more efficient if they were directed to households that face more pressing wealth constraints. In contrast, payments to households with substantial wealth are inefficient in the sense that these payments are not required to overcome a wealth constraint.

The efficiency of government spending that promotes cleaner production, such as subsidies for solar panels, will be of greater significance following the onset of the COVID-19 pandemic and related budget pressure. Government revenue is likely to be reduced substantially following the economic contraction (Clemens and Veuger, 2020). This will consequently limit resources for sustainable investments. There could be tendencies to focus on immediate and urgent issues following the pandemic, at the expense of green practices that target longer term sustainability (Amankwah-Amoah, 2020). In the energy sector, support may initially focus on exemptions from paying utility bills in some cases rather than longer-term investments supporting energy infrastructure (McKibbin and Fernando, 2020). Stimulus plans may not focus on the ongoing sustainable transitions in some cases (Gosens and Jotzo, 2020).

There may also be cases where large amounts of money are directed toward investment in rooftop solar panels, as part of economic stimulus packages (Vaka et al., 2020). Employment opportunities in the renewable energy industry are a further benefit of greater uptake of household solar panels, as installation tends to be labour intensive (Muniyoor, 2020). Efficiency of spending is of high importance when spending increases, to avoid wasting public resources that could be directed to other uses.

Government consideration of means testing for household solar subsidies can consider a series of question to pursue efficiency, regardless of whether the issue is a lack of available funds in some countries, or a surge of new funds in stimulus payments in other countries. These questions include:

- Is means testing the preferred alternative?
- If yes, should means testing be based on assets or income?
- If assets, should means testing be based on financial or non-financial assets?
- If financial assets, which component of financial assets is best for means testing?
- What is(are) the appropriate threshold level(s) for subsidy support?

1.5 The relevance of Australia for solar uptake analysis

The current context in Australia includes a range of policies set by national and subnational governments to support household solar-panel uptake. The key national policy is the Small-scale Renewable Energy Scheme (SRES), which effectively provides an upfront capital subsidy without any means testing. Feed-in tariffs at subnational levels were particularly influential prior to 2013, offering large payments per kilowatt hour of electricity delivered by household solar panels back to the grid (Chapman et al., 2016). These policies were not means tested. More recently, subnational governments in Australia have introduced means testing, usually based on an income threshold (Australian Government, 2020). A common income threshold has restricted eligibility to households with income up to A$180,000, which covers approximately 85% of households (ABS, 2019). For the state of Victoria, a threshold of $A3 million for house values has been introduced, although this excludes very few households.

A report by the International Energy Agency (IEA, 2020) reveals that Australia had the highest solar PV capacity per capita, of 644 watts per capita at the end of 2019, followed by Germany (589 W/cap), Japan (500 W/cap), and Belgium (425 W/cap). When focusing only on residential solar PV, Australia's lead is much more pronounced, because of the initial Australian focus on residential over industrial-scale installations. Residential PV penetration rates per household have been more than three-times higher in Australia compared to Germany (IEA, 2016). There has also been a boom in Australian residential uptake in recent years (APVI, 2020). Capacity additions in countries with larger populations are higher in total but much lower as a proportion of the number of households (Qiu et al., 2020).

Australia's world-leading installation of solar-panel systems as a proportion of total households has partly been driven by generous policy support. Future growth is expected to be slower, as policy support is predicted to be wound back. For example, the current SRES assistance has started to taper toward zero in 2030. Despite this policy cessation, projections suggest that solar uptake may triple by 2050 (Australian Energy Market Commission, 2020). With a continuation in the solar-adoption growth trend, instead of a slowing trend, there could be over 40 gigawatts of distributed solar capacity by 2050 rather than around 30 gigawatts (Green Energy Markets, 2020). This outcome would be more likely with cost-effective means testing based on asset thresholds.

Australia may be the ideal country for solar uptake analysis due to the world-leading uptake of small-scale solar panels and the world-class collection of wealth and other data (OECD, 2013a). Australia is also highly ranked for data availability, openness, and format (Open Data Barometer, 2020). Australia's outcomes have major implications for the rest of the world, including developed countries in the short term and developing countries in the medium term. Other countries can learn from Australia's successes and areas for improvement.

1.6 Contributions

We are not aware of any studies that have comprehensively assessed the impact of wealth components on household solar uptake. This would make our goal of quantifying the impact of each wealth component on solar uptake a novel contribution. Key findings are that all three asset components, and total liabilities, have a positive association with solar uptake. Of the asset variables, financial capital categories have a much more robust association with solar uptake than non-financial assets. This is a useful addition to the prior literature, given that most studies omit assets entirely or occasionally control for a non-financial asset type of housing assets. The size of liabilities is also important, as households with higher total liabilities are more likely to adopt solar panels, all else equal.

The empirical analysis in this paper can be crucial for policy improvements that promote sustainable transitions toward further clean energy production. Means testing has great potential to target economic constraints in general (OECD, 2013b) and can readily be applied to solar policies. Currently, means testing for solar policy support is quite limited globally and the types and levels of means testing may not have a strong analytical basis. Our study is therefore relevant for analysts and policymakers in any country, who can consider the potential for more efficient policy support through means testing based on assets in each context.

2. Method and data

This paper focuses on the impacts of wealth components on solar-panel uptake, as indicated by the general format in equation (1).

$$U_h = \alpha + \boldsymbol{P}'_h\boldsymbol{\rho} + \boldsymbol{O}'_h\boldsymbol{\theta} + \boldsymbol{N}'_h\boldsymbol{\nu} + \lambda L_h + \boldsymbol{C}'_h\boldsymbol{\omega} + \varepsilon_h \tag{1}$$

The dependent variable is solar uptake for each of h households. This is a binary variable equal to one for households that have adopted solar panels. To model this dichotomous variable, we focus on probit regressions. In addition, we undertake logit regressions and linear probability models to show that the results are robust across model types. The constant term is α and the error term is ε_h.

Showing results from all three models is useful as each method has its own advantages and it demonstrates robustness. An advantage of the linear probability model is the interpretation of coefficients without the need for additional calculations to produce marginal effects. In contrast, probit and logit models ensure that predicted probabilities are not outside the unit interval. While the coefficients for the models will generally differ, the marginal effects from the probit and logit models will often be similar to each other (Hill et al., 2008). These marginal effects will also often be similar to the linear probability coefficients. This means that the choice between models may not be a major issue in many cases.

The explanatory variables that make this paper unique to prior literature are the $\boldsymbol{P}, \boldsymbol{O}, \boldsymbol{N}$ and L variables in equation (1). $\boldsymbol{P}$ is private pension balances, which is referred to as superannuation accounts in Australia. $\boldsymbol{O}$ is other financial assets. $\boldsymbol{N}$ is non-financial assets, which is predominantly residential housing. L is the total liabilities of households, which is mostly mortgages for homeowners.

The $\boldsymbol{C}$ vector includes control variables that have been analysed in prior studies, such as income, tenure, housing variables, and sociodemographic characteristics of occupants. In particular, the control vector includes the log of disposable income. There are also binary variables for mortgage holders, private renters, public renters, tenure at the same location for over 25 years, apartments, couples without dependents, couples with dependents, and single-parent households. In addition, there are numerical variables for the number of bedrooms, people, employed people, and dependent children, along with a variable for the age of the household respondent. There is also a set of binary location variables which split Australia into 87 Statistical Area Level 4 (SA4) regions, which is useful to control for unobserved heterogeneity at this regional level.

We assess different formats of the key financial variables. We start with the log of these variables. In our first regression in Section 3, we combine ***P*** and ***O*** to give financial assets in total. We then assess quartiles with binary variables. This style of analysis is useful for policymakers who set thresholds for means testing.

All variables are from the Survey of Income and Housing (SIH) which was conducted over 2017 and 2018 by the Australian Bureau of Statistics (ABS, 2019). This survey used a stratified multistage cluster approach that resulted in a large and nationally representative sample of 14,060 Australian households. The mean values for the key variables from the SIH that are used in this study are shown in Table 1.

Table 1. Mean values of key household variables

Variable	Mean
Solar panel uptake, binary	0.17
Private pension balances	218,393.20
Other financial assets	209,898.40
Total financial assets	428,291.60
Non-financial assets	687,593.90
Total liabilities	157,350.90
Disposable income (weekly)	1,661.45
Mortgage, binary	0.35
Private renter, binary	0.27
Public renter, binary	0.04
Long tenure, binary	0.13
Unit/apartment, binary	0.09
Number of bedrooms	3.12
Number of people	2.39
Number of employed people	1.18
Number of dependent children	0.47
Age of respondent	52.57
Couple only, binary	0.25
Couple with dependents, binary	0.24
Single parent, binary	0.06

Notes: There are 14,060 observations. Binary location controls for 87 Statistical Area Level 4 (SA4) regions are available through the code in the Supplementary section.

The value of focusing on wealth instead of income is initially apparent by referring to Figure 1. Solar uptake varies across net-wealth quartiles to a much greater extent than the variation across disposable-income quartiles. For example, the bottom two wealth quartiles have proportional solar uptake that is 12 and 23 percentage points lower than the highest-wealth quartile. In contrast, the corresponding differences for the bottom two disposable-income quartiles, compared to the top quartile, are five and nine percentage points. There is a similar pattern if the sample is restricted to homeowners in a figure that is available through the code in the Supplementary section.

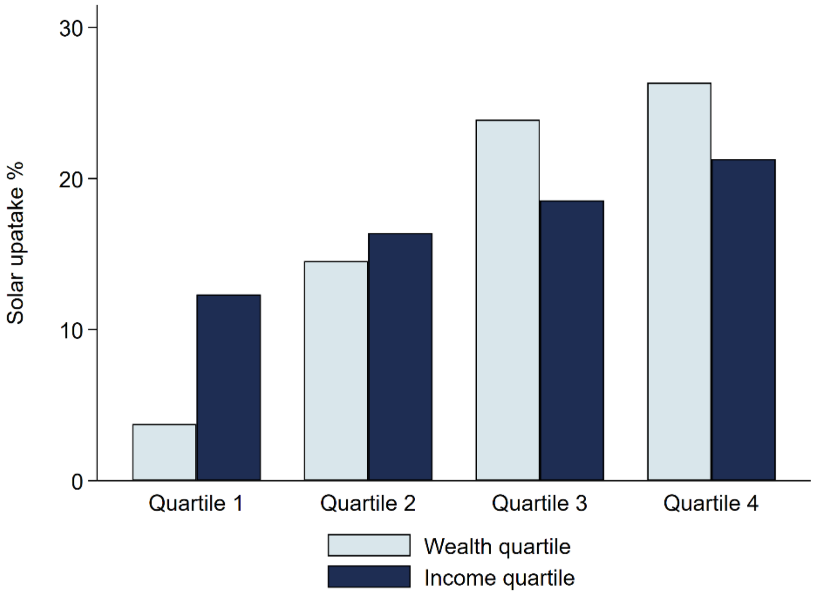

Figure 1. Wealth and income impacts on solar uptake. Quartile 1 is the lowest wealth or income, while quartile 4 is the highest. Source: Based on ABS (2019) data.

Figure 2 gives a more detailed analysis of wealth components. Each of the three asset categories of private pension balances, other financial assets, and non-financial assets show considerable variation in solar uptake across asset quartiles. In each case, the pattern of increasing uptake is evident as wealth increases from quartile 1 to quartile 4. There is major variation between quartile 1 of the non-financial assets and the other quartiles, although caution is suggested at this stage of the analysis, because this may be driven by home ownership differences. We assess this in Section 3 by controlling for housing tenure variables. The two financial asset categories tend to have quite similar solar uptake across quartiles.

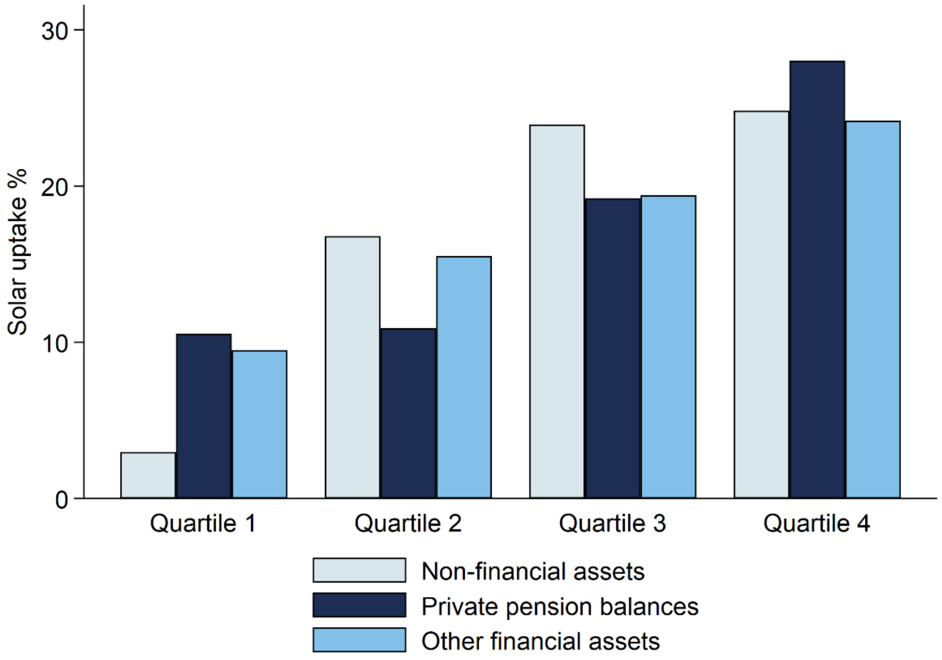

Figure 2. Wealth components and solar uptake. Quartile 1 is the lowest wealth, while quartile 4 is the highest. Source: Based on ABS (2019) data.

There are also differences in solar uptake according to the presence of household liabilities, as shown in Figure 3. Renters and non-renters are shown separately, due to the high influence of mortgage debt that is only relevant for the homeowner category. For both separate groups of renters and non-renters, there is a higher proportion of households having solar panels when they have positive amounts of liabilities, compared to households that do not have liabilities.

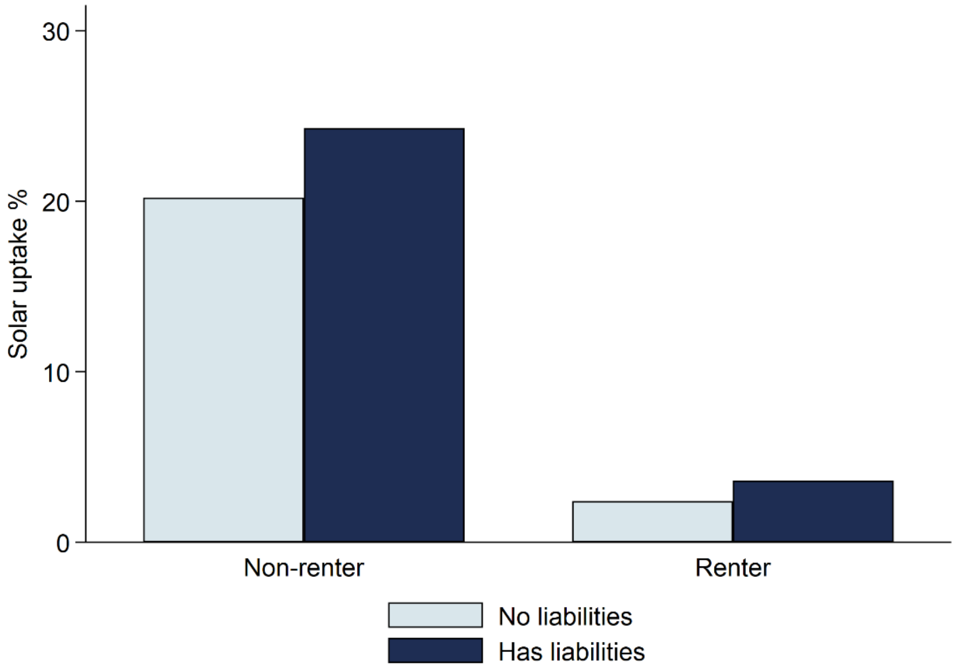

Figure 3. Liabilities and solar uptake, for renters and non-renters. Source: Based on ABS (2019) data.

3. Results

Table 2 has probit coefficients for a concise set of wealth components. There is a positive and significant coefficient for the log of each of the three wealth variables. This includes the log of financial assets, with significance at the 1% level, non-financial assets at the 10% level, and total liabilities at the 5% level. The variable for total liabilities uses the inverse hyperbolic sine transformation so that households with zero liabilities are not dropped.

The results in Table 2 imply that financial assets might be more important than non-financial assets for solar uptake, as the significance of the coefficients suggests a more robust relationship for financial assets. A caveat at this stage of the analysis is that the coefficient magnitudes are very similar. Our subsequent analysis compares financial and non-financial components in more detail. The coefficient for liabilities suggests that households who are more willing and able to take on larger debts are more likely to have solar panels.

In contrast to the significant wealth-component coefficients, there is an insignificant coefficient for log disposable income. This aligns with Figure 1 which shows that there is substantially less variation in solar panel uptake across the income distribution, as compared to the net-wealth distribution.

Control variables for tenure in Table 2 produce plausible coefficients. There are negative and significant coefficients for tenure variables of having a mortgage and renting, compared to the omitted category of homes owned outright. The renting coefficients are more negative than the mortgage coefficient, which would relate to the property rights constraints faced by renters. There is also a negative and significant coefficient for long property tenure for the binary variable for homes owned for more than 25 years. Older homes may be less suitable for solar panels, or householders that have long-established routines may be less likely to make the substantial change of installing solar panels.

There are also reasonable coefficients for variables for housing structure and characteristics of household occupants. The negative coefficient for living in an apartment is significant at the 1% level, as is the positive coefficient for the number of bedrooms. Both variables may pick up some size effects, such that more space available for solar panels may promote solar investments. Apartments also face property rights constraints where roof space is often owned through common property arrangements. The negative coefficient for the number of employed people may suggest that being busy at work, or being away from home more while at work, could contribute to lower solar panel uptake, all else equal. The positive and significant coefficient for age may suggest that older adults are more amenable to long-term investments like solar panels, in comparison to younger adults who may be more likely to move houses. There is a positive coefficient for households that only have a couple and a negative coefficient for single-parent households, although only the couple coefficient is significant. There is also an insignificant coefficient for households with couples with dependents.

Table 2. Probit coefficients, concise capital variables

	Coefficient	Standard error
Log financial assets	0.060***	(0.013)
Log non-financial assets	0.057*	(0.031)
Log total liabilities (IHS)	0.014**	(0.006)
Log disposable income	0.037	(0.027)
Mortgage, binary	-0.103*	(0.062)
Private renter, binary	-0.708***	(0.099)
Public renter, binary	-1.378***	(0.258)
Long tenure, binary	-0.136**	(0.055)
Unit/apartment, binary	-0.801***	(0.203)
Number of bedrooms	0.133***	(0.025)
Number of people	0.074***	(0.028)
Number of employed people	-0.056*	(0.031)
Number of dependent children	-0.040	(0.038)
Age of respondent	0.004**	(0.002)
Couple only, binary	0.139***	(0.045)
Couple with dependents, binary	-0.001	(0.066)
Single parent, binary	-0.056	(0.106)

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. The sample size is 13,763, as households that do not report positive disposable income (from any source including government payments) or assets are dropped when taking logs. This includes 297 households in total from the full sample of 14,060. The pseudo-R^2 is 0.181. There is also a category of 'other tenure' which is not shown. Coefficients for 87 SA4 location binary controls are available through the code in the Supplementary section. IHS stands for inverse hyperbolic sine transformation.

Table 3 summarises marginal effects based on a probit model and includes quartile variables for asset values for a more detailed assessment of asset associations across the range of values. The financial asset variable, which was significant at the 1% level in Table 2, is also split into two categories for Table 3: private pension balances and other financial assets. The full set of control variables that applied for Table 2, including the 87 binary variables for SA4 regions, are also used for Table 3, but are not shown to save space. These other coefficients are available through the code in the Supplementary section.

The coefficients for the binary financial asset variables are all significant at the 1% level in Table 3. Compared to the omitted category of quartile 4, the highest category, there are negative coefficients for each of the lower financial-asset categories. The negative signs in Table 3 are consistent with the result of higher levels of assets promoting higher probabilities of solar panel uptake in Table 2, because the negative coefficients in Table 3 are in relation to the excluded category of quartile 4 that has the highest assets.

For households with private pension balances in quartile 1, the lowest quartile, the probability of having solar panels is around 5.6 percentage points lower than the omitted category of quartile 4 in Table 3. The difference in probability progressively shrinks for households that have higher private pension balances in quartiles 2 and 3. There is still a substantial difference between quartile 3 and 4, with a magnitude of around 3.3 percentage points.

The magnitudes for the other-financial-asset quartiles have very similar magnitudes to those for the private pension balances. This suggests that either of the categories of financial assets are appropriate for identifying constraints faced by households. The analysis with control variables in Table 3 supports the initial view of similarity between the impact of financial asset components in Figure 2.

The magnitudes of the marginal effects can be compared to the unconditional relationships in Figure 2. For example, Figure 2 shows a gap of around 15 percentage points in solar uptake between quartile 1 and 4 based on either financial asset category. When controlling for other variables in Table 3, the magnitude is not as large, but is still major and important. The six percentage-point gap between quartile 1 and quartile 4 for either financial asset category suggests binding capital constraints that may not be overcome without policy assistance.

Table 3 shows insignificant coefficients for the non-financial asset variables. This contrasts to the case for the financial asset categories but could perhaps be partly anticipated based on the coefficient for log non-financial assets only being significant at the 10% level in Table 2. The non-significant coefficients for non-financial assets in Table 3 tell a different story to the unconditional associations suggested by Figure 2. There are major gaps between the solar uptake of households in quartile 1 based on non-financial assets and higher quartiles in Figure

2, although this effect disappears when controlling for other variables in Table 3. Key controls in this context are the renting variables, as the households in the lowest quartile for non-financial assets are mostly renters. For these households, the primary constraint may be that they do not have permission from their landlords to install solar panels, even if they could access financial resources for the solar investment.

The positive and significant coefficient for the total liabilities variable in Table 3 supports the case that debt aversion could be an important constraint for solar panel uptake. This is because some solar panels would be financed through loans. The result is also consistent with Figure 3, which also shows a positive impact of having liabilities on solar panel uptake, for either renters or non-renters.

Table 3. Marginal effects, probit model, asset-component quartiles

	Marginal effect	Standard error
Private pension balances, quartile 1	-0.056***	(0.012)
Private pension balances, quartile 2	-0.049***	(0.011)
Private pension balances, quartile 3	-0.033***	(0.010)
Other financial assets, quartile 1	-0.058***	(0.012)
Other financial assets, quartile 2	-0.036***	(0.010)
Other financial assets, quartile 3	-0.027***	(0.010)
Non-financial assets, quartile 1	-0.017	(0.025)
Non-financial assets, quartile 2	-0.020	(0.013)
Non-financial assets, quartile 3	-0.001	(0.010)
Log total liabilities (inverse hyperbolic sine)	0.002**	(0.001)

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. Coefficients for controls are available through the code in the Supplementary section. The controls are the same as Table 2. The sample size is 13,985, as households that do not report positive disposable income (from any source including government payments) are dropped when taking the log. This includes 75 households from the full sample of 14,060. The pseudo-R^2 is 0.186.

Table 4 produces a range of robustness tests that show that across a range of specifications, wealth-component coefficients are similar in sign, significance, and magnitude. Column (1) again shows probit coefficients (not marginal effects), although the standard errors are clustered at the state level. The coefficients for the financial asset components, including both private pension balances (PPB) and other financial assets (OFA), are nearly all significant at the 1% level, as is the coefficient for log total liabilities (LTL). Column (2) drops variables that might have a small number of values with measurement error, as suggested by negative values for total liabilities and disposable income. This has minimal impact on the asset-quartile coefficients. Column (3) is also very similar when excluding renters, leaving a sample of nearly 10,000 homeowners.

Columns (4) and (5) of Table 4 use logit and linear probability models respectively, so the coefficient magnitudes are not directly comparable to the other columns of Table 4. The sign and significance of coefficients are similar in column (4), which uses a logit model. The same pattern of coefficients becoming less negative as assets increase is evident, compared to the omitted category of quartile 4. This pattern is also evident in column (5) for a linear probability model. For example, households in quartile 1 based on other financial assets are least likely to have solar panels, with a gap of six percentage points from uptake in the omitted category of quartile 4. The corresponding differences for quartile 2 and 3 are four and three percentage points, respectively. This matches the case in Table 3, which shows marginal effects based on a probit model. The linear probability model in column (5) produces coefficients for private pension balances that are slightly more negative than the corresponding marginal effects in Table 3.

Columns (6) and (7) of Table 4 show that the coefficients for private pension balances are not overly affected by multicollinearity. When dropping asset variables that might lead to concerns over multicollinearity, the coefficients for private pension balances are very similar in column (6), compared to the other columns with probit coefficients, such as columns (1)-(3). This is also the case in column (7), which also drops the 87 binary variables for SA4 regions. Variance inflation factors, which are available through the code in the Supplementary section, further reduce any concerns over multicollinearity. The average variance inflation factor is two for the full model shown in column (5), and the maximum for one variable is six. These values are well below a common threshold of 10.

Table 4. Robustness tests, regression coefficients.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PPB1	-0.290***	-0.313***	-0.309***	-0.526***	-0.072***	-0.341***	-0.327***
	(0.046)	(0.063)	(0.068)	(0.114)	(0.014)	(0.063)	(0.060)
PPB2	-0.256***	-0.266***	-0.278***	-0.442***	-0.071***	-0.301***	-0.251***
	(0.017)	(0.058)	(0.064)	(0.105)	(0.013)	(0.058)	(0.056)
PPB3	-0.172***	-0.178***	-0.175***	-0.299***	-0.053***	-0.199***	-0.146***
	(0.064)	(0.049)	(0.052)	(0.086)	(0.012)	(0.048)	(0.046)
OFA1	-0.302***	-0.300***	-0.311***	-0.526***	-0.058***		
	(0.085)	(0.061)	(0.067)	(0.112)	(0.012)		
OFA2	-0.184***	-0.186***	-0.168***	-0.308***	-0.040***		
	(0.038)	(0.053)	(0.056)	(0.093)	(0.012)		
OFA3	-0.139**	-0.144***	-0.157***	-0.237***	-0.028**		
	(0.057)	(0.049)	(0.051)	(0.086)	(0.012)		
NFA1	-0.090	-0.144	-0.091	-0.197	0.016		
	(0.077)	(0.124)	(0.246)	(0.259)	(0.018)		
NFA2	-0.105	-0.123*	-0.112*	-0.150	-0.019		
	(0.066)	(0.064)	(0.068)	(0.116)	(0.014)		
NFA3	-0.004	-0.018	0.011	0.012	0.012		
	(0.038)	(0.050)	(0.051)	(0.087)	(0.013)		
LTL	0.011***		0.014**	0.024**	0.002**	0.012**	0.008*
	(0.001)		(0.006)	(0.010)	(0.001)	(0.006)	(0.005)
Obs.	13,985	14,060	9,705	13,985	13,985	13,985	13,985
R^2	0.186	0.185	0.119	0.187	0.130	0.182	0.126

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. Coefficients for controls are available through the code in the Supplementary section. PPB is private pension balances; OFA is other financial assets; NFA is non-financial assets; LTL is the natural log of total liabilities, using the inverse hyperbolic sine transformation. The numbers in the description column are quartiles. For example, PPB1 is the first quartile of households that have the lowest private pension balances. The omitted reference categories are the fourth quartiles that have the most assets for each of private pension balances, other financial assets, and non-financial assets. The R^2 is a pseudo measure for probit and logit models. The columns are (1): probit with standard errors clustered by state, (2): probit without variables that include a small number of negative variables (liabilities and disposable income), (3): probit excluding renters, (4): logit model, (5): linear probability model, (6): probit excluding other financial assets and non-financial assets, (7): probit excluding other financial assets and non-financial assets and also excluding location controls.

4. Discussion and conclusion

4.1 Discussion

This paper finds that wealth components are much more important for solar-panel uptake than income. There are positive and significant associations for each of the three components of net wealth. The relationship is particularly robust for financial assets, followed by liabilities, with a less robust relationship of non-financial assets with solar-panel uptake. The latter finding adds value to the prior literature, given that when studies do control for assets, it is usually non-financial assets, which appears to be the least important wealth component.

We find no evidence that income is important for solar panel uptake, when accounting for our comprehensive control set.

The contribution of this paper includes the quantification of wealth-component impacts on solar-panel uptake. We find that there are similar and robust relationships between either of the exhaustive categories of financial assets with solar-panel uptake. Compared to the highest-asset quartile, constraints are evident for each other quartile for both financial asset types. The constraint magnitudes are approximately six, four, and three percentage points of solar uptake on average as the asset quartiles become higher from quartile 1 to 3.

Our results of a positive relationship between total liabilities and solar uptake suggest that loans will not be viewed favourably by a substantial proportion of debt-averse households. Loan schemes in Australia for distributed energy investments could still be a suitable approach to encourage some potential household investment, even if the debt-averse households are not interested in this approach. A current example of a loan scheme is in the state of New South Wales (NSW Government, 2020).

4.2 Implications for cleaner production and sustainability

The large gaps shown in our results between the wealthiest quartile based on financial assets and the other quartiles suggest that solar uptake could be substantially higher in Australia, if financial constraints can be overcome. For example, if solar uptake were higher by six, four, and three percentage points in the bottom three quartiles, to remove the conditional gaps with the wealthiest quartile, overall uptake could have been higher by over three percentage points. This corresponds to over 300,000 more installations or around one gigawatt of extra solar capacity. This means that cleaner energy production could have avoided substantial emissions from industrial-scale production of energy based on fossil fuels.

While household solar uptake is predicted to grow rapidly across many countries, actual outcomes may fall short of projections if capital constraints are more severe than expected following the COVID-19 pandemic and the related economic contraction. If the key barrier of a lack of accumulated financial resources can be overcome through targeted policy support, the sustainable energy transition can be promoted through greater solar uptake among constrained households across many countries.

4.3 Implications for policymakers and future studies

Policymakers can consider whether means testing is appropriate, as this is somewhat a normative question. Targeting subsidies to households with low financial assets can address a key constraint for this group of households and promote higher solar uptake. A benefit of this approach for policymakers includes lower spending compared to universal benefit schemes. This is likely to be extremely important following the onset of COVID-19 due to revenue shortfalls, the need for other urgent welfare assistance, and future debt repayments following temporary stimulus spending.

Our results support the case for means testing based on assets instead of income, in contrast to the current context in most Australian examples (Australian Government, 2020). Our results indicate that policy support targeting households with low levels of financial assets would be the most effective approach, due to the large conditional difference between uptake for the first and fourth quartiles. This would help to reduce the occurrences where subsidies go to households who would have installed solar panels even without the subsidy support. This more targeted approach helps to achieve more solar panel installations for a given level of policy support, leading to a more cost-effective contribution to the sustainable transition toward cleaner energy production.

One type of financial asset, private pensions balances, is particularly suitable for means testing, based on the strong association with solar uptake. There is also wide availability of this data for most households in Australia, as the Australian Taxation Office collect this information already through the pension funds.

As means testing involves some type of distinct threshold, our approach of using binary variables aligns well with pragmatic policy analysis. In cases where means testing is currently used for solar subsidies in Australia, households are effectively split into two income categories (Australian Government, 2020). Our approach of using quartiles allows for greater detail in analysis without suffering from having too many subcategories.

When considering how many households are eligible for subsidy schemes, policymakers can consider the full range of benefits provided by solar panels. There are private benefits of lower financial stress and energy poverty for low-asset households. Solar panels have potential to contribute to major reductions in energy poverty (Best and Burke, 2019). Social benefits of emissions reduction from using a cleaner type of energy production are also a key aspect. The cost effectiveness of emission reduction through solar panels may be reasonable (Best et al., 2019b; Burtt and Dargusch, 2015). This is likely to improve as the cost of solar panels continues to fall.

Limitations to the transferability of our findings to other countries may exist for a number of reasons. Other countries may currently lack suitable data for corresponding analysis, motivating further data collection in the future. Countries may also differ in terms of the degrees of wealth and income inequality across households. Differences also relate to financing approaches and ownership of solar systems. Third-party ownership, where the homeowner does not own the solar panels on their rooftop, is more common in some countries. Differences in the cost of capital for each sector of the economy, and differences in environmental factors such as solar irradiance and land availability, can also contribute to differing suitability of household solar installations in comparison to industrial-scale production of clean energy through solar farms. These factors could lead to different results for other countries, motivating future studies that consider the context in each country.

Future studies that assess impacts of financial assets on solar uptake can refer to our novel contribution. Policymakers can also refer to the magnitudes of the constraints that our paper has identified for households with low levels of financial assets. There is great potential for future policies to reduce barriers for constrained households, leading to greater solar uptake and cleaner production of energy at a global scale.

If the policies implemented follow the suggested approach of means testing based on asset thresholds, future studies can potentially quantify the corresponding cost per tonne of avoided emissions relating to industrial-scale production of energy. This cost can then be compared to other policies without asset tests, which would involve higher proportions of payments to households that can afford energy investments without subsidy support.

Future research can apply our approach of analysing wealth components to many other contexts relating to clean energy production and consumption. For example, similar analysis could be conducted for home battery uptake. There is also potential to assess the role of wealth-component constraints for electric vehicles. This can make a major contribution to the sustainable energy transition by promoting vehicle purchases that substitute for vehicles using gasoline.

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